HOLMIUM:YAG LASER LITHOTRIPSY

PETER MANUEL KRONENBERG

A thesis submitted in partial fulfillment of the requirements for the Doctoral Degree in Medicine, in the specialty of Clinical Investigation in Urology at Faculdade de Ciências Médicas | NOVA Medical School of NOVA University Lisbon

February, 2025

HOLMIUM:YAG LASER LITHOTRIPSY

Peter Manuel Kronenberg

A thesis submitted in partial fulfilment of the requirements for the Doctoral Degree in Medicine, in the specialty of Clinical Investigation in Urology

February, 2025

To all who encouraged and supported me in writing and submitting this

Table of Contents

Acknowledgments

Words cannot express my gratitude to my fellowship mentor, Prof. Olivier Traxer, for igniting the first spark in me with his infectious enthusiasm for laser lithotripsy, for his never-ending support, guidance, and most of all, for his friendship.

I'm deeply indebted to my former residency mentor, Dr. Fernando Ribeiro, who gave me all his knowledge and made me the urologist I am today. I'm still trying to reach the level of calmness and serenity that he displays in every problem he faces, always acting with confidence and thoughtfulness. Dr. Fernando is an example of the highest integrity and professionalism, a true urological master.

I would also like to thank my former department head, Dr. Carrasquinho Gomes, for always encouraging my development during and after my residency.

I'm also grateful to my current department head, Dr. Paulo Vale, who himself is an example of continuous and relentless learning of new technologies, and who also encourages me to further improve my academic pursuits.

Finally, I would like to thank my family for their support, especially my wife, Rita. My academic endeavors would not have been possible without her constant support, her tolerance for my shortcomings, her standing in for me when I was away from home, and her encouragement to pursue my dreams. I would like to express my deepest gratitude to her, my love.

List of Abbreviations

ALFTS	Automated Laser Fragmentation Testing System
HiFr-LoPE	High frequency-Low pulse energy
Ho:YAG	Holmium:yttrium-aluminum-garnet
LoFr-HiPE	Low frequency-High pulse energy

Abstract

The subject of this thesis is holmium laser lithotripsy (Holmium:yttrium-aluminum-garnet). This thesis is presented in accordance with the current regulations of the cycle of studies leading to the degree of Doctor of Medicine at NOVA Medical School – Faculdade de Ciências Médicas da Universidade Nova de Lisboa, Regulation No. 519/2015 published in *Diário da República*, 2nd series, No. 153, on August 7, 2015. This thesis is presented in the form of a compilation of already published scientific works as an alternative to the thesis, in accordance with articles 4 and 20 of the aforementioned regulation.

The scientific works included are:

Article 1: **Kronenberg P**, Traxer O. In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU International 2014; 114(2):261–7 (doi: 10.1111/bju.12567 PubMed ID: 24219145).

Video 1: **Kronenberg P**, Traxer O. V1718 Laser fibers, pulse energy and retropulsion – what we can see and what we can't. The Journal of Urology 2013; 189(4):e707 (doi: 10.1016/j.juro.2013.02.2964).

Video 2: **Kronenberg P**, Traxer O. Myths, Doubts, and Facts about Laser Lithotripsy. Journal of Endourology Part B, Videourology 2014; 2(28) (doi: 10.1089/vid.2013.0101).

Article 2: **Kronenberg P**, Traxer O. The truth about laser fiber diameters. Urology 2014; 84(6):1301–7 (doi: 10.1016/j.urology.2014.08.017 PubMed ID: 25432821).

Article 3: **Kronenberg P**, Traxer O. Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. The Journal of Urology 2015; 193(3):1030–5 (doi: 10.1016/j.juro.2014.07.110 PubMed ID: 25102206).

Article 4: **Kronenberg P**, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World Journal of Urology 2015; 33(4):463–9 (doi: 10.1007/s00345-014-1395-1 PubMed ID: 25185524).

Article 5: **Kronenberg P**, Traxer O. Lithotripsy Performance of Specially Designed Laser Fiber Tips. The Journal of Urology 2016; 195(5):1606–12 (doi: 10.1016/j.juro.2015.10.135 PubMed ID: 26523881).

Article 6: Villa L, Cloutier J, Compérat E, **Kronenberg** P, Charlotte F, Berthe L, Rouchausse Y, Salonia A, Montorsi F, Traxer O. Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes. Journal of Endourology 2016; 30(3):332–7 (doi: 10.1089/end.2015.0232 PubMed ID: 26472513).

Editorial: **Kronenberg P**. Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al. Journal of Endourology 2018; 32(4):296 (doi: 10.1089/end.2018.0152 PubMed ID: 29495879).

Article 7: **Kronenberg P**, Somani B. Advances in Lasers for the Treatment of Stones – a Systematic Review. Current Urology Reports 2018; 19(6):45 (doi: 10.1007/s11934-018-0807-y PubMed ID: 29774438).

Article 8: Lildal SK, Andreassen KH, Baard J, Brehmer M, Bultitude M, Eriksson Y, Ghani KR, Jung H, Kamphuis G, **Kronenberg** P, Turney B, Traxer O, Ulvik Ø, Osther PJS. Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy. World Journal of Urology 2021; 39(6):1673–82 (doi: 10.1007/s00345-020-03481-9 PubMed ID: 33067728).

Article 9: Keller EX, **Kronenberg P**, Tailly T, Corrales M, Juliebø-Jones P, Pietropaolo A, Somani B, Coninck V de. Laser accessories: surgical fibers, strippers, cleavers, and protective glasses. Current Opinion in Urology 2022; 32(3):330–8 (doi: 10.1097/MOU.0000000000000977 PubMed ID: 35256579).

Article 10: Kwok J-L, Coninck V de, Ventimiglia E, Panthier F, Corrales M, Sierra A, Emiliani E, Talso M, Miernik A, **Kronenberg P**, Enikeev D, Somani B, Ghani KR, Traxer O, Keller EX. Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology. European Urology Focus 2024 Jul;10(4):599-611 (doi: 10.1016/j.euf.2023.10.004 PubMed ID: 37940392).

According to the quantitative criteria and in compliance with the calculation method in Article 20 of Regulation 519/2015 of August 7, the score obtained from the sum of the published works is 71.07 (Table 1). Three relevant publications are also mentioned, and although they are published in indexed journals and have been peer-reviewed, they are not classical articles in the strict sense, so they do not have any value in the score.

Title of the scientific paper	Scientific Journal	Citations	First author?	Impact factor at publication date	Impact factor at the current date	Score at publication date	Score at the current date
Article 1: In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters	BJU international	111	Yes	3.533	5.969	7.07	11.94
Video 1: V1718 Laser fibers, pulse energy and retropulsion – What we can see and what we can't	The Journal of Urology	14	Yes	–	–	–	–
Video 2: Myths, Doubts, and Facts about Laser Lithotripsy.	Journal of Endourology Part B, Videourology	1	Yes	–	–	–	–
Article 2: The truth about laser fiber diameters	Urology	34	Yes	2.188	2.633	4.38	5.27
Article 3: Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser	The Journal of Urology	53	Yes	4.700	7.641	9.40	15.28
Article 4: Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers	World Journal of Urology	205	Yes	2.397	3.661	4.79	7.32
Article 5: Lithotripsy Performance of Specially Designed Laser Fiber Tips	The Journal of Urology	26	Yes	5.157	7.641	10.31	15.28
Article 6: Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes.	Journal of Endourology	39	No	1.124	2.619	1.12	2.62
Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al.	Journal of Endourology	0	Yes	–	–	–	–
Article 7: Advances in Lasers for the Treatment of Stones – a Systematic Review	Current Urology Reports	175	Yes	2.079	2.872	4.16	5.74
Article 8: Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy.	World Journal of Urology	25	No	4.226	3.661	2.11	1.83
Article 9: Laser accessories: surgical fibers, strippers, cleavers, and protective glasses.	Current Opinion in Urology	10	No	2.808	2.808	2.81	2.81
Article 10: Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology.	European Urology Focus	12	No	5.952	5.952	2.98	2.98
Total as first author		604	9			**40.11**	**60.83**
Total		705	13			**49.13**	**71.07**

Table 1 – The score or sum of the impact factors of the published articles is obtained using the following methodology: the impact factor of the journal is used, doubled for works in which the doctoral candidate is the first author; for articles in which he/she is not the first author and with up to and including 10 authors, the impact factor is used; if he/she is not the first author and the article has more than 10 authors, the impact factor divided by 2 is used. In quantitative terms, the candidate must achieve, according to the methodology presented, a sum score of impact factors >=20, and must obtain a minimum score of 10 as first author.

Resumo

O tema da presente tese é litotrícia a laser de hólmio (Holmium:yttrium-aluminum-garnet). Esta tese é apresentada de acordo com o regulamento vigente do ciclo de estudos conducente ao grau de Doutor em Medicina da NOVA Medical School – Faculdade de Ciências Médicas da Universidade Nova de Lisboa, Regulamento n.º 519/2015 publicado em *Diário da República*, 2.ª série, N.º 153, a 7 de Agosto de 2015. A tese é apresentada sob forma de compilação de trabalhos científicos já publicados alternativos à tese, de acordo com os artigos 4.º e 20.º do referido regulamento.

Os trabalhos científicos incluídos são:

Artigo 1: **Kronenberg P**, Traxer O. In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU International 2014; 114(2):261–7 (doi: 10.1111/bju.12567 PubMed ID: 24219145).

Vídeo 1: **Kronenberg P**, Traxer O. V1718 Laser fibers, pulse energy and retropulsion – what we can see and what we can't. The Journal of Urology 2013; 189(4):e707 (doi: 10.1016/j.juro.2013.02.2964).

Vídeo 2: **Kronenberg P**, Traxer O. Myths, Doubts, and Facts about Laser Lithotripsy. Journal of Endourology Part B, Videourology 2014; 2(28) (doi: 10.1089/vid.2013.0101).

Artigo 2: **Kronenberg P**, Traxer O. The truth about laser fiber diameters. Urology 2014; 84(6):1301–7 (doi: 10.1016/j.urology.2014.08.017 PubMed ID: 25432821).

Artigo 3: **Kronenberg P**, Traxer O. Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. The Journal of Urology 2015; 193(3):1030–5 (doi: 10.1016/j.juro.2014.07.110 PubMed ID: 25102206).

Artigo 4: **Kronenberg P**, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World Journal of Urology 2015; 33(4):463–9 (doi: 10.1007/s00345-014-1395-1 PubMed ID: 25185524).

Artigo 5: **Kronenberg P**, Traxer O. Lithotripsy Performance of Specially Designed Laser Fiber Tips. The Journal of Urology 2016; 195(5):1606–12 (doi: 10.1016/j.juro.2015.10.135 PubMed ID: 26523881).

Artigo 6: Villa L, Cloutier J, Compérat E, **Kronenberg** P, Charlotte F, Berthe L, Rouchausse Y, Salonia A, Montorsi F, Traxer O. Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes. Journal of Endourology 2016; 30(3):332–7 (doi: 10.1089/end.2015.0232 PubMed ID: 26472513).

Editorial: **Kronenberg P**. Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al. Journal of Endourology 2018; 32(4):296 (doi: 10.1089/end.2018.0152 PubMed ID: 29495879).

Artigo 7: **Kronenberg P**, Somani B. Advances in Lasers for the Treatment of Stones – a Systematic Review. Current Urology Reports 2018; 19(6):45 (doi: 10.1007/s11934-018-0807-y PubMed ID: 29774438).

Artigo 8: Lildal SK, Andreassen KH, Baard J, Brehmer M, Bultitude M, Eriksson Y, Ghani KR, Jung H, Kamphuis G, **Kronenberg** P, Turney B, Traxer O, Ulvik Ø, Osther PJS. Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy. World Journal of Urology 2021; 39(6):1673–82 (doi: 10.1007/s00345-020-03481-9 PubMed ID: 33067728).

Artigo 9 : Keller EX, **Kronenberg P**, Tailly T, Corrales M, Juliebø-Jones P, Pietropaolo A, Somani B, Coninck V de. Laser accessories: surgical fibers, strippers, cleavers, and protective glasses. Current Opinion in Urology 2022; 32(3):330–8 (doi: 10.1097/MOU.0000000000000977 PubMed ID: 35256579).

Artigo 10: Kwok J-L, Coninck V de, Ventimiglia E, Panthier F, Corrales M, Sierra A, Emiliani E, Talso M, Miernik A, **Kronenberg P**, Enikeev D, Somani B, Ghani KR, Traxer O, Keller EX. Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology. European Urology Focus 2024 Jul;10(4):599-611 (doi: 10.1016/j.euf.2023.10.004 PubMed ID: 37940392).

De acordo com os critérios quantitativos e em cumprimento da metodologia de cálculo do Artigo 20.º do Regulamento n.º 519/2015 de 7 de agosto, o *score* obtido da soma dos trabalhos publicados é de 71,07 (tabela 1). São igualmente mencionados três trabalhos relevantes, que apesar de estarem publicados em revistas indexadas e terem sido sujeitos a *peer-review*, por não se tratarem de artigos clássicos, não lhes é atribuído qualquer valor que figure no *score*.

Título do trabalho científico	Revista Científica	Citações	Primeiro autor?	Fator de impacto à data da publicação	Fator de impacto actual	*Score* à data da publicação	*Score* à data actual
Artigo 1: In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters	BJU international	111	Sim	3,533	5,969	7,07	11,94
Vídeo 1: V1718 Laser fibers, pulse energy and retropulsion – What we can see and what we can't	The Journal of Urology	14	Sim	–	–	–	–
Vídeo 2: Myths, Doubts, and Facts about Laser Lithotripsy.	Journal of Endourology Part B, Videourology	1	Sim	–	–	–	–
Artigo 2: The truth about laser fiber diameters	Urology	34	Sim	2,188	2,633	4,38	5,27
Artigo 3: Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser	The Journal of Urology	53	Sim	4,700	7,641	9,40	15,28
Artigo 4: Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers	World Journal of Urology	205	Sim	2,397	3,661	4,79	7,32
Artigo 5: Lithotripsy Performance of Specially Designed Laser Fiber Tips	The Journal of Urology	26	Sim	5,157	7,641	10,31	15,28
Artigo 6: Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes.	Journal of Endourology	39	Não	1,124	2,619	1,12	2,62
Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al.	Journal of Endourology	0	Sim	–	–	–	–
Artigo 7: Advances in Lasers for the Treatment of Stones – a Systematic Review	Current Urology Reports	175	Sim	2,079	2,872	4,16	5,74
Artigo 8: Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy.	World Journal of Urology	25	Não	4,226	3,661	2,11	1,83
Artigo 9: Laser accessories: surgical fibers, strippers, cleavers, and protective glasses.	Current Opinion in Urology	10	Não	2,808	2,808	2,81	2,81
Artigo 10: Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology.	European Urology Focus	12	Não	5,952	5,952	2,98	2,98
Total como primeiro autor		604	9			**40,11**	**60,83**
Total		705	13			**49,13**	**71,07**

Tabela 1 – O *score* ou soma de fatores de impacto dos artigos publicados obtém-se recorrendo à seguinte metodologia: usa-se o fator de impacto da revista, duplicado nos trabalhos em que o doutorando for o primeiro autor; nos artigos em que não é o primeiro autor e com até 10 autores (inclusive) usa-se o fator de impacto; nos artigos em que não é o primeiro autor e com mais de 10 autores, usa-se o fator de impacto dividido por 2. Em termos quantitativos, o candidato deve conseguir, segundo a metodologia apresentada, um *score* de soma de fatores de impacto >=20, devendo obter um *score* mínimo de 10 como primeiro autor.

Introduction

It's funny how random life is, how it generates occasions and events, and unintentionally creates opportunities and chances that you never dreamed of. It all started several years ago, during a one-month clinical fellowship in Paris in 2012 with Prof. Olivier Traxer, one of the most renowned endourologists in the world. His specialty is laser lithotripsy, an endoscopic technique for treating urinary stones using a laser generator, a Ho:YAG laser lithotripter. At the beginning of this fellowship, during a simple 5-minute conversation between surgeries, he confided to me that the best lithotripter settings were still a mystery, that many things were still unknown about laser lithotripsy. Prof. Traxer admitted how the future development of reliable testing methods could bring light and insight into the realm of the Ho:YAG laser.

In fact, a review of the available literature showed that endourologists disagreed as to which holmium laser energy settings fragmented urinary stones most quickly and efficiently. Some authors claimed that high-frequency lithotripsy was the most efficient approach, while others favored higher pulse energies.[1,2] At that time, published in-vitro laser lithotripsy studies had only focused separately on the ablation efficiency of different laser fiber diameters, different pulse energies, or different laser types.[3–9] No systematic study had been performed to determine how the different lithotripsy settings interact to shape fragmentation efficiency. In addition, previous studies have all used different experimental approaches, ranging from single-pulse laser delivery [3,5,10], to repetitive laser delivery [1,11], to simple perforation of the stone samples.[9] Furthermore, in most studies, the majority of the tests were performed manually and/or used other irregular approaches that could introduce human bias and/or error.[11–15]

After reading most of the papers on the subject and considering my mentor's questions and doubts, a trickle of thoughts soon turned into a river that flooded my brain with various research ideas. I felt confident that I could systematically address all these doubts and answer most of these questions.

My Journey of Discovery and Advances in Laser Lithotripsy Research

Laser Lithotripter Parameters and Laser Fibers, Along with Their Effects on Calculi and Ablation Efficiency – Which laser settings are the best?

To address the controversy over the best settings for laser lithotripsy, a dynamic and innovative test procedure was needed. It had to be accurate, provide highly reproducible results, and be free of human interaction to avoid manipulation bias. Thus, I envisioned and created an Automated Laser Fragmentation Testing System (ALFTS), in which a stationary laser fiber is fired at the surface of an artificial stone that is moved along an axis at a constant speed, creating a fissure on the stone's surface. The ALFTS consisted of a support assembly made entirely of Lego Technic™, including a horizontally sliding holder that held an artificial stone in place as it was moved at a constant speed; a specially designed laser fiber holder that kept the laser fiber tip in contact with the stone; all the motorized mechanical elements to move the system; and the entire system immersed in 0.9% saline, as in any real life laser lithotripsy (Figure 1). A wide range of Ho:YAG laser lithotripter settings were tested, including low and high pulse energies, low and high pulse frequencies, low and high power levels, and small and large-core laser fibers to evaluate possible variations due to different sized laser fibers.

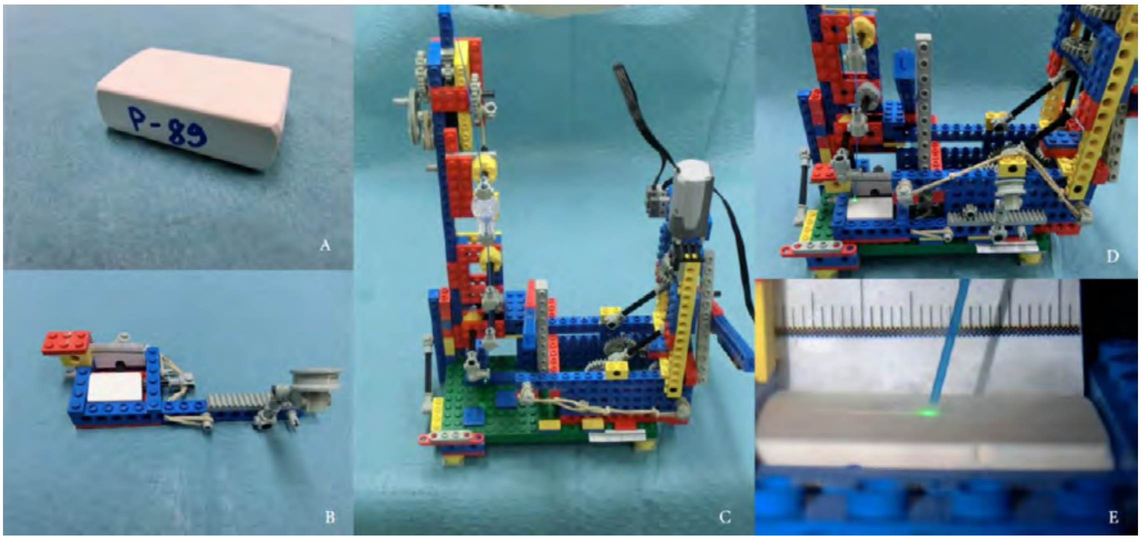


Figure 1 – Automated Laser Fragmentation Testing System. (A) An artificial stone with a size of 30 × 20 × 10 mm. (B) The sliding stone holder bearing an artificial stone. (C) The support assembly with the laser fiber holder and the electric motor but without the stone holder. (D) The support assembly with the inserted stone holder just before immersion in the tank. (E) A close-up of the laser fiber tip and the artificial stone during laser fragmentation in saline. The laser holder maintained the laser fiber at a 75–80° angle (instead of 90º) to prevent it from becoming trapped inside the stone during fragmentation.

The width, depth and volume measurements of the resulting stone fissures showed that low frequency-high pulse energy (LoFr-HiPE) settings were (up to six times) more ablative than high frequency-low pulse energy (HiFr-LoPE) at the same power levels. There were linear correlations between pulse energy and ablation volume, fissure width, and fissure depth, but none regarding total power. Additionally, the laser fiber diameter did not affect ablation volume, except at very low pulse energies, where larger fibers became less efficient. All results, their comparisons and analysis were supported with statistical significance levels of ($p < 0.001$).

I was able to demonstrate the importance of pulse energy over pulse frequency for more efficient ablation of urinary stones. Contrary to what everyone thought at the time, these experiments showed that it wasn't the total power level that was important, but rather the balance between pulse energy and pulse frequency when performing laser lithotripsy. The role of laser fiber diameter was also established, showing no ablation difference at all, thus paving the way for the safe use of small-diameter laser fibers whenever possible, with their inherent advantages of achieving more endoscopic irrigation and better scope maneuverability.

The data and results obtained were presented at several congresses, including the Congress of the Portuguese Association of Urology, where the presentation was awarded with the First Prize for Best Oral Communication (see Appendix page 157).

These results and conclusions were published as an article entitled “In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fiber diameters” in the BJU International journal in 2013:

Kronenberg P, Traxer O. In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int. 2014; 114(2):261–7 (doi: 10.1111/bju.12567 PubMed ID: 24219145).

Since its publication, this article has received consistent attention and recognition, accumulating more than 100 citations throughout the years (see Table 1 on page 15).

High-Speed Video Analysis Can Provide New Insights into Laser Lithotripsy – Seeing is believing

During the time I did the previous study on different lithotripter settings, I also wanted to analyze in more detail the forces in play during laser lithotripsy, in particular retropulsion. Retropulsion is an effect that occurs during laser emission, that pushes the urinary stone away from the laser fiber tip. [3,8,10] It can be very annoying for the urologist, who has then to constantly adjust the laser fiber position in relation to the stone. Retropulsion reduces the ablation efficiency, increases the surgical time, and sometimes can even make the urinary stone inaccessible. Thus, I decided to do single laser pulse studies and recording them with a high-speed video camera to evaluate how retropulsion is affected by pulse energy, laser fiber diameter, the use of different lithotripters and by any other observable aspect. I developed another testing support, also made of Lego Technic™ to perform these tests (Figure 2).

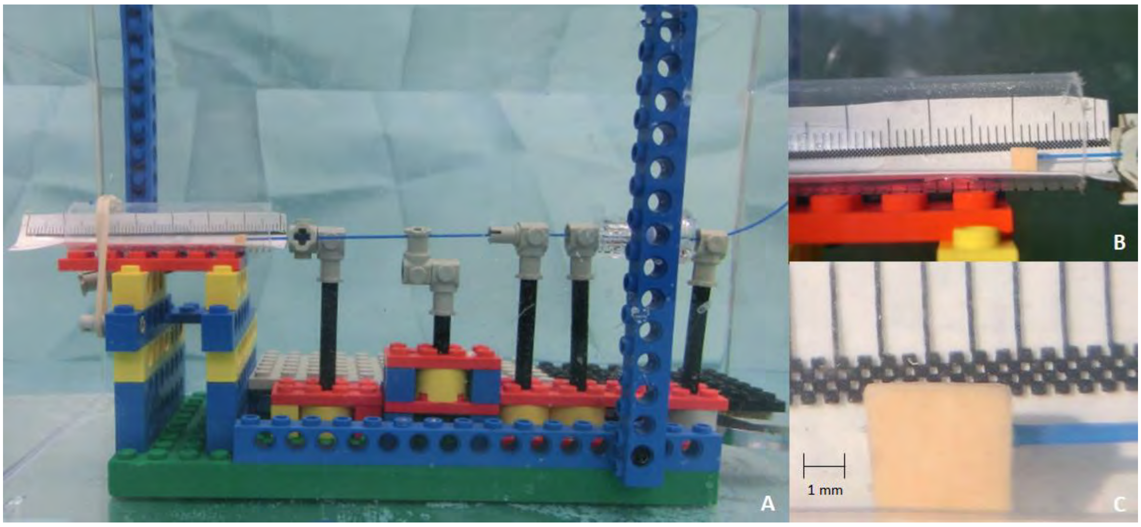


Figure 2 – (A) Retropulsion testing support made of Lego Technic™ inside a water tank filled with saline. (B) The cube shaped artificial stone is placed inside a transparent horizontal tube. (C) The laser fiber tip is centered and touches the stone surface before a single laser pulse is fired. A sub-millimetric scale allows precise retropulsion distance measurements.

My recordings and measurements showed that as pulse energy increased, so did the distance the artificial stones traveled after laser impact, regardless of the lithotripter or laser fiber diameter used. At the same energy level, larger laser fiber diameters were associated with significantly greater stone displacement, regardless of pulse energy level or laser lithotripter used. High-speed video analysis revealed other interesting effects: when the laser fiber tip was inside a fragmentation crater, retropulsion increased significantly (sometimes more than 40%); the sudden generation of expanding and collapsing vapor bubbles at the laser fiber tip and the resulting shock waves were recorded, showing that even those stones that were not in direct contact with the laser fiber tip could be affected over considerable distances; at very high pulse energies (2.0 J or higher), the sudden stone displacement generated a turbulence wave that pushed the stone even further away than the retropulsion effect alone.

I was able to demonstrate that high-speed video analysis can provide new insights into laser lithotripsy, revealing details that might otherwise remain hidden to the human eye. And because of the "visual nature" of this study and the amazing slow motion video recordings, I decided to publish the results in a video format. A comprehensive video with narration was presented at the 2013 Annual Meeting of the American Urological Association in San Diego:

Kronenberg P, Traxer O. V1718 LASER FIBERS, PULSE ENERGY AND RETROPULSION – WHAT WE CAN SEE AND WHAT WE CAN'T. The Journal of Urology 2013; 189(4):e707 (doi: 10.1016/j.juro.2013.02.2964).

It was selected to be presented at a video session called "Award-Winning Videos: The Best of the Best" and was awarded the First Prize by the American Urological Association (see Appendix page 158). A translated version of this video with narration in Portuguese, was also presented at the Congress of the Portuguese Association of Urology and was awarded the Third Prize for Best Video Presentation (see Appendix page 160-159).

However, there were still many different opinions and beliefs about the ideal lithotripter settings and myths surrounding laser lithotripsy among urologists. The Automated Laser Fragmentation Testing System (ALFTS) that I developed and the high-speed video analysis that I did could provide new insights into laser lithotripsy and reveal details that might otherwise remain hidden to the human eye. I gathered all the information from the measurements and studies I had done and created an informative video with narration entitled "Myths, Doubts, and Facts about Laser Lithotripsy" to set the record straight.

It was presented at the 31st World Congress of Endourology, in New Orleans (USA) and won the TOP TEN VIDEO PRESENTATION award (see Appendix page 161). Because of the video's success in explaining and clarifying things, I was invited to publish the video in the one and only journal that accepts videos for indexed peer-reviewed publication, the Journal of Endourology Part B Videourology:

Kronenberg P, Traxer O. Myths, Doubts, and Facts about Laser Lithotripsy. Journal of Endourology Part B, Videourology 2014; 2(28) (doi: 10.1089/vid.2013.0101).

The success of this last video was such that even three years after it was first shown in 2013, it was still considered one of the most read and viewed video articles in the Journal of Endourology in 2016 as stated in the Endourological Society Newsletter, April 2016 (see Appendix section page 162).

Discrepancies in Laser Fiber Diameters and Their Impact on Lithotripsy Performance – Something doesn't feel right

The previous studies involved handling dozens of different laser fibers of various sizes. While handling them, I noticed that a fiber labeled as a 365-µm laser fiber felt much thicker than that. But what was even more intriguing was that some fibers from different manufacturers that were labeled as having the same diameter didn't feel the same between my fingers, some of them felt much thicker. In any other field, this apparent difference might be considered a peculiarity, but in endourology, diameter differences between instruments and accessories can have a significant impact on surgical performance and patient outcomes.[16–18] Therefore, I decided to measure the various diameters of laser fibers from several leading laser fiber manufacturers and compare them to their advertised diameters. In addition, industry representatives from the manufacturers were interviewed about the diameter of their fibers.

Measurements showed that for all fibers, the outer and cladding diameters differed significantly from the advertised diameter. The outer diameter, which is of most practical relevance for urologists, exhibited a median increase over 80%! The outer, cladding, and core diameters of fibers with equivalent advertised diameters differed by up to 180, 100, and 78 µm, respectively. Some 200-µm fibers had larger outer diameters than the outer diameters of some 270–273-µm fibers (Figure 3). All packaging material and all laser fibers lacked clear and precise fiber diameter information labels.

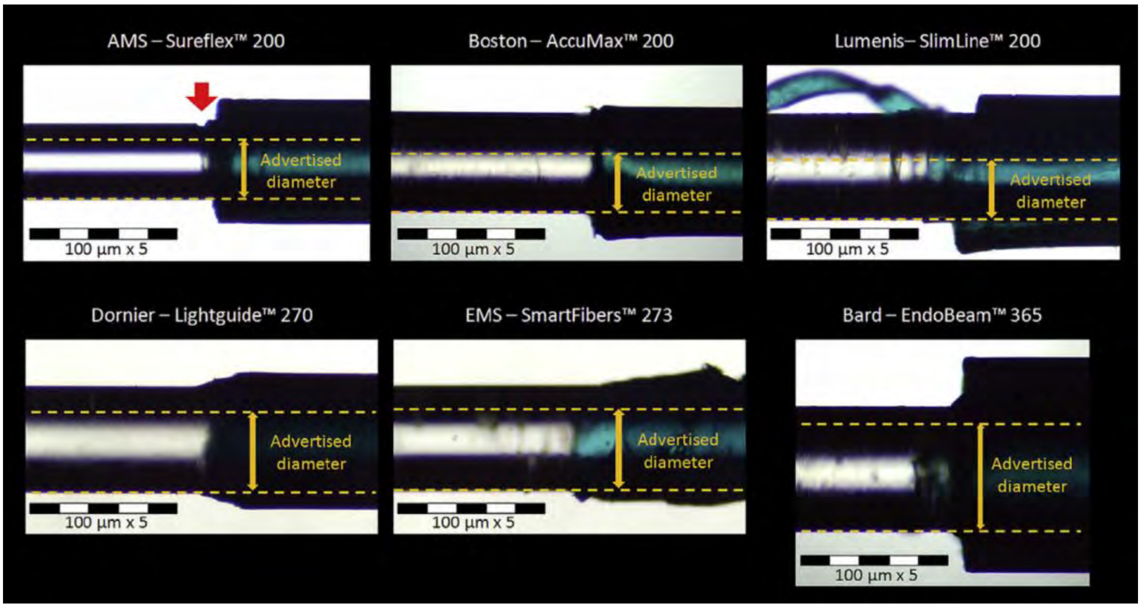


Figure 3 – Photographs depicting the advertised and measured outer diameters of some of the fibers that were tested. These photos were taken for illustrative purposes only to show both the cladding and its coating and to give the observer a rough idea of the discrepancies that were observed. These images do not reflect the measurements at high precision. Because most laser fiber information labels lack units or references to what the label numbers refer to, units were also omitted for each fiber of this figure. Attention is drawn to the arrow on the upper left image, indicating a small fissure on the cladding caused by an initially to tight and ill-adjusted laser fiber stripper.

The large majority of representatives considered the advertised diameter to be the outer diameter, and several times the answers given by one representative, differed from another representative within the same company. This study exposed at the time, a lack of uniformity between laser fiber manufacturers, and that most of the information conveyed to urologists regarding laser fiber diameter was incorrect.

However, these conclusions take on another dimension because of their impact on the surgery itself. A urologist may mistakenly believe that one manufacturer's exchangeable fiber has the same outer diameter as another manufacturer's fiber, when in fact it may be significantly larger. This is important because a larger fiber diameter can affect the urologist's surgical performance in several ways, depending on the setting in which these fibers are used: First, increasing the diameter of the accessories used in flexible ureterorenoscopy, including guidewires, stone retrievers, and laser fibers, decreases the degree of deflection of the ureterorenoscope, thereby limiting the main advantage of the flexible scope, which is its ability to reach difficult locations such as the lower calyces. Second, given the small size of the working channels through which these laser fibers are passed, any increase in size also affects the irrigation rate, which is critical for good visualization and prompt identification of structures, and thus indirectly affects the operating time. Since flow resistance is inversely proportional to the diameter of the obstructing object to the power of four[19], this means that for any given fiber, if the fiber diameter increases by 19%, 50%, or 100%, the degree of obstruction in terms of irrigation flow increases by 100%, 400%, and 1500%, respectively. Since fiber diameter does not significantly affect stone ablation volume, but does have a significant effect on scope deflection and irrigation flow, the outer diameter is the most important diameter for the urologist. Third, large fibers have been shown to promote retropulsion compared to smaller fibers, which reduces the effectiveness of laser lithotripsy, increases procedure time, and sometimes renders a stone inaccessible by pushing it into the renal pelvis. These considerations underscore the importance of outer diameter uniformity among laser fibers labeled with the same diameter.

In addition, some reusable laser fibers must be prepared and stripped prior to use. Miscalculation of the diameter of the fiber, whether because it is larger than advertised, lack of uniformity between brands, or misleading information on the packaging, can lead to the use of an inappropriate laser fiber stripper on a supposedly smaller fiber. This can result in damage to the cladding that is so critical to laser conduction, and the risk of laser leakage that can inadvertently damage patient tissue or our expensive surgical instruments.

In addition to revealing how this misinformation affected key interventional parameters and could have surgical implications, this study also revealed that there are many confusing terms and expressions for the various laser fiber components, some of which refer to the same components or include multiple components, leading to further misinterpretation.

These facts, led me to recommend that all laser fibers and their respective packaging be correctly labeled with the three most important diameters, namely, the outer diameter, the cladding diameter, and the core diameter. Such measures would facilitate straightforward comparisons between laser fibers, improve the understanding of laser fiber products by both urologists and industry representatives, and avoid future misunderstandings.

Initial results of this study were presented at the 2nd Meeting of the EAU section of Urolithiasis (EULIS) in Copenhagen, Denmark, where the study won the Clinical Research Award (see Appendix page 163). Because of the serious revelations and clinical implications that were laid bare, the study made headlines in several major urological and scientifical newsletters such as EAUNews, ScienceDaily or Biophotonics (see Appendix pages 164–166).

The final results and conclusions were published as an article entitled "The truth about laser fiber diameters" in the journal Urology in 2013:

Kronenberg P, Traxer O. The truth about laser fiber diameters. Urology 2014; 84(6):1301–7 (doi: 10.1016/j.urology.2014.08.017 PubMed ID: 25432821).

The Impact of Laser Fiber Tip Preparation Methods on Lithotripsy Performance – Sometimes the world is wrong and you're right

During my fellowship I also had the opportunity to observe, assist and perform several laser lithotripsy procedures. In addition to gaining valuable experience, I noticed that my fellowship mentor, Dr. Olivier Traxer, was doing certain things that were different from what was common practice at the time. There was a widespread belief that the tip of the laser fibers should be stripped to achieve better lithotripsy performance. In fact, brand-new laser fibers are shipped with the laser fiber tip already stripped of its plastic coating, and this practice is described in technical manuals and recommended by experts in the field.[20–22] Thus, the preparation of the laser fiber tip prior to a laser lithotripsy procedure has been a common practice worldwide and consists of stripping the terminal portion of the polymer coating (i.e., the usually blue or green colored plastic coating) and then cutting off several millimeters of the end of the glassy fiber components. This is especially true for reusable laser fibers, which must be reprocessed to restore their performance.[20,23] Even during laser lithotripsy, damage to the fiber tip occurs due to burn-back effects, and such damage can affect the efficiency of the fiber. Specialized tools such as laser fiber strippers and ceramic scissors have been developed for this purpose, and many experts in the field are engaged in such laser fiber tip preparation.[21,22,24] However, my mentor didn't engage in such complicated preparations and didn't use any special instruments to prepare the laser fiber tip. He just cut the fiber tip with a simple surgical scissors and didn't even bother to strip the fiber. Similar to my mentor, I didn't notice any degradation in lithotripsy performance by not stripping the fiber and limited myself to cutting the laser fiber tip with a modest metal surgical scissors in my daily practice. Given these differing opinions, I decided to evaluate whether stripping the laser fiber tip with a specialized laser fiber stripper or cutting the tip with ceramic or metal scissors affected lithotripsy performance. Again, I used my previously developed Automated Laser Fragmentation Testing System (ALFTS) to obtain reproducible results free of human interaction bias.

Coated laser-fiber tips always achieved higher ablation volumes than the stripped laser-fiber tips ($p<0.00001$), regardless of scissor type, stone material, or lithotripter settings. Comparison of the effect of metal and ceramic scissors on the coated fibers revealed that overall, these scissors did not influence ablation volume ($p=0.16$). Photographic analysis of the fiber tips before and after lithotripsy generated several findings the most important being that coated fibers exhibited less degradation of the glassy fiber components during lithotripsy than the stripped fibers. Additionally, high-pulse energy settings caused more damage to the fiber tip than low-pulse energy settings, regardless of scissor type, stone type, and presence of the coating. Moreover fiber-tip degradation was more pronounced when harder stone material was used, regardless of the scissor type, lithotripsy settings, and presence of the coating (Figure 4).

The results of this study shattered the widely held belief that the tip of laser fibers should be stripped to achieve better lithotripsy performance. I was able to show that regardless of how the tip was cut, how hard the stone was, and what power setting was used, coated fibers always produced higher ablation volumes than stripped fibers. Major laser fiber manufacturers include a special laser fiber stripper in their sales catalog, but our study provided photographic evidence of how such a fiber stripper can cause extensive damage to the cladding, since the cladding is a vital component of the laser fiber, thus explaining the reduced lithotripsy performance of these stripped fibers. In addition, given the controversy over mislabeling of laser fiber diameters that are actually thicker than advertised (see previous section), such mislabeling makes it more likely that stripping will damage the fiber: if the opening is too large, the stripper will not strip the fiber, and if it is too narrow, the cladding may be damaged, resulting in poor lithotripsy performance.

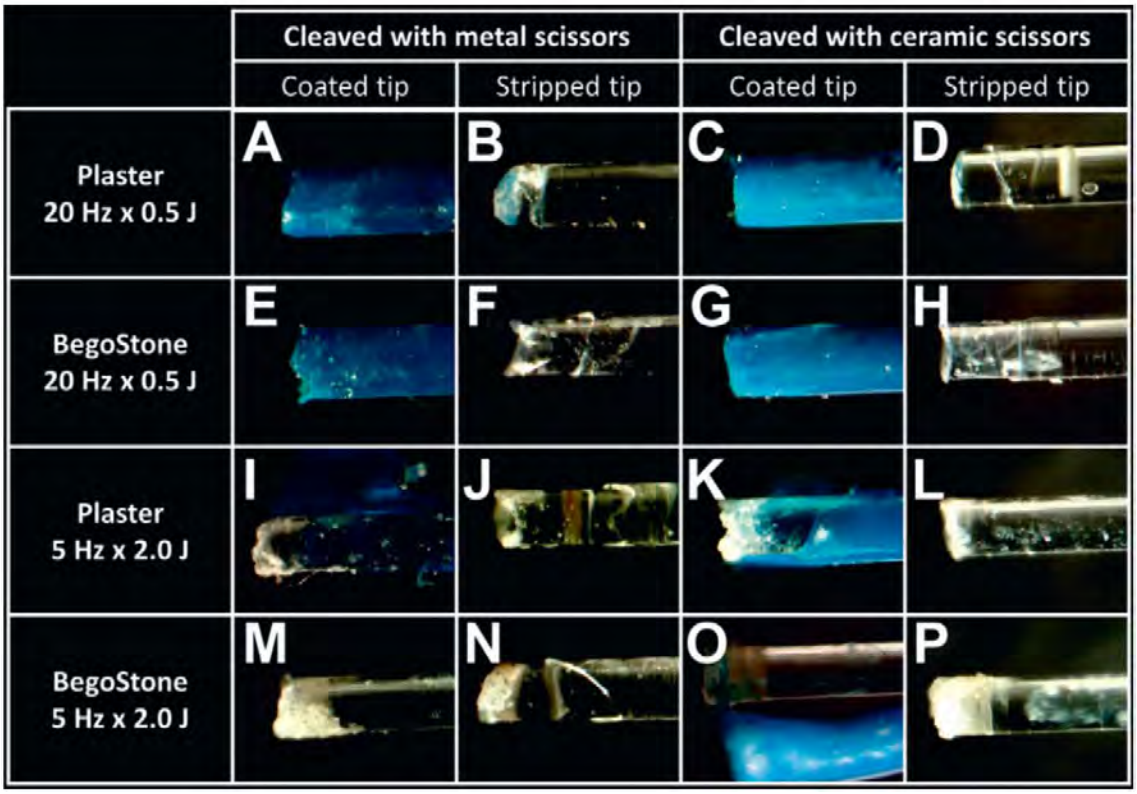


Figure 4 – Photographs A to P, microscopic photographs show laser fiber tips after laser emission. Note tip degradation characteristics associated with different fiber tip preparation methods, lithotripter settings and stone materials.

In addition to demonstrating an increase in lithotripsy performance by using coated fibers, this article was an opportunity to highlight the other benefits of using coated fibers. Coated fibers are much easier to distinguish from the surrounding medium, even in the presence of blood, allowing for faster and more accurate positioning, further reducing procedure time and preventing inadvertent tissue or even scope damage due to positioning errors. By maintaining the coating on the fiber tip, the likelihood that cladding fragments or even entire transparent segments of the stripped fiber tip will break off unnoticed and disappear in the patient's urinary system is greatly reduced.

Shortly before publication, I presented my results at the Challenges in Endourology conference in Paris, a prestigious mid-sized urology meeting that has become a traditional gathering place for the world's leading endourologists. I was fortunate that my session was chaired by Prof. Glenn Preminger, a distinguished endourologist, but also attended by none other than the founding father of endourology, Dr. Artur Smith (the original author of Smith's Textbook of Endourology, after whom the international Arthur Smith Award is named, the Arthur Smith Institute of Urology is named,...). After my presentation, Dr. Smith questioned the chairman and the audience if anyone knew why everyone, including himself, kept stripping the laser fibers. The entire audience fell silent, and since no one had an answer, the silence was finally broken by enthusiastic applause from the entire audience, including Dr. Arthur Smith. That was the moment I knew that my research would have a worldwide impact, albeit a small one.

The results and conclusions were published as an article entitled “Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance.” in the Journal of Urology in 2014:

Kronenberg P, Traxer O. Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J. Urol. 2015; 193(3):1030–5 (doi: 10.1016/j.juro.2014.07.110 PubMed ID: 25102206).

A Comprehensive Review on Ho:YAG Laser Lithotripsy, Its Enduring Impact and Unexpected Surprises

The articles I had written earlier began to receive widespread attention in the urological community, especially among those who perform lithotripsy. This growing reputation, combined with my enthusiastic interest in the field, was, I believe, the reason why I was invited to write topic paper on laser lithotripsy for the World Journal of Urology. I decided to write a comprehensive review on Ho:YAG laser lithotripsy, summarizing all the important knowledge I had acquired over the years.

I used the most important articles published up to that time, including my previous publications, as well as some unpublished research of mine. This research included the evaluation of long pulse lithotripsy, a lithotripsy modality that newer models of laser lithotripters are capable of. These new lithotripters allow the urologist to choose between different pulse durations, the traditional short pulse mode and the new long pulse mode. All other settings of the laser lithotripter remain the same, with the same pulse frequency, the same pulse energy, the same power level, and therefore the same amount of energy delivered per unit of time. In short pulse mode, the energy delivered by a single laser pulse occurs in a given period of time, while in long pulse mode, the same amount of energy is delivered over a longer period of time. Both modes have exactly the same average power, but their peak power is different. I was able to show that the long-pulse mode is significantly less ablative than the short-pulse mode, but also that the damage to the laser fiber tip is significantly less with the long-pulse mode (Figure 5).

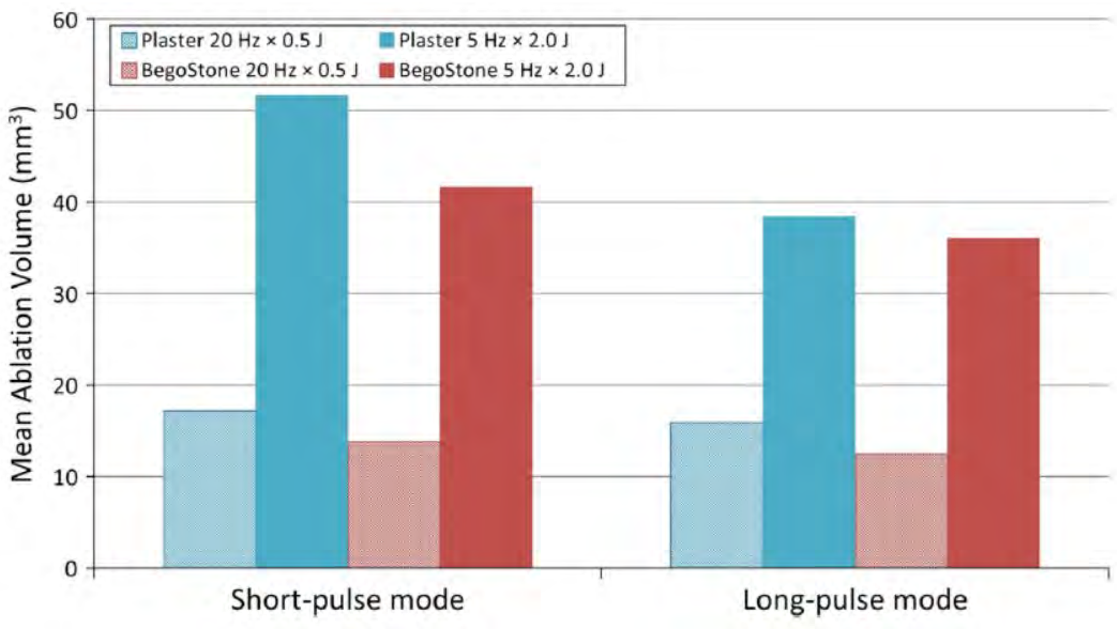


Figure 5 – Comparison of the traditional short-pulse mode with the recently developed long-pulse mode of new laser lithotripters. Regardless of laser settings or stone material, the traditional short-pulse mode is significantly more ablative than the long-pulse mode.

I also presented results on the laser light dispersion patterns of new fibers and fibers prepared with metal scissors, and examined these patterns before and after lithotripsy. As expected, and in accordance with my previous experiments, the light dispersion patterns of different fibers were almost indistinguishable after lithotripsy, further questioning the importance of specialized and time-consuming fiber tip preparation.

However, the most important part of this review was the comprehensive review of the different variables related to laser lithotripters, laser fibers, stone types and their effects on calculi and instruments. All this knowledge was summarized in a table for easy consultation and quick reference for other colleagues on this topic, allowing them to easily adjust their laser parameters to their individual needs (Table 2).

Changeable parameters						**Parameter-dependable variables**				
Defined by user					**Defined by nature**					
Lithotripter settings				Fiber diameter	Stone type	**Effects on calculi**		**Effects on instruments**		
Power (W)	Pulse energy (J)	Pulse frequency (Hz)	Pulse mode			Ablation volume	Retropulsion	Fiber tip degradation	Scope deflection	Irrigation
↑	↑	-	-	-	-	↑	↑	↑	n/a	n/a
↓	↓	-	-	-	-	↓	↓	↓	n/a	n/a
↑	-	↑	-	-	-	↑	=/↑	↑	n/a	n/a
↓	-	↓	-	-	-	↓	=/↑	↓	n/a	n/a
=[†]	↑	↓	-	-	-	↑	↑	↑	n/a	n/a
=[†]	↓	↑	-	-	-	↓	↓	↓	n/a	n/a
-	-	-	Short-pulse	-	-	↑	↑	↑	n/a	n/a
-	-	-	Long-pulse	-	-	↓	↓	↓	n/a	n/a
-	-	-	-	↑	-	=[‡]	↑	↓	↓	↓
-	-	-	-	↓	-	=	↓	↑	↑	↑
-	-	-	-	-	Hard stone	↓	N/K*	↑	n/a	n/a
-	-	-	-	-	Soft stone	↑	N/K*	↓	n/a	n/a

Table 2 – This overview table shows how changes in one parameter (in red) affect other variables involved in the lithotripsy procedure

This review was published as an article entitled “Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers.” in the World Journal of Urology in early 2015:

Kronenberg P, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 2015; 33(4):463–9 (doi: 10.1007/s00345-014-1395-1 PubMed ID: 25185524).

After its publication, the article enjoyed an unexpected fame and dissemination, becoming widely known in the endourological field. Its success was such that it was recognized as the 2015 Article of the Year, an award presented by the World Journal of Urology and the Societé Internationale d'Urologie in October 2016 (see Appendix page 167). It remains one of the most cited articles in holmium laser lithotripsy to date.

Continuing my research on laser pulse duration, that I partially revealed in the paper mentioned above, after evaluating all the data acquired, I presented my final results through various abstract presentations at several meetings in 2015 and 2016. Two presentations, entitled "Long-pulse versus short-pulse laser lithotripsy performance" and "Burst laser lithotripsy – a novel lithotripsy mode" won the Best Poster award in 2015 and 2016, respectively, at the Annual Congresses of the European Association of Urology (see Appendix pages 168–172).

But an additional surprise came when I presented the abstract "Ultra-short, short, medium and long-pulse laser lithotripsy performance" at the Annual Meeting of the American Urological Association in 2016. It was considered one of the best abstracts among the several thousand presented at that meeting and was honored by being additionally showcased and presented by me at the Plenary Session before a large audience of attendees (see Appendix pages 173–174). Due to several circumstances, I never came to publish these final results as an isolated paper.

Evaluating the Performance of 'Special' Laser Fiber Tips in Lithotripsy – Debunking the hype

Laser lithotripters weren't the only part of laser lithotripsy to undergo advances and developments. Laser fibers have also been improved, including novel features such as special connectors, coatings, or fiber tip configurations that were claimed to increase ablation performance and/or facilitate passage of the laser fiber through the endoscope. [25–28] Therefore, I decided to test these claims by comparing a ball-tipped fiber and a special polished fiber to a simple standard laser fiber.

I again used my Automated Laser Fragmentation Testing System (ALFTS) built with Legos, as well as high-resolution microscopic images before and after using the laser fibers.

The results were astounding, showing that the standard laser fiber was as good as, and sometimes better than, the custom-designed fibers (Figure 6). The rapid degradation of the specially designed laser fiber tips severely limited their general usefulness. The promising ball-shaped tip fibers were useful only in very specific situations, but they also degraded very quickly and even assumed a threatening and potentially harmful configuration for the delicate instruments used in endourology, as shown in the high-resolution photos. So, these special laser fibers weren't so special after all...

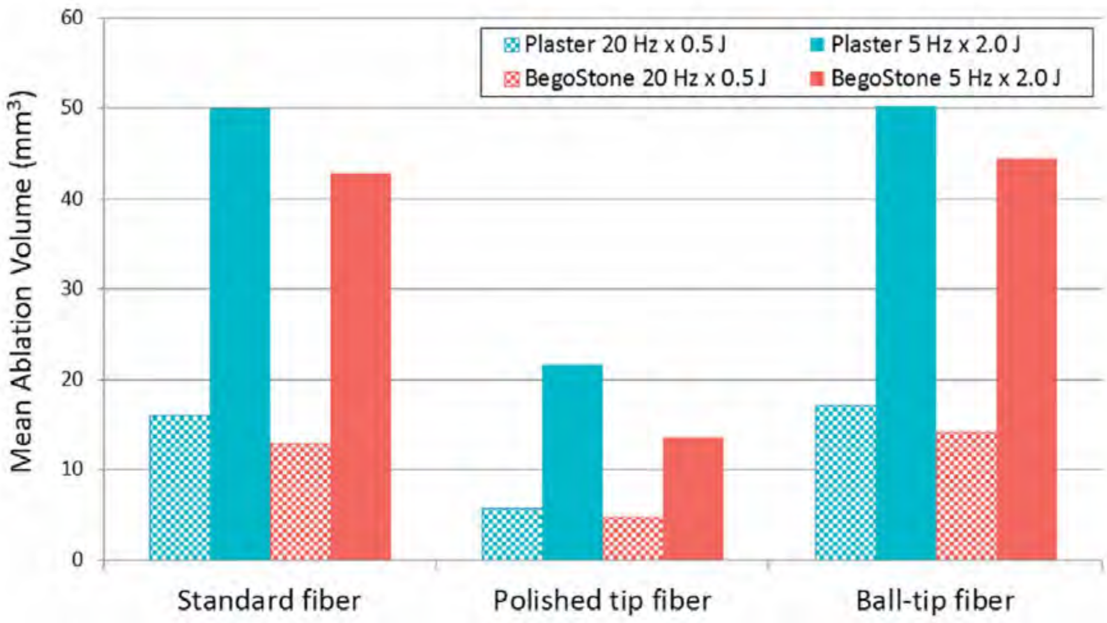


Figure 6 – Ablation volumes of 3 laser fibers tested using soft and hard stone material. Standard and ball-shaped tip fibers did not differ in ablation volume but each was superior to polished tip fiber by factor of almost 3.

The article with its results and conclusions was published under the title "Lithotripsy Performance of Specially Designed Laser Fiber Tips" in the Journal of Urology in 2016:

Kronenberg P, Traxer O. Lithotripsy Performance of Specially Designed Laser Fiber Tips. The Journal of Urology 2016; 195(5):1606–12 (doi: 10.1016/j.juro.2015.10.135 PubMed ID: 26523881).

After the publication, other "special" laser fibers, except for the ball-tip laser fibers, were removed from the market, or manufacturers simply stopped labeling them as "special" laser fibers.

Evaluating the Necessity of Eye Protection During Ho:YAG Laser Procedures – A tale about lasers, eyes and pigs

Whenever one uses a certain tool or technology on a regular basis, one begins to question certain beliefs regarding that same tool and technology if one has never experienced any effects regarding said belief. One of these beliefs is the need to use eye protection when using the Ho:YAG laser. The fact is that Ho:YAG laser manufacturers and the European Association of Urology guidelines on lasers recommend that all intraoperative personnel wear appropriate eye protection to prevent corneal or retinal damage in the event of accidental laser exposure.[29–32] And although there have been several reports of eye injury with the use of medical lasers, none have been reported with the use of Ho:YAG lasers.[33] Therefore, I collaborated with other researchers to determine the potential harmful effects of accidentally hitting the ocular surface with a Ho:YAG laser beam.

For this purpose, we performed an ex vivo animal study on porcine eyes to evaluate the effect of a Ho:YAG laser set at the most commonly used parameters and at different distances on different ocular structures. In addition, we determined the real protection offered by laser safety glasses and standard eyeglasses in preventing ocular lesions, and we evaluated the photothermal effect of the Ho:YAG laser transmitted in air on thermal paper at different distances to implement the results obtained in the first part of the study. My contribution to this work was the development, execution and evaluation of the thermal paper experiments.

We concluded that in the unlikely event of an accident during endourologic procedures, the Ho:YAG laser does not cause injury to the lens or retina of the eye. It can cause corneal lesions, but only in the absence of eye protection and only at high energy (2 J) and from a short distance (0-5 cm). Eyeglasses are as effective as laser safety goggles in preventing harmful laser effects on the cornea (Figure 7). Although the risk of eye injury is minimal, the use of laser safety eyewear, or at least eyeglasses, during endourologic procedures requiring the use of the Ho:YAG laser should be recommended to all intraoperative personnel who are in close proximity to the laser source.

Figure 7 – (A) Ablation volumes A 272 μm core laser fiber pointed toward a pig eye and placed in contact with the cornea just before activation. (B) Laser safety glasses after 1 second (black arrow) and 5 seconds (red arrow) of Ho:YAG laser exposure at 2 J and 10 Hz with the laser fiber tip in contact with the glasses.

The results and conclusions were published as an article titled “Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes” in the Journal of Endourology in 2016:

Villa L, Cloutier J, Compérat E, Kronenberg P, Charlotte F, Berthe L, Rouchausse Y, Salonia A, Montorsi F, Traxer O. Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes. Journal of Endourology 2016; 30(3):332–7 (doi: 10.1089/end.2015.0232 PubMed ID: 26472513).

Editorial on the Benefits and Risks of High-Wattage Laser Lithotripters – With great power comes great responsibility

Over the past few years, laser lithotripters have evolved to include more complex features, but have also become larger and more powerful. While in the beginning Ho:YAG lasers with a maximum power of 15 to 20 watts were the norm/mainstream, today the best laser lithotripters reach 100 to 120 watts or even more. I was invited to write an editorial comment for the Journal of Endourology on an article with such a 120-watt laser.

In that editorial, I praised the authors for the excellent article they had written. I pointed out the various benefits to both patients and surgeons that these new powerful machines brought and that were clearly evident in the results presented by the authors.

However, releasing higher power levels in an endourological setting, i.e., in a small enclosed space such as the ureter or renal calices, can raise the temperature of the surrounding medium to levels dangerous to human tissues. Therefore, I advised caution when using such high-power lasers. That's why the saying "With great power comes great responsibility" is not just for kings, rulers or superheroes, but also for urologists.

Editorial comment with the tittle "Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al." published in the Journal of Endourology in 2018:

Kronenberg P. Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al. J Endourol 2018; 32(4):296 (doi: 10.1089/end.2018.0152 PubMed ID: 29495879).

A Systematic Review of Recent Advances in Laser Lithotripsy – Results from three years of laser blasting

Because of my experience and enthusiasm in this field, I was invited to conduct a systematic review on laser lithotripsy. The purpose was to highlight the recent advances in lasers for the treatment of urolithiasis over the past 3 years.

To do this, a Pubmed search was performed for articles with relevant keywords related to laser lithotripsy and in the relevant time frame. However, this seemingly simple task yielded over 1200 articles that I had to review individually. In addition, abstracts from major urology meetings were screened for relevant data. In the end, more than 100 articles and references were included in the review. To further enhance the quality of the review, I followed the PRISMA guidelines.

The relevant data from the publications and abstracts were categorized into four main groups including laser lithotripters, laser fibers, laser settings and technique and finally laser safety and related complications.

The systematic review was published as an article titled “Advances in Lasers for the Treatment of Stones—a Systematic Review” in the Current Urology Reports in 2018:

Kronenberg P, Somani B. Advances in Lasers for the Treatment of Stones – a Systematic Review. Curr Urol Rep 2018; 19(6):45 (doi: 10.1007/s11934-018-0807-y PubMed ID: 29774438).

The article has been well received by the endourological community and has also become a reference article in the field of laser lithotripsy with an increasing number of citations over the last few years.

Consensus on Kidney Stone Treatment – Lasers, stones and a pandemic

In 2019, I was invited to participate in a consensus of experts discussing the state of the art in kidney stone treatment in Copenhagen. The world's best experts were invited to present and discuss their respective areas of expertise. I was assigned to present on laser lithotripsy and explained and discussed the relevant details. This included the importance of laser fiber size, fiber tip configuration and preparation, and laser settings to achieve a successful laser lithotripsy procedure. Finally, over the course of several months, all of this knowledge was synthesized into a comprehensive paper. Due to the scope of this large and ambitious task, which required the agreement of so many specialists, and the delays caused by the covid pandemic, the publication of this consensus was postponed for almost 2 years.

The consensus was finally published as an article entitled "Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy" in the World Journal of Urology in 2021:

Lildal SK, Andreassen KH, Baard J, Brehmer M, Bultitude M, Eriksson Y, Ghani KR, Jung H, Kamphuis G, Kronenberg P, Turney B, Traxer O, Ulvik Ø, Osther PJS. Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy. World J Urol 2021; 39(6):1673–82 (doi: 10.1007/s00345-020-03481-9 PubMed ID: 33067728).

A Comprehensive Review of Laser Accessories in Urology – God is in the details (of laser fibers)

According to this quote by the architect Ludwig Mies van der Rohe and the art historian Aby Warburg, small details can have a tremendous impact on the whole, including surgical laser lithotripsy procedures. Therefore, I and several other researchers decided to conduct a review to provide the most recent findings on the properties, efficacy, and safety of laser fibers and related accessories in the field of urology. My contributions to this paper were all the photographic materials, the editing of the manuscript, and its final revision.

After reviewing and summarizing our research, it became clear that there is more to laser accessories and their characteristics than meets the eye. When it comes to surgical laser fibers, the actual fiber diameter is significantly larger than the size listed on the package label. Smaller fibers may allow for better irrigation flow, greater flexibility, and less risk of breakage, but conversely, they may have a greater risk of fiber tip degradation due to burnback effects. The latter effect occurs after only a few laser pulses during laser lithotripsy, thus questioning the need for fiber tip reprocessing and limiting the benefit of the ball-tip design. In this context, cutting the laser fibers through their protective plastic sheath with ordinary metal scissors is an advantageous technique for reprocessing fiber tips. Standard metal scissors are sufficient to cut the fiber (Figure 8). Regarding eyewear, laser-specific eyewear can be omitted for Holmium:YAG applications, but must be worn when using green-light lasers to prevent eye injury. There are several issues to consider when using laser accessories, and future developments may allow for smaller, safer and more durable laser fibers.

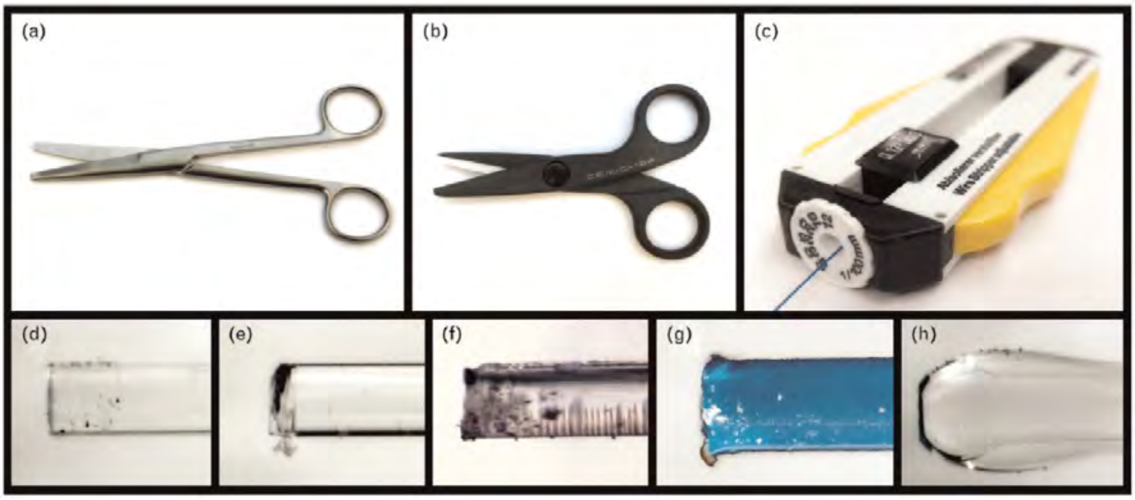


Figure 8 – Fiber tip reprocessing. (a) Metallic scissors. (b) Ceramic scissors. (c) Fiber stripper. (d) New and polished tip. (e) Stripped and cleaved tip. (f) Damages to the fiber cladding caused by the stripper tool. (g) Unstripped, coated tip. (h) Ball-tip design.

The review was published as an article titled "Laser accessories: surgical fibers, strippers, cleavers, and protective glasses" in Current Opinion in Urology in 2022:

Keller EX, Kronenberg P, Tailly T, Corrales M, Juliebø-Jones P, Pietropaolo A, Somani B, Coninck V de. Laser accessories: surgical fibers, strippers, cleavers, and protective glasses. Curr Opin Urol 2022; 32(3):330–8 (doi: 10.1097/MOU.0000000000000977 PubMed ID: 35256579).

Defining Key Metrics and a Unified Language for Laser Lithotripsy Performance – Preparing the way for the future

During these years of research and reading other authors, I noticed that there is sometimes no standardized terminology for reporting laser lithotripsy ablation performance metrics in terms of volume, energy, and time. Therefore, my colleagues and I decided to address this issue by evaluating and summarizing the outcome measures and related terminology from studies of laser lithotripsy performance using stone volume versus time or energy. Most importantly, our goal was to try to develop and propose a standardized terminology for reporting laser performance metrics. My contributions to this paper were the editing of the manuscript and its scientific and final revisions.

Our review revealed a wide range of laser lithotripsy performance outcomes reported for the ablated volume in relation to energy and time metrics as well as high heterogeneity for the study methodologies applied both in vitro and in vivo studies, with corresponding differing terminology. We proposed a standardized terminology for future studies on laser lithotripsy, including laser ablation efficiency (mm^3/J), laser ablation speed (mm^3/s), and laser energy consumption (J/mm^3), as well as laser efficacy (mm^3/min) as a broader term that is based on the total operative time that encompasses the whole technique using the laser.

This proposed standardized terminology will allow uniformity and more objective comparisons of results between papers, techniques and technologies in the future.

All this gathered data and our proposal was published as a review article entitled "Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology" in European Urology Focus ins 2023:

Kwok J-L, Coninck V de, Ventimiglia E, Panthier F, Corrales M, Sierra A, Emiliani E, Talso M, Miernik A, Kronenberg P, Enikeev D, Somani B, Ghani KR, Traxer O, Keller EX. Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology. European Urology Focus 2024 Jul; 10(4):599-611 (doi: 10.1016/j.euf.2023.10.004 PubMed ID: 37940392).

This last paper concludes this compilation of papers about Holmium:YAG laser lithotripsy.

Published Scientific Works

Article 1: In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters

BJUI
BJU International

Upper Urinary Tract

In vitro fragmentation efficiency of holmium: yttrium-aluminum-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters

Peter Kronenberg and Olivier Traxer*

*Departments of Urology, Hospital Prof. Doutor Fernando Fonseca, Amadora, Portugal, and *Hôpital Tenon, Université Pierre et Marie Curie – Paris VI, Paris, France*

Objective

To assess the fragmentation (ablation) efficiency of laser lithotripsy along a wide range of pulse energies, frequencies, power settings and different laser fibres, in particular to compare high- with low-frequency lithotripsy using a dynamic and innovative testing procedure free from any human interaction bias.

Materials and Methods

An automated laser fragmentation testing system was developed.

The unmoving laser fibres fired at the surface of an artificial stone while the stone was moved past at a constant velocity, thus creating a fissure.

The lithotripter settings were 0.2–1.2 J pulse energies, 5–40 Hz frequencies, 4–20 W power levels, and 200 and 550 μm core laser fibres.

Fissure width, depth, and volume were analysed and comparisons between laser settings, fibres and ablation rates were made.

Results

Low frequency-high pulse energy (LoFr-HiPE) settings were (up to six times) more ablative than high frequency-low pulse energy (HiFr-LoPE) at the same power levels ($P < 0.001$), as they produced deeper ($P < 0.01$) and wider ($P < 0.001$) fissures.

There were linear correlations between pulse energy and fragmentation volume, fissure width, and fissure depth (all $P < 0.001$).

Total power did not correlate with fragmentation measurements.

Laser fibre diameter did not affect fragmentation volume ($P = 0.81$), except at very low pulse energies (0.2 J), where the large fibre was less efficient ($P = 0.015$).

Conclusions

At the same total power level, LoFr-HiPE lithotripsy was most efficient. Pulse energy was the key variable that drove fragmentation efficiency.

Attention must be paid to prevent the formation of time-consuming bulky debris and adapt the lithotripter settings to one's needs.

As fibre diameter did not affect fragmentation efficiency, small fibres are preferable due to better scope irrigation and manoeuvrability.

Keywords

holmium:YAG laser lithotripsy, urinary calculi, high frequency lithotripsy, lithotripter settings, automated laser fragmentation testing system

Introduction

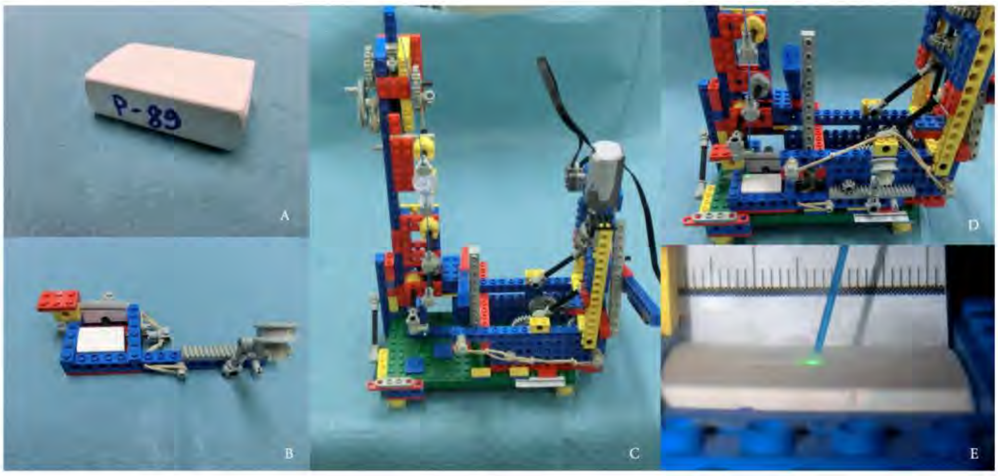
The high and rising prevalence of stone disease [1–3] has led to increasing numbers of lithotripsy treatments in urology departments. The opinions of urologists differ about which holmium laser energy setting fragments urinary stones in the quickest and most efficient manner. Some claim that high-frequency lithotripsy is the most efficient approach [4,5].

To date, the published *in vitro* laser lithotripsy studies have only focused separately on the effect on fragmentation (ablation) efficiency of different laser fibre diameters [6,7], different pulse energies [8,9], or different laser types [10–12].

BJU International © 2013 BJU International | doi:10.1111/bju.12567
Published by John Wiley & Sons Ltd. www.bjui.org

BJU Int 2014; **114:** 261–267
wileyonlinelibrary.com

Fig. 1 Experimental setup and support assembly. (**A**) An artificial stone with a size of 30 × 20 × 10 mm. (**B**) The sliding stone holder bearing an artificial stone. (**C**) The support assembly with the laser fibre holder and the electric motor but without the stone holder. (**D**) The support assembly with the inserted stone holder just before immersion in the tank. (**E**) A close-up of the laser fibre tip and the artificial stone during laser fragmentation in saline. The laser holder maintained the laser fibre at a 75–80° angle (instead of 90°) to prevent it from becoming trapped inside the stone during fragmentation.



A systematic study examining how the various lithotripsy settings interact with each other in shaping fragmentation efficiency has not been performed. In addition, the previous studies all used different experimentation methods. For example, stone samples were subjected to single-pulse laser emission [6,8,13], repeated laser emission [4,14], or just straight-forward perforation [12]. Moreover, in some studies, the majority of tests were performed manually [15–17] and/or used other irregular approaches [14,17,18] that could introduce human bias and/or error.

To address the controversy about the best settings for lithotripsy, the present comprehensive study was performed. Thus, a dynamic and innovative testing procedure that is accurate, yields highly reproducible results, and is free from human interaction was developed. The fragmentation efficiency of high frequency-low pulse energy (HiFr-LoPE) was compared with the fragmentation efficiency of low frequency-high pulse energy (LoFr-HiPE) lithotripsy by measuring fragmentation over wide ranges of pulse energies, pulse frequencies, total power settings, and with different laser fibre diameters.

Materials and Methods

Automated Laser Fragmentation Testing System

To ensure precision, laser fragmentation experiments were performed using an automated system where the immovable laser fibre fires at the surface of an artificial stone that is moved along an axis at a constant velocity, thereby engraving a fissure on the stone surface. The stone was chosen to be the moving component instead of the laser fibre as this meant a less complicated automated mechanism could be used, thus ensuring accuracy.

The system consisted of an automated experimentation support assembly that was made from Lego Technic™ (Fig. 1). The assembly included a sliding holder that kept the artificial stone in place while it was moved at a constant velocity (21 mm/30 s) along a horizontal plane by an electric motor for 30 s (during which time the stone moved a distance of exactly 21 mm). The assembly also included a specially designed holder for the laser fibre that kept the fibre tip at 75–80° and allowed the tip to move slightly and adapt itself to changes in the stone surface that arose from stone fragmentation. This ensured that the fibre tip always remained in contact with the stone material. It also prevented the fibre tip from becoming trapped in a crater and being dragged away by the sliding stone. The whole support assembly was immersed in a tank filled with 0.9% saline.

Preparation of Artificial Stones

Artificial stones were made from plaster of Paris, using the appropriate powder to water ratio of 1.5:1 by weight [19]. The stones were left to dry for >96 h at room temperature. The

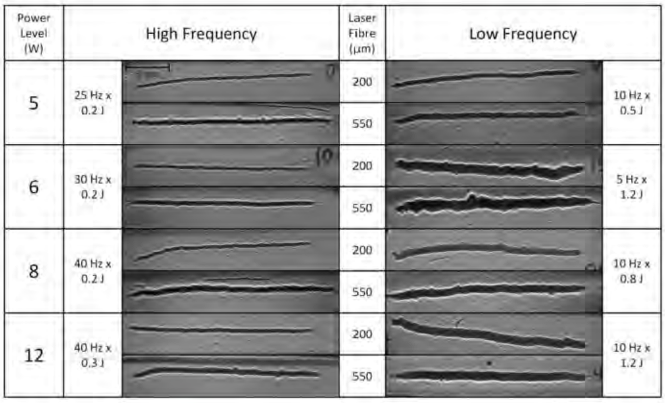


Fig. 2 Surface photographs of the artificial stones that were exposed to high- or low-frequency laser emissions from laser fibres whose diameters were 200 or 550 μm and which were used at power levels that ranged from 5 to 12 W. Naked eye observations show that low-frequency emissions clearly had superior outcomes. This was confirmed by subsequent digital volumetric measurements. The large 550 μm fibre produces wide but shallow fissures, while the small 200 μm fibre generates deep but narrow fissures.

tensile strength of these stones is very similar to several types of urinary stones [20]. Moreover, they are composed of a relatively soft material [21]. This makes them suitable for measuring fragmentation at very low pulse energies that might not yield detectable fragmentation if harder materials were used.

Before the experiment, the artificial stones were submerged in 0.9% saline and soaked in a uniform manner. The experiment began when the stone holder was put into motion, laser emission was initiated, and a fissure was carved into the stone.

Lithotripsy Fibres

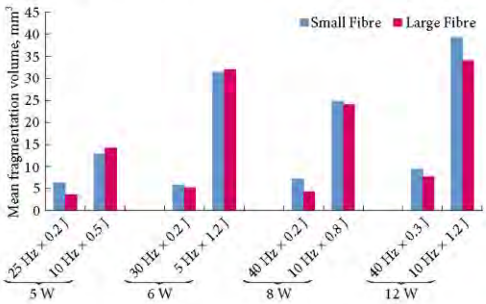
To assess possible variations resulting from differently sized laser fibres, each experiment was performed with either a small 200 or large 550 μm core laser fibre (Lumenis – SlimLine™). Brand new laser fibres were used and the tip was cleaved after each experiment to avoid any possible fibre tip degradation bias.

Lithotripsy Settings

A broad range of laser lithotripter settings was used. There were three groups of experiments. The high- vs low-frequency experiment involved 16 different settings with total power levels of 5, 6, 8 and 12 W, pulse energies of 0.2, 0.3, 0.5, 0.8, and 1.2 J, pulse frequencies of 5, 10, 25, 30, and 40 Hz, and small and large fibres. The combinations are specified in Figs 2 and 3.

The 6 W experiments, which were performed to more closely evaluate the changes in fragmentation efficiency as frequency declined and pulse energy rose, included four experiments of the previous test group and eight additional experiments at pulse energies of 0.2, 0.3, 0.4, 0.6, 1.0, and 1.2 J, and pulse frequencies of 5, 6, 10, 15, 20 and 30 Hz. The combinations, which were performed with small and large fibres, are specified in Table 1.

Fig. 3 The mean fragmentation volume achieved by small (200 μm) and large (550 μm) fibres at four different power levels and at high-or low-frequency lithotripter settings.



Another 10 experiments involved the following five W/Hz/J combinations, which were performed with both small and large fibres: 4/8/0.5, 6.4/8/0.8, 9.6/8/1.2, 16/40/0.4, and 20/40/0.5. These 10 experiments were added to the 16 high- vs low-frequency experiments and the eight additional 6 W experiments to make the 34 test dataset displayed and analysed in Fig. 4.

The laser lithotripter used was the Lumenis™ VersaPulse® Powersuite 100 W, which can be used at these multiple frequency and pulse energy settings.

Fissure Measurements

After the experiments were completed, the stones were dried for >96 h at room temperature and the fissure width, depth, and volume were measured. Fissure depth was measured

Table 1 Relationship between fragmentation and pulse energy at the 6 W power level. Comparison of the fragmentation (ablation) rates with the initial fragmentation volumes († and ‡) reveals an almost directly proportional increase as pulse energy rises for both types of laser fibres. If the pulse energy level doubled, tripled or even quintupled in relation to the initial high frequency setting, the fragmented volume ratios rose in an equivalent fashion although the power level remained the same (6 W).

Frequency, Hz	Pulse energy, J	Small 200 μm fibre		Large 550 μm fibre		Proportional increase of initial pulse energy (0.2 J)
		Mean (SD) FV, mm³	Ratio of FV to initial FV†	Mean (SD) FV, mm³	Ratio of FV to initial FV‡	
30	0.2	5.73† (0.05)	1.0	5.18‡ (0.18)	1.0	1.0
20	0.3	8.57 (0.07)	1.5	11.32 (0.46)	2.2	1.5
15	0.4	10.67 (0.21)	1.9	12.27 (0.71)	2.4	2.0
10	0.6	17.59 (1.08)	3.1	21.34 (1.59)	4.1	3.0
6	1.0	24.46 (1.65)	4.3	25.73 (1.72)	5.0	5.0
5	1.2	31.30 (0.78)	5.5	31.98 (0.75)	6.2	6.0

FV, fragmentation volume.

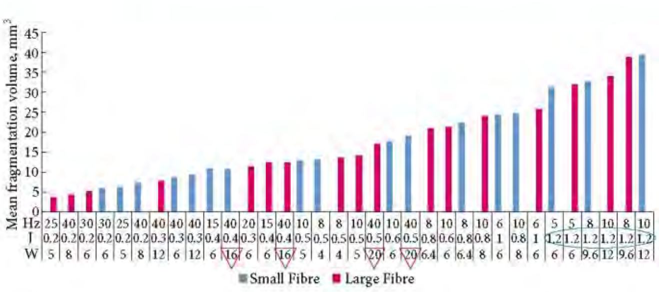


Fig. 4 Organisation of the 34 experiment dataset according to mean fragmentation volume. High frequencies at higher power settings (inverted red triangles) did not yield higher fragmentation rates than LoFr-HiPE settings, even when the settings of the latter were several orders of magnitude smaller. By contrast, the highest pulse energies were associated with the highest fragmentation volumes (green circle).

accurately by using the depth of focus of a calibrated optical microscope (Nikon Labophot 2) [22]. Concerning fissure width, the borders of the fissure were sometimes too irregular to make exact measurements. To overcome this, high resolution photographs were taken with tangential lighting to reveal the outlines of the fissure. After photographic calibration and use of image processing software (ImageJ 1.46r, U.S. National Institutes of Health, Bethesda, Maryland, USA), the depth, width, and volume of the fissure were calculated. The volume measurement served as the primary measure of fragmentation efficiency. Fissure width and depth served as secondary measures.

Statistical Analyses

Statistical analysis was performed using StatEL 2.6, AD Science, Paris, France. The *t*-test was used to compare high- vs low-frequency settings and small vs large laser fibres. Pearson's correlation test was used to evaluate relationships between the different laser settings and the resulting ablation rates. A $P < 0.05$ was considered to indicate statistical significance.

Results

Figures 2 and 3 show the high- vs low-frequency experimental data. At the same power level, LoFr-HiPE lithotripsy achieved a higher fragmentation (ablation) volume than HiFr-LoPE for all power levels that were tested, regardless of the fibre size. Compared with HiFr-LoPE, LoFr-HiPE increased the volume on average by 4.5 (SD 1.4)-fold ($P < 0.001$).

When the mean fragmented volumes of the 16 LoFr-HiPE vs HiFr-LoPE tests were ordered from the lowest to the highest volumes, the tests with the highest pulse energy (1.2 J) congregated at the higher end. When these tests were combined with another 18 tests involving other power, pulse energy, and pulse frequency combinations (see above), thus yielding 34 tests, the same distribution was seen (Fig. 4). There was a linear correlation between pulse energy and fragmentation volume ($P < 0.001$). However, the power (W) used did not correlate with fragmentation volume ($P = 0.29$).

The results of secondary experiments at the 6 W power level are shown in Table 1. This indicated that gradual increases in pulse energy were accompanied by steady, almost proportional, increases in mean fragmented volume. Thus, compared with the initial high-frequency setting, increasing the pulse energy essentially increased the fragmented volume ratios in a proportional manner.

Analyses of fissure width and depth revealed that these variables showed similar relationships as the mean fragmentation volume. First, LoFr-HiPE settings were associated with significantly wider and deeper fissures than HiFr-LoPE ($P < 0.001$ and $P < 0.01$, respectively). Second, analysis of the 34 experiments revealed that higher pulse energy correlated significantly with wider ($P < 0.001$) and deeper fissures ($P < 0.001$).

When different laser fibres were used for these experiments, statistically significant fragmentation volume changes were not detected. This was generally true even when the experiments were grouped according to regular total power or pulse energy intervals ($P = 0.81$). The exception was at very low pulse energies: at the energy of 0.2 J, the 550-μm fibre was significantly less effective at fragmentation than the smaller 200-μm fibre ($P = 0.015$). Notably, large fibres were always associated with wide fissures ($P < 0.001$) and small fibres were always associated with deep fissures ($P < 0.001$), regardless of the frequency, pulse energy, or total power used.

It was observed during the experiments that the high-frequency experiments generated very small, almost powder-like fragments, whereas low-frequency lithotripsy generated slightly larger fragments. However, all of these debris pieces were very friable and turned completely into dust. Consequently, measurable fragments were not available for further evaluation.

Discussion

There are only a few studies on high-frequency laser lithotripsy. One evaluated the effect of pulse frequency and the so-called 'popcorn effect' on multiple loose stone fragments. It was found that while increasing frequency tended to increase the fragmentation rate, there was a decline when very high frequency and higher energy settings were used [4]. The present study showed that at the same power levels, HiFr-LoPE was significantly less efficient than LoFr-HiPE lithotripsy.

The present study also showed that the fragmentation (ablation) volume, fissure width, and fissure depth increased when the pulse energy rose. This relationship between fragmentation volume and pulse energy has already been described in the early publications of leading experts in the field, such as Teichman and Vassar [8,9]. However, these single-pulse laser emission studies analysed the effect of pulse energy on its own; the possible interactive effects of different pulse frequency or total power were not examined. A more recent study that included high-frequency tests found that when the same frequency is maintained, fragmentation increases four-fold when 10-times as much pulse energy is applied [17]. In the present study, the effect on fragmentation efficiency of varying both frequency and total power levels was examined. This revealed that higher total power settings did not guarantee higher fragmentation volumes or wider or deeper fissures, even when significantly higher total power was used compared to LoFr-HiPE (Fig. 4). The secondary experiments at the 6 W power level also revealed another interesting association (Table 1): as the pulse energy increased, the mean fragmented volume ratio increased in an almost directly proportional way. In other words, if the pulse energy level doubled, tripled or even quintupled in relation to the initial high-frequency setting, the fragmented volume ratios rose in an equivalent fashion. This indicates that the key variable that affects fragmentation efficiency is the pulse energy, whereas frequency, especially high frequency, and total power setting play more minor roles.

Several studies have shown that low pulse energy settings produce smaller stone fragments than high pulse energy settings [5,23]. This was also marginally observed in the present study, although no measurable fragments resulting from any of the lithotripter settings tested were recovered. Many endourologists claim that HiFr-LoPE settings assist in achieving a more thorough stone fragmentation because they 'dust' the stone and leave no fragments to remove afterwards; nevertheless the present study shows that these same settings can be up to six-times slower if one considers the total ablation volume. But one admits that *in vivo* stone material (other than plaster of Paris) may possibly produce some bulky debris with LoFr-HiPE, debris whose removal may be time-consuming. The influence of debris size and the importance of uniformly dusting the stone should not be underestimated, as indicated by the following example of three different-sized stones whose length is 1, 2 or 3 cm, respectively. These stones have a stone volume of 1, 8, and 27 mL, respectively, and their fragmentation into 5-mm fragments would result in 8, 64 or 216 5-mm fragments, respectively. All of these fragments would have to be removed individually. If a 10/12 F ureteric access-sheath was used, the stones would have to be reduced to 3-mm fragments, which is the maximum stone size that can be accommodated by this sheath. In the case of the 3-cm stone, 1000 3-mm fragments would be produced. During laser lithotripsy, whether using the slower HiFr-LoPE setting or the faster LoFr-HiPE setting, it is important to ensure that the lithotripter setting that is applied ablates the stone uniformly and does not generate numerous large fragments. The removal of such fragments significantly increases the operating time, may require the use of a stone-removal device or specific laser lithotripsy techniques (e.g. the 'popcorn effect') to reduce the stone burden [4]. Cutting of the stone into small, removable pieces should be considered only when a small residual stone volume remains. Thus, slower ablating HiFr-LoPE, but only dust producing settings can be a useful element in the fragmentation procedure as a whole. Similar studies using real-life stone material are needed to confirm these results.

The studies comparing large and small laser fibres have yielded contradictory results: some suggest that at the same laser lithotripter settings, large fibres fragment large volumes [13], whereas others have found the opposite [9]. In the present study, large fibres always created wider fissures, while small fibres always generated deep fissures, but neither surpassed the other in terms of fragmentation volume. Indeed, for any given laser setting (with the exception of very low energy settings), the small fibre produced narrower yet deeper fissures than the large fibre. As a result, the two fibres fragmented similar volumes. The disparities between the present study and those of others may relate to the experimental approaches that were used. When isolated single laser pulses [8,9,13] or repeated laser pulses scattered over a surface are used [14,17], or handheld experiments are conducted [15,17], the impact of the laser never or rarely occurs at the same location twice. If the stone structure around these isolated fragmentation craters is weakened by the first impact, any new impacts on the same site could generate a significantly higher fragmentation volume. However, this effect cannot be detected by the above-described study designs. By contrast, the present study used continuous laser emission, where the same place was hit several times while moving the fibre steadily along a path. This closely mimics real-life lithotripsy and allows the effect of repeated laser emission impacts on the same area to be measured. This may explain the differences between the present and previous studies.

The large and small laser fibres differed only at the smallest energy level that was tested, namely, at 0.2 J when the large fibre was less effective. This may relate to energy dispersion. As the tip of the large laser fibre has a significantly larger contact area (7.5-times bigger) than the small fibre, the amount of energy delivered at the 0.2 J level may be too dispersed to exceed the ablation threshold [11].

Although the present study showed that the laser fibre diameters that were tested did not influence the laser ablation rate directly, the physical properties of the fibres can still exert a positive or negative effect on the lithotripsy procedure overall. Large-diameter laser fibres are more resistant to fibre tip degradation or the 'burn-back' effect, but their stiffness hampers scope deflection and their diameter obstructs irrigation flow. By contrast, small-diameter laser fibres are more fragile and prone to degradation phenomena with higher energies, but facilitate ureterorenoscope flexibility and irrigation rates at the same irrigation pressure, thereby increasing accessibility and visibility [7,9,14,24,25]. As fragmentation volume is not affected, the advantages of small-diameter laser fibres, namely, their increased scope deflection facility and irrigation rate (and consequent better visibility), lead us to prefer and recommend the use of small-diameter laser fibres, notwithstanding the financial costs associated with increased fibre degradation.

The present study did not take retropulsion into account, and did so intentionally. Retropulsion is affected by known factors, e.g. stone mass and pulse energy [11,13,26], the latter being one of the main variables analysed, but retropulsion is probably also influenced by other features like stone shape, friction between the surrounding tissue and the stone, etc. With the exception of pulse energy, all the previous variables could introduce potentially bias, leading to irreproducible results and conceal otherwise significant outcomes concerning pulse energy, frequency, total power and laser fibre diameter, the real focus of the present study. Nevertheless, retropulsion poses a problem to urologists because it reduces the laser's efficiency, increases operating time, and sometimes makes the calculus inaccessible. Some of the recommendations the present study advises might be impractical for very small free floating stones (e.g. minor ureteric calculi), because retropulsion increases with rising pulse energy [11,13]. However, in those stones only slightly influenced or completely unaffected by retropulsion due to size, location (e.g. trapped in a calyx), being fixed or impacted, our recommendations of using LoFr-HiPE can be useful and accelerate the procedure, especially on the brink of changing guidelines considering constantly larger stones suitable for retrograde intrarenal surgery (RIRS) [27,28].

The present study showed that should urologists wish to use the same total power level, they can accelerate their lithotripsy procedure simply by increasing the pulse energy and reducing frequency, although attention must be paid to preventing the production of bulky debris that might have an opposing effect and prolong the procedure. It also showed that urologists can use small-diameter laser fibres without compromising stone ablation efficiency, with the added benefit of having better irrigation, visibility, and manoeuvrability. Conventional laser lithotripters continue to offer as much as other high-frequency lithotripters at the power levels tested without jeopardising the fragmentation rate or surgery time.

The limitations of the present study concern the recommendation's applicability to very small calculi and the associated retropulsion. In the future, the next experimental step would be to mimic laser lithotripsy of very small non-impacted ureteric calculi. However, to include the simultaneous analysis of lithotripter settings, ablation volume and retropulsion of such small stones, and examine how they influence each other using this experimental setup, one would have to develop a system, where, besides all regular variables used, the retropulsion effect needs to be measurable and independent but still someway 'mechanised' and consistent, regardless of the different experimental parameters used. We are not sure if such a model can be developed that integrates ablation rate and retropulsion in a mechanised and reproducible fashion without introducing new factors, influencing existing ones, and leaving others to chance. This dilemma may be similar in analogy to Heisenberg's uncertainty principle in particle physics: one may either know the precise velocity of a particle or know its exact location, but never both of them at the same time [29].

The experimental setup of the present study met all planned criteria and proposed objectives that were described in the Introduction and Materials and Methods sections. Strenuous efforts were made to limit possible bias. Future comparisons with other testing methods will assess the power and reliability of the present study.

Acknowledgments

The authors want to thank Jérémie Berg for all the unconditional technical support given at the OR facilities of Hôpital Tenon in Paris where the experiments took place, and Rita Marques Silva, of the Department of Biostatistics of Faculdade de Ciências Médicas of NOVA University in Lisbon, for soothing and answering all our statistical fears and doubts.

Conflict of Interest

None declared.

References

1 Scales CD, Smith AC, Hanley JM, Saigal CS. Prevalence of kidney stones in the United States. *Eur Urol* 2012; 62: 160–5
2 Hyams ES, Matlaga BR. Cost-effectiveness treatment strategies for stone disease for the practicing urologist. *Urol Clin North Am* 2013; 40: 129–33
3 Lee M, Bariol SV. Evolution of stone management in Australia. *BJU Int* 2011; 108 (Suppl. 2): 29–33
4 Chawla SN, Chang MF, Chang A, Lenoir J, Bagley DH. Effectiveness of high-frequency holmium:YAG laser stone fragmentation: the 'popcorn effect'. *J Endourol* 2008; 22: 645–50
5 Spore SS, Teichman JM, Corbin NS, Champion PC, Williamson EA, Glickman RD. Holmium: YAG lithotripsy: optimal power settings. *J Endourol* 1999; 13: 559–66
6 Lee H, Ryan RT, Kim J et al. Dependence of calculus retropulsion dynamics on fiber size and radiant exposure during Ho:YAG lithotripsy. *J Biomech Eng* 2004; 126: 506–15
7 Blackmon RL, Irby PB, Fried NM. Thulium fiber laser lithotripsy using tapered fibers. *Lasers Surg Med* 2010; 42: 45–50
8 Teichman JM, Vassar GJ, Glickman RD. Holmium:yttrium-aluminum-garnet lithotripsy efficiency varies with stone composition. *Urology* 1998; 52: 392–7
9 Vassar GJ, Teichman JM, Glickman RD. Holmium:YAG lithotripsy efficiency varies with energy density. *J Urol* 1998; 160: 471–6
10 Teichman JM, Chan KF, Cecconi PP et al. Erbium: YAG versus holmium: YAG lithotripsy. *J Urol* 2001; 165: 876–9
11 Blackmon RL, Irby PB, Fried NM. Comparison of holmium:YAG and thulium fiber laser lithotripsy: ablation thresholds, ablation rates, and retropulsion effects. *J Biomed Opt* 2011; doi: 10.1117/1.3564884
12 Jelínková H, Köhler O, Miyagi M et al. Comparison of Ho:YAG and Er:YAG lasers for lithotripsy. *Proc SPIE* 7161: Photonic Therapeutics and Diagnostics V: 71611H (February 23, 2009); doi: 10.1117/12.808667
13 Kang HW, Lee H, Teichman JM, Oh J, Kim J, Welch AJ. Dependence of calculus retropulsion on pulse duration during Ho: YAG laser lithotripsy. *Lasers Surg Med* 2006; 38: 762–72
14 Delvecchio FC, Auge BK, Brizuela RM, Weizer AZ, Zhong P, Preminger GM. In vitro analysis of stone fragmentation ability of the FREDDY laser. *J Endourol* 2003; 17: 177–9
15 Blackmon RL, Irby PB, Fried NM. Holmium:YAG (lambda = 2,120 nm) versus thulium fiber (lambda = 1,908 nm) laser lithotripsy. *Lasers Surg Med* 2010; 42: 232–6
16 Sroka R, Hecht V, Reich O, Seitz M, Stief CG, Bader MJ. *In vitro* comparison of laser induced lithotripsy on artificial stones by means of different laser systems. *Proc SPIE* 7161: Photonic Therapeutics and Diagnostics V: 71611T (February 23, 2009); doi: 10.1117/12.812216
17 Sea J, Jonat LM, Chew BH et al. Optimal power settings for Holmium:YAG lithotripsy. *J Urol* 2012; 187: 914–9
18 Marguet CG, Sung JC, Springhart WP et al. In vitro comparison of stone retropulsion and fragmentation of the frequency doubled, double pulse Nd:YAG laser and the holmium:yag laser. *J Urol* 2005; 173: 1797–800
19 Auge BK, Sekula JJ, Springhart WP, Zhu S, Zhong P, Preminger GM. *In vitro* comparison of fragmentation efficiency of flexible pneumatic lithotripsy using 2 flexible ureteroscopes. *J Urol* 2004; 172: 967–70
20 Chuong CJ, Zhong P, Preminger GM. A comparison of stone damage caused by different modes of shock wave generation. *J Urol* 1992; 148: 200–5
21 Vekinis G, Ashby MF, Beaumont PW. Plaster of Paris as a model material for brittle porous solids. *J Mater Sci* 1993; 28: 3221–7
22 Liu JJ, Tian C, Wang Z, Lin JM. Measurement of channel depth by using a general microscope based on depth of focus. *Eurasian J Anal Chem* 2007; 1: 12–20
23 Corbin NS, Teichman JM, Nguyen T et al. Laser lithotripsy and cyanide. *J Endourol* 2000; 14: 169–73
24 Pasqui F, Dubosq F, Tchala K et al. Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. *Eur Urol* 2004; 45: 58–64
25 Knudsen BE, Pedro R, Hinck B, Monga M. Durability of reusable holmium:YAG laser fibers: a multicenter study. *J Urol* 2011; 185: 160–3
26 Robinson M, Teichman JMH. 1063 Laser lithotripsy retropulsion varies with stone mass. *Eur Urol Suppl* 2013; 12: e1063
27 EAU Guidelines Office ed. EAU Guidelines. Edition presented at the 26th EAU Annual Congress in Vienna. Arnhem, The Netherlands; 2011
28 EAU Guidelines Office ed. EAU Guidelines. Edition presented at the 28th EAU Annual Congress in Milan. Arnhem, The Netherlands; 2013
29 Heisenberg W. Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. *Zeitschrift fur Physik* 1927; 43: 172–98

Correspondence: Peter Kronenberg, Urology Department, Hospital Prof. Doutor Fernando Fonseca, IC-19, 2720-276 Amadora, Portugal.

e-mail: peterkronenberg@gmail.com

Abbreviations: HiFr-LoPE, high frequency-low pulse energy; LoFr-HiPE, low frequency-high pulse energy.

Article 2: The truth about laser fiber diameters

Endourology and Stones

The Truth About Laser Fiber Diameters

Peter Kronenberg and Olivier Traxer

OBJECTIVE To measure the various diameters of laser fibers from various manufacturers and compare them with the advertised diameter.

METHODS Fourteen different unused laser fibers from 6 leading manufacturers with advertised diameters of 200, 270, 272, 273, 365, and 400 µm were measured by light microscopy. The outer diameter (including the fiber coating, cladding, and core), cladding diameter (including the cladding and the fiber core), and core diameter were measured. Industry representatives of the manufacturers were interviewed about the diameter of their fibers.

RESULTS For all fibers, the outer and cladding diameters differed significantly from the advertised diameter ($P < .00001$). The outer diameter, which is of most practical relevance for urologists, exhibited a median increase of 87.3% (range, 50.7%-116.7%). The outer, cladding, and core diameters of fibers with equivalent advertised diameters differed by up to 180, 100, and 78 µm, respectively. Some 200-µm fibers had larger outer diameters than the 270- to 273-µm fibers. All packaging material and all laser fibers lacked clear and precise fiber diameter information labels. Of 12 representatives interviewed, 8, 3, and 1 considered the advertised diameter to be the outer, the cladding, and the core diameter, respectively. Representatives within the same company frequently gave different answers.

CONCLUSION This study suggests that, at present, there is a lack of uniformity between laser fiber manufacturers, and most of the information conveyed to urologists regarding laser fiber diameter may be incorrect. Because fibers larger than the advertised laser fibers are known to influence key interventional parameters, this misinformation can have surgical repercussions. UROLOGY 84: 1301−1307, 2014. © 2014 Elsevier Inc.

In the last 2 decades, urinary stone management has changed markedly, largely because of advances in technology and the development of minimally invasive techniques. One technique that has shown particularly rapid development is endourologic laser lithotripsy.[1,2] The success of laser lithotripsy has promoted the appearance of increasing numbers of laser fiber manufacturers, some of whose fibers have been approved for use with various commercially available lithotripters rather than just 1 particular laser lithotripter machine.[3-5] However, a prevailing perception of the surgeons in our institutions is that the diameters of the laser fibers from different brands differ from the advertised diameters; this is particularly apparent when laser fibers with supposed equal diameters are compared. The surgeons have also noticed inconsistencies in the statements of industry representatives regarding the diameter of their laser fibers.

To date, studies that systematically verify the advertised diameter of laser fibers have not been accomplished. Consequently, the present study was performed to objectively confirm the diameter of several laser fibers and to assess how well the diameters reported by a broad range of industry representatives conformed to the actual practically relevant values.

METHODS

Definitions

There are many terms in the literature for the laser fiber components, including "plastic coating," "polymer jacket," "buffer," "cladding," "primary and secondary cladding," "fiber core," "optical core," "pure silica core," "outside diameter," "inner diameter," "total diameter," "core diameter," and "true diameter."[6-10] Some of these terms refer to the same component or comprise several components, which lead to misinterpretations. To avoid such misunderstandings, the authors called the tested fiber components according to strict and established definitions used by renowned authorities in the field.[5-10] Coating is defined as the usually blue polymer (ethylene tetrafluoroethylene) jacket that covers and protects the glassy optical elements of the fiber, that is, the cladding and the core. The cladding is the outermost glassy component that envelops the core and whose surface is exposed after stripping the coating from the laser fiber. The core is defined as the innermost component of the fiber, which can only be observed by light microscopy of the fiber tip. Thus,

Financial Disclosure: Olivier Traxer is a medical consultant and advisor for American Medical Systems. Peter Kronenberg declares that he has no relevant financial interests.

From the Urology Department, Hospital Professor Doutor Fernando Fonseca, Amadora, Portugal; and the Urology Department, Université Paris 6 Pierre et Marie Curie, Hôpital Tenon, Paris, France

Address correspondence to: Peter Kronenberg, M.D., Department of Urology, Hospital Professor Doutor Fernando Fonseca, IC-19, 2720-276 Amadora, Portugal. E-mail: [illegible]

Submitted: May 21, 2014, accepted (with revisions): August 12, 2014

http://dx.doi.org/10.1016/j.urology.2014.08.017 1301
0090-4295/14

3 diameters can be defined, the outer diameter (including the fiber coating, cladding, and fiber core), the cladding diameter (comprising the cladding and the core), and the core diameter.

Laser Fibers and Their Preparation

Fourteen different brand-new laser fibers from 6 leading brands (SureFlex, American Medical Systems; EndoBeam, Bard; AccuMax, Boston Scientific; Lightguide, Dornier; SmartFibers, Electro Medical Systems; and SlimLine, Lumenis) were evaluated. These fibers had the numbers 200, 270, 272, 273, 365, or 400 printed on them and on their packaging material. Although careful inspection of all printed packaging and fiber material did not show any references to which diameter these printed numbers referred to, it was assumed to be the advertised diameter in micrometers. Consequently the authors were forced to compare these printed numbers with all possible measured diameters and addressed this issue in the comment section. All fibers tested were sequentially numbered and are listed together with their specifications in Table 1. Two centimeters of the coating on the free extremity of each laser fiber were removed by using a laser fiber stripper that was individually adjusted to each laser fiber (FOC&T GmbH, Burghausen, Germany). The tip of the fiber was then perpendicularly cleaved with a pair of ceramic scissors (CS-124; Kyocera Corporation, Kyoto, Japan).

Measurements

For each fiber, 3 diameters were measured. Eight lateral measurements for each of the outer diameter and the cladding diameter were made by using a calibrated optical microscope (Labophot 2; Nikon Corporation, Tokyo, Japan) and image processing software (Olympus DP-Soft 3.2; Soft Imaging System GmbH) (Fig. 1). Because this technique did not allow us to distinguish the individual optical elements from one another, additional 8 frontal measurements were made, thus allowing the fiber core to be identified and its diameter measured (Fig. 2).

Industry Representative Surveys

For each laser fiber brand that was tested, 2 specialized industry representatives were interviewed regarding the fiber diameter at 2 key urology congresses, namely, the 2013 American Urological Association Annual Meeting in San Diego, CA, and the 28th Annual European Association of Urology Congress in Milan, Italy. In total, 12 representatives were asked what the actual diameters of their fibers were and to which component their answer related.

Statistical Analyses

All measured laser fiber diameters were compared with their advertised diameter. A 10% diameter deviation was arbitrarily considered to be the maximum acceptable deviation. For each fiber, the means ± standard deviations of the measured diameters at the 3 locations were compared with the advertised fiber diameter using the Student t test and computer software (StatEl 2.6; ad Science, Paris, France).

RESULTS

For all fibers, the measured outer diameter differed significantly from the advertised diameter (all $P < .00001$). If the advertised diameter is deemed to be the outer diameter, none of the fibers had a measured diameter within the 10% tolerance range. The outer diameters of the fibers exceeded their advertised diameters by a median of 87.3% (range, 50.7%-116.7%). Four of the fibers (fiber numbers 1, 3, 7, and 13) were more than twice as large as advertised (Figs. 1, 3; Table 1). Three manufacturers had fibers that were advertised to have 200 µm and also had fibers that were advertised to have 270-273 µm. Comparison of the outer diameters of these 200-270 µm pairs (fiber numbers 1, 4, and 10 vs 2, 5, and 11) within each brand revealed that they differed on average by 30.5 µm. In 1 brand, this difference was <15 µm (fiber number 1 and 2). When all 5 fibers from various brands that were advertised as having 200 µm were compared with the 4 fibers that were advertised as having 270-273 µm, several of the presumed 200-µm fibers were actually larger than several of the presumed ~270-µm fibers (fiber numbers 7, 13 vs 2, 5, and 11). Furthermore, when the 4 fibers that were advertised as having 365 µm (fiber numbers 3, 6, 12, and 14) were compared, their outer diameters differed by >180 µm.

The cladding diameter of all fibers also differed significantly from the advertised diameter (all $P < .00001$). If the advertised diameter is deemed to be the cladding diameter, only 1 fiber (fiber number 9) respected the 10% margin. The cladding diameter of the remaining fibers exceeded the advertised diameter by a median of 30.9% (range, 16.7%-80.1%). When the cladding diameters of fibers with a supposed equal diameter were compared, they differed by up to 100 µm.

If the advertised diameter is deemed to be the core diameter, then the majority of the fibers (85.7%) respected the 10% margin. The core diameter of the fibers exceeded the advertised diameter by a median of 0.5% (range, −9.3% to 1.7%). One of the fibers (fiber number 9) was 9.3% thinner than advertised. Only 2 fibers were markedly larger than advertised (19.7% and 39.0% larger for fiber number 7 and 13, respectively). However, when the fibers with a supposed equal diameter were compared, their core diameters differed by up to 78 µm (Figs. 2, 3; Table 1).

In our survey, all industry representatives considered the numbers printed on the fibers or packaging material to represent its diameter. Eight representatives (66.7%) indicated that the advertised diameter was the outer diameter. Three representatives (25%) considered the advertised diameter to be the cladding diameter and acknowledged that the outer fiber diameter was larger than the advertised diameter. Only 1 representative (8.3%) referred the advertised diameter to be the core diameter. Several times, the answer given by 1 representative at 1 congress was different from the response given by another representative from the same company at the other congress.

COMMENT

The veracity of the advertised diameter of laser fibers used in medicine has not been investigated systematically.

Table 1. Specifications, measured and advertised diameters of the 14 different laser fibers tested

Fiber Number	Manufacturer	Reusability	Advertised Diameter	Mean Outer Diameter ± SD (Measured), µm	Mean Cladding Diameter ± SD (Measured), µm	Core Diameter ± SD (Measured), µm	% Increase in Measured Diameter Relative to the Advertised Diameter		
							Increase in Outer Diameter, %	Increase in Cladding Diameter, %	Increase in Core Diameter, %
1	SureFlex, AMS	Reusable	200	407.1 ± 0.8	259.5 ± 1.1	203.4 ± 0.3	**103.6**	**29.7**	1.7
2	SureFlex, AMS	Reusable	273	421.9 ± 1.2	326.9 ± 1.0	271.4 ± 0.5	**54.6**	**19.7**	−0.6
3	SureFlex, AMS	Reusable	365	737.9 ± 1.5	429.7 ± 1.2	365.0 ± 0.6	**102.2**	**17.7**	0.0
4	EndoBeam, Bard	Single use	200	383.6 ± 1.5	277.5 ± 0.9	199.4 ± 0.4	**91.8**	**38.7**	−0.3
5	EndoBeam, Bard	Single use	272	409.9 ± 0.8	324.4 ± 1.6	271.1 ± 0.4	**50.7**	**19.3**	−0.3
6	EndoBeam, Bard	Single use	365	728.6 ± 1.8	426.1 ± 1.4	359.1 ± 0.3	**99.6**	**16.7**	−1.6
7	AccuMax, Boston	Single use	200	433.4 ± 1.0	340.0 ± 0.9	239.4 ± 0.3	**116.7**	**70.0**	**19.7**
8	Lightguide, Dornier	Single use	270	456.4 ± 1.3	356.8 ± 0.8	270.9 ± 0.5	**69.0**	**32.1**	0.3
9	Lightguide, Dornier	Single use	400	741.2 ± 0.7	424.9 ± 1.6	362.8 ± 0.6	**85.3**	6.2	−9.3
10	SmartFibers, EMS	Reusable	200	378.5 ± 1.5	277.7 ± 0.7	199.8 ± 0.4	**89.2**	**38.8**	−0.1
11	SmartFibers, EMS	Reusable	273	428.9 ± 1.4	361.3 ± 1.3	271.3 ± 0.8	**57.1**	**32.4**	−0.6
12	SmartFibers, EMS	Reusable	365	556.5 ± 1.0	436.7 ± 1.0	365.6 ± 0.7	**52.5**	**19.6**	0.2
13	SlimLine, Lumenis	Reusable	200	433.1 ± 1.2	360.2 ± 1.2	278.0 ± 0.7	**116.6**	**80.1**	**39.0**
14	SlimLine, Lumenis	Reusable	365	555.8 ± 0.8	433.5 ± 1.3	360.1 ± 0.8	**52.3**	**18.8**	−1.3

AMS, American Medical Systems; EMS, Electro Medical Systems; SD, standard deviation.

With regard to outer diameters, all fibers are at least 50% larger than advertised. Some are more than twice as large. With regard to cladding diameter, only 1 fiber respects the 10% tolerance margin. All measurements that differed significantly from the advertised diameter are indicated by bolded percentages (all $P < .00001$, as determined by the Student t test).

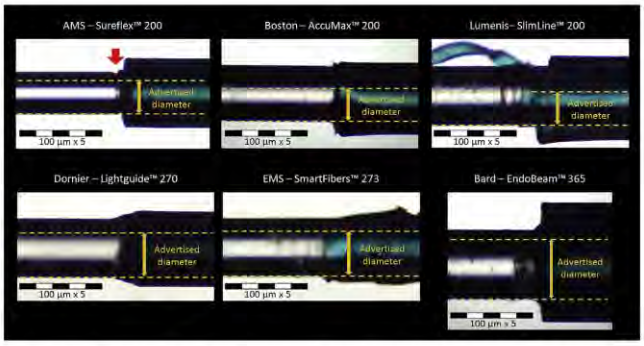


Figure 1. Photographs depicting the advertised and measured outer diameters of some of the fibers that were tested. These photos were taken for illustrative purposes only to show both the cladding and its coating and to give the observer a rough idea of the discrepancies that were observed. These images do not reflect the measurements at high precision. Because most laser fiber information labels lack units or references to what the label numbers refer to, units were also omitted for each fiber of this figure. Attention is drawn to the arrow on the upper left image, indicating a small fissure on the cladding caused by an initially to tight and ill-adjusted laser fiber stripper. (Color version available online.)

Figure 2. Light microscopy images of the tip of some of the fibers tested. This is the only way to visualize the innermost component of the fiber, namely, the core (seen as the bright inner disk). In some images, several layers of the cladding can be observed (seen as darker rings around the bright inner disk). The coating cannot be seen because it is out of focus. Note that the upper row of images relates to 3 fibers that are advertised as being 200 µm in diameter: the diameters of the cores are all different and the one to the right is clearly considerably larger than the diameters of the other 2 cores. Because most laser fiber information labels lack units or references to what the label numbers refer to, units were also omitted for each fiber of this figure. (Color version available online.)

Although differences between the advertised and apparent diameters have been observed and reported 3 times, these observations were only mentioned in an incidental manner and their serious implications were overlooked.[6,7,9] To our knowledge, only 1 study has focused partially on the discrepancy found between advertised diameter and real diameter.[11] The present study showed that for all of the 14 laser fibers that were tested, the advertised diameters differed markedly from the measured outer and cladding diameters. Although the core diameter of the majority of the fibers deviated from the advertised diameter by <10%, there are some noteworthy outliers (Fig. 3; and fiber numbers 7 and 13 in Table 1). In addition, even with fibers whose core diameter was exactly the same as the advertised diameter (eg, 200 µm), all fibers had a significantly wider outer diameter than the advertised diameter: in 4 cases, the outer diameters of the fibers were double the advertised diameter (fiber numbers 1, 3, 7, and 13) without any reference on the packaging as discussed below. Further inconsistencies were observed when fibers from the same brand that were supposed to differ in size were compared

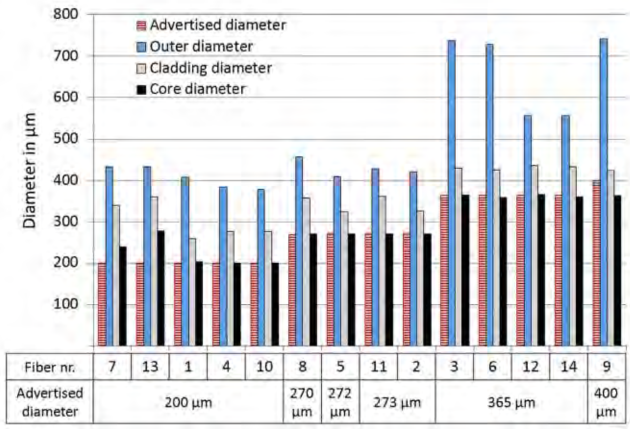


Figure 3. The outer, cladding, and core diameters of the fibers in relation to their advertised diameter. There are noticeable differences in the 200-µm category fibers in all 3 diameter types. The 200- and 270- to 273-µm categories are sometimes quite similar or even unpredictably different as some diameters of the 200-µm category exceed those of the 270- to 273-µm categories. The 365-µm category fibers differ markedly from each other in terms of outer diameter. In all cases, the outer diameters exceed the advertised diameter considerably. The fiber numbers correspond as follows: 1-3, SureFlex, American Medical Systems; 4-6, EndoBeam, Bard; 7, AccuMax, Boston Scientific; 8 and 9, Lightguide, Dornier; 10-12, SmartFibers, Electro Medical Systems; 13 and 14, SlimLine, Lumenis. (Color version available online.)

in terms of outer diameters (200 vs 270-273 µm): instead of an expected ~70 µm outer diameter growth, they increased in average of only 30.5 µm (Fig. 3).

Many of the fiber manufacturers could claim that their advertised diameter refers to the core diameter. However, this was not stated anywhere on the packaging or information labels of each fiber. In some cases, the number (eg, 200, 272, or 365) on the package was integrated within the laser fiber reference name. In other cases, the number was stamped in isolation on the package. Only 1 manufacturer wrote the word "size" next to the number. However, the word "diameter" was absent in all cases. Thus, it was manifestly unclear what the number meant, let alone whether it referred to a specific diameter (eg, outer diameter, cladding diameter, or core diameter). Moreover, in half of the cases, the number on the package lacked a unit. The remaining packages that did bear a unit misused it: 1 had the symbol "µ" stamped next to the number, which is just a Système International d'Unités (SI) prefix and is useless without an associated SI unit that would define the nature of the physical quantity to which the number refers. In another package, the number was associated with the term "micron", which is no longer an SI unit, being dropped by the SI committee in 1968.[12] Only 1 package had the term "µm" associated with the number. However, in all cases where a unit was used, it was not clear that it related to a diameter of the fiber. Consequently, the authors of this study were required to compare these numbers with all 3 measurable diameters.

The incorrect or misleading labeling of medical materials or devices has been reported previously.[13-15] Indeed, it occurs to such an extent that quality controls and regulations like the Conformité Européene mark of the European Union or those of the Food and Drug Administration of the United States of America have been implemented, including for device packaging.[16,17] However, when the labeling of medical materials and devices are subjected to external audits similar to those of the present study, the results lead to doubts about the efficacy of these quality standards.[18] In front of the obvious incongruities herein exposed, more scrutiny of medical devices (including their correct labeling) is urgently needed and may explain why this surveillance tends to be increasing within the European Union.[19]

The present study showed that the outer diameters of the fibers were vastly different from the advertised diameters and that laser fibers from different manufacturers advertised to have the same diameter actually differed significantly from each other in outer diameter (Figs. 1, 3). This is troubling because it could cause a urologist to erroneously believe that the interchangeable fiber from one manufacturer has the same outer diameter as the interchangeable fiber from another manufacturer, when in fact it is considerably larger. This is important because a larger fiber diameter can affect the urologist's surgical performance in several ways depending on the setting in which these fibers are used. First, increasing the diameter of accessories used in flexible ureterorenoscopy, including guide wires, stone retrieval devices, and laser fibers, hampers the degree of scope deflection, thereby limiting the main advantage of the flexible scope, namely, its ability to reach difficult locations such as the lower calyces.[20-22] Second, considering the small size of the working channels through which these laser fibers are passed, any increase in size also affects the rate of irrigation, which is crucial for good visualization and the prompt identification of structures and thus indirectly influences the operating time.[21,22] According to the law defined by Poiseuille in 1840, flow is inversely proportional to the diameter to the power of 4.[23] This means that for any given fiber, if the fiber diameter increases by 19%, 50%, or 100%, the degree of obstruction concerning irrigation flow increases by 100%, 400%, and 1500%, respectively. Because fiber diameter does not significantly affect stone ablation volume but does exert a major impact on scope deflection and irrigation flow, the outer diameter is the most important diameter for the urologist.[24] Third, large fibers have been shown to promote retropulsion relative to smaller fibers, thus reducing the efficacy of laser lithotripsy, increasing the operating time, and sometimes causing a calculus to become inaccessible by pushing it into the renal pelvis.[25] All these considerations emphasize the importance of outer diameter uniformity between laser fibers that are labeled with the same diameter.

Another aspect concerns the widespread use of reusable laser fibers that need to be prepared and stripped before usage.[26] Miscalculation of the fiber's diameter, whether because it is larger than advertised, lacks uniformity between brands or due to misguiding information on its packaging, the use of an ill-adapted laser fiber stripper on a supposedly smaller fiber may damage the cladding (arrow in Fig. 1), so essential for laser conduction, risking laser radiation leaks that can cause damage to tissues and instruments.[10]

Misinformation from the pharmaceutical and medical device industry has been described in the medical literature.[18,27,28] Our survey suggests that, at present, the majority of industry representatives (91.7% in our study) are not aware of the diameter of the laser fibers they represent, and only 1 representative (8.3%) mentioned the existence of the core diameter. The discrepancies found in the responses between and even within companies can only be explained by a lack of correct information given to the representatives during their own training sessions in the first place. This means that despite the sincere goodwill of industry representatives and their manifest desire to provide urologists with the most up-to-date information regarding their products, the information that they are giving at present may be incorrect or inadvertently misleading.

One might criticize that this survey was done in a casual manner and that no paper questionnaire was given to be filled out by the industry representatives. However, this informal approach was deliberately chosen by the authors, because they didn't want to intimidate or somehow influence the representatives into looking up any technical literature, unless they did it by themselves before giving an answer. By doing so the authors hoped to obtain the answer the representatives would give to any urologist asking this simple question, and thus avoid any bias that a formal paper questionnaire might introduce. Development of validated questionnaires for this issue and performing more interviews could shed more light on this topic and are therefore limitations of this study.

Two reports have recommended ways to avoid misinterpretations concerning labeling of medical devices, including laser fiber diameters but have not been followed to date.[11,16] It should be emphasized that given the deleterious effects of large laser fibers on laser lithotripsy that are described previously and the ever increasing miniaturization of the instruments today, urologists generally only want to know the outer diameter of the fibers that they introduce into the small working channels of their instruments. Although the intermediary diameters of the fiber (eg, the core diameter) are of much less-practical relevance for urologists, they are still essential, for example, the cladding diameter, indispensable for safe stripping of the fiber. Therefore, the authors of the present study recommend that all fibers and their respective packaging be correctly labeled with the 3 diameters that were measured in this study, namely, the outer diameter, the cladding diameter, and the core diameter. This will facilitate straightforward comparisons between laser fibers, improve the understanding of laser fiber products by both urologists and industry representatives, and avoid future misunderstandings.

CONCLUSION

The present study showed that the advertised diameters of the laser fibers currently do not correspond to their outer diameters, which are the most practically relevant diameters for urologists. Moreover, fibers from different manufacturers that are labeled with the same diameter were found to differ significantly in terms of their outer diameters. The packaging and information labels of all of these fibers were observed to be imprecise as they lacked appropriate and clear diameter specifications. The majority of industry representatives were not aware of the outer laser fiber diameters or what the diameters that were advertised actually referred to. Thus, most of the information that is presently conveyed to urologists regarding laser fiber diameter may be incorrect. Because larger than advertised laser fibers are known to influence key interventional parameters, this misinformation can have surgical repercussions.

Acknowledgments. The authors thank the Surgical Pathology Department of Hospital Professor Doutor Fernando Fonseca in Amadora, in particularly Dr. Rita Theias Manso for providing and helping out with the microscopic equipment.

References

1. Fry SM. New technologies for interventional radiology. *Invest Radiol*. 1990;25:93-97.
2. Ather MH, Paryani J, Memon A, et al. A 10-year experience of managing ureteric calculi: changing trends towards endourological

intervention—is there a role for open surgery? *BJU Int.* 2001;88: 173-177.

3. Reynders McVeigh Capital Management LLC. *IPG Photonics: Recent News.* 2013.
4. Grupp H. Learning in a science-driven market: the case of lasers. *Ind Corporate Change.* 2000;9:143-172.
5. Verdaasdonk RM, van Swol CF. Laser light delivery systems for medical applications. *Phys Med Biol.* 1997;42:869-894.
6. Khemees TA, Shore DM, Antiporda M, et al. Evaluation of a new 240-μm single-use holmium:YAG optical fiber for flexible ureteroscopy. *J Endourol.* 2013;27:475-479.
7. Monga M. *Ureteroscopy: Indications, Instrumentation & Technique.* Totowa, NJ: Humana Press; 2013:163-164.
8. Paschotta R. *Encyclopedia of Laser Physics and Technology.* Weinheim: Wiley-VCH; 2008.
9. Herrmann TR, Bach T, Imkamp F, et al. FlexGuard: a new laser insertion sheath: functional aspects in ureterorenoscopy (URS). *World J Urol.* 2007;25:269-273.
10. Nazif OA, Teichman JM, Glickman RD, et al. Review of laser fibers: a practical guide for urologists. *J Endourol.* 2004;18: 818-829.
11. Mues AC, Teichman JM, Knudsen BE. Evaluation of 24 holmium: YAG laser optical fibers for flexible ureteroscopy. *J Urol.* 2009;182: 348-354.
12. Terrien J. News from the International Bureau of Weights and Measures. *Metrologia.* 1968;4:41-46.
13. FDA: Portex Uncuffed Pediatric Tracheal Tubes Recalled, November 2009; 11Set2009. Available at: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/psn/printer.cfm?id=1140. Accessed October 19, 2013.
14. FDA: Enforcement Report - Week of October 10, 2012; 7Set2012. Available at: http://www.accessdata.fda.gov/scripts/enforcement/enforce_rpt-Event-Detail.cfm?action=detail&id=63136&w=10102012&lang=eng. Accessed October 19, 2013.
15. Caceres CA, Yolken HT, Jones RJ, et al. *Medical Devices, Measurements, Quality Assurance, and Standards. Online-ausg.* Philadelphia, PA: American Society for Testing and Materials; 1983 (ASTM STP 800).
16. Medical devices; current good manufacturing practice (CGMP) final fule; quality system regulation–FDA. Final rule. *Fed Regist.* 1996;61:52602-52662.
17. Donawa ME. European and US quality system requirements for packaging. *Med Device Technol.* 1997;8:12-14; 16-7.
18. Levin M. More than standards and regulations are needed to provide safe and effective devices. *Biomed Instrum Technol.* 2001;35:331-337.
19. O'Dowd A. Europe plans to strengthen surveillance system for medical devices, MPs are told. *BMJ.* 2012;344:e4179.
20. Kuo RL, Aslan P, Zhong P, et al. Impact of holmium laser settings and fiber diameter on stone fragmentation and endoscope deflection. *J Endourol.* 1998;12:523-527.
21. Pasqui F, Dubosq F, Tchala K, et al. Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. *Eur Urol.* 2004;45:58-64.
22. Bach T, Geavlete B, Herrmann TR, et al. Working tools in flexible ureterorenoscopy–influence on flow and deflection: what does matter? *J Endourol.* 2008;22:1639-1643.
23. Poiseuille J. Recherches expérimentales sur le mouvement des liquides dans les tubes de très petits diamètres: III. Influence du diamètre sur la quantité de liquide qui traverse les tubes de très petits diamètres. *C R Acad Sci.* 1840:1041-1048.
24. Kronenberg P, Traxer O. In vitro fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy—a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. *BJU Int.* 2014; 114:261-267.
25. Kronenberg P, Traxer O. Laser fibers, pulse energy and retropulsion—what we can see and what we can't. *J Urol.* 2013; 189:e707.
26. Bagley DH, Das A. *Endourologic Use of the Holmium Laser.* Jackson, WY: Teton NewMedia; 2001.
27. Mejía R, Avalos A. Material informativo entregado por los agentes de propaganda médica. *Medicina (B Aires).* 2001;61: 315-318.
28. Barros JA. A (des)informação sobre medicamentos: o duplo padrão de conduta das empresas farmacêuticas. *Cad Saude Publica.* 2000; 16:421-427.

Article 3: Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser

Are We All Doing It Wrong? Influence of Stripping and Cleaving Methods of Laser Fibers on Laser Lithotripsy Performance

Peter Kronenberg* and Olivier Traxert†

From the Hospital Professor Doutor Fernando Fonseca, Amadora, Portugal, and Université Paris 6, Pierre et Marie Curie-Hôpital Tenon (OT), Paris, France

Abbreviations and Acronyms

HiFr-LoPE = high frequency-low pulse energy

LoFr-HiPE = low frequency-high pulse energy

Accepted for publication July 28, 2014.

* Correspondence: Hospital Professor Doutor Fernando Fonseca, Urology, IC-19, 2720-276 Amadora, Lisbon, Portugal (telephone: +351 917323480; FAX: +351 210073441).

† Financial interest and/or other relationship with American Medical Systems, Coloplast, Olympus and Rocamed.

Purpose: We assessed whether stripping and cleaving the laser fiber tip with specialized tools, namely laser fiber strippers, or ceramic or metal scissors, would influence lithotripsy performance.

Materials and Methods: Laser fiber tips were stripped with a specialized laser fiber stripper or remained coated. The tips were then cleaved with metal or ceramic scissors. Laser lithotripsy experiments were performed with the 4 fiber tip combinations using an automated laser fragmentation testing system with artificial stones made of plaster of Paris or BegoStone Plus (Bego, Lincoln, Rhode Island). High frequency-low pulse energy (20 Hz and 0.5 J) and low frequency-high pulse energy (5 Hz and 2.0 J) settings were used for 30 seconds. Fissure width, depth and volume, and laser fiber tip photos were analyzed.

Results: Coated laser fiber tips always achieved significantly higher ablation volumes (sometimes greater than 50%) than stripped laser fiber tips ($p < 0.00001$) regardless of cleaving scissor type, stone material or lithotripter setting. Coated fiber tips cleaved with metal scissors ablated as well as those cleaved with ceramic scissors ($p = 0.16$). However, stripped fibers were much less ablative when they were cut with metal scissors compared to ceramic scissors ($p < 0.00001$). Harder stone material decreased ablation volume ($p < 0.00001$). Low frequency-high pulse energy settings were an average of 3 times more ablative than high frequency-low pulse energy settings ($p < 0.00001$). Stripping the fibers, a harder stone material and low frequency-high pulse energy settings were associated with increased fiber tip degradation.

Conclusions: Coated laser fibers provided better lithotripsy performance and metal scissors were as good as ceramic scissors to cleave coated fibers. This knowledge may improve and simplify the way that laser lithotripsy procedures are done worldwide.

Key Words: urinary calculi; lithotripsy; lasers, solid-state; instrumentation; equipment reuse

SINCE the introduction of laser lithotripsy in the late 1980s,[1] endoscopic laser lithotripsy of urinary calculi has been increasingly performed with thousands of procedures now done worldwide each day.[2]

Preparation of the laser fiber tip before initiating laser lithotripsy is current practice. This consists of stripping off the terminal portion of the polymer jacket (ie the usually blue plastic coating) and then cleaving

0022-5347/15/1933-1030/0
THE JOURNAL OF UROLOGY®

http://dx.doi.org/10.1016/j.juro.2014.07.110
Vol. 193, 1030-1035, March 2015
Printed in U.S.A.

several mm off the end of the glassy fiber components.[3] Specialized tools such as laser fiber strippers and ceramic scissors have been developed for that purpose and many experts in the field perform such laser fiber tip preparation.[3–5] However, in our daily practice we observed that not stripping the fiber tip did not noticeably impair lithotripsy performance. We now often use simple metal surgical scissors to only cleave the laser fiber tip.

In view of these divergent opinions we assessed whether stripping the laser fiber tip with a specialized laser fiber stripper or cleaving the tip with ceramic or metal scissors would influence lithotripsy performance.

MATERIALS AND METHODS

Automated Laser Fragmentation Testing System

To ensure precision the laser fragmentation experiments were performed using an automated testing system. The reproducibility and reliability of this system were reported previously.[6] The system consists of an automated experimentation support assembly constructed from Lego® Technic (fig. 1, *A*). This fires the immovable laser fiber for 30 seconds on the surface of an artificial stone that is moved along an axis at a constant velocity. Thus, the fiber engraves a fissure on the stone surface. The whole support assembly is immersed in a tank filled with 0.9% saline.

Preparation

Artificial stones. To assess the effect of laser fiber tip preparation on ablation efficiency 2 types of 30 × 20 × 10 mm artificial stones were generated (fig. 1, *B* and *C*). One type was made of plaster of Paris and the other type was made of BegoStone Plus using the appropriate powder-to-water ratios of 1.5:1 and 5:1 by weight, respectively.[7,8] The stones were left to dry for more than 96 hours at room temperature. Plaster is a good material for mimicking soft urinary calculus-like struvite[9] while BegoStone Plus simulates harder urinary stones such as calcium oxalate monohydrate.[10]

Before the experiment the artificial stones were submerged in 0.9% saline and soaked in a uniform manner. The experiment began when the stone holder was put into motion, laser emission was initiated and a fissure was carved in the stone.

Laser fiber tip. New 272 μm core laser fibers (No. MF272STs, Rocamed, Principality of Monaco) were used for all experiments, which were done in the operating room facilities at Hôpital Tenon, Paris, France. The plastic coating of the free extremity of the laser fiber (ie the laser fiber tip) was left untouched or 10 mm were stripped off with a specialized adjusted laser fiber stripper (FOC&T, Burghausen, Germany) (fig. 1, *D*). Subsequently 5 mm of the stripped or coated laser fiber tips were cleaved off by ordinary metal surgical scissors or specialized CS-124 ceramic scissors (Kyocera, Kyoto, Japan) (fig. 1, *E* and *F*). This procedure generated 4 laser fiber tip configurations, including 1) coated fiber cut with metal scissors, 2) stripped fiber cut with metal scissors, 3) coated fiber cut with ceramic scissors and 4) stripped fiber cut with ceramic scissors. Before and after each experiment photographs were obtained of the laser fiber tip using a Bresser® 5201000 microscope and analyzed. After each experimental run this fiber tip preparation procedure was applied again to ensure that fiber tip degradation would not bias the results.

Lithotripsy Settings

Two laser lithotripter settings were used, namely high and low frequency settings. HiFr-LoPE experiments were performed at 20 Hz and 0.5 J and LoFr-HiPE experiments were performed at 5 Hz and 2 J. Each setting used a total power level of 10 W. The 4 fiber tip configurations, the 2 stone types and the 2 laser lithotripter settings resulted in 16 experimental conditions (fig. 2). Each condition was repeated 8 times, resulting in 96 experiments. We used the MH 01-ROCA FTS 30 laser lithotripter (Rocamed).

Fissure Measurements

Fissure width, depth and volume were measured as previously described.[6] Fissure depth was measured using the

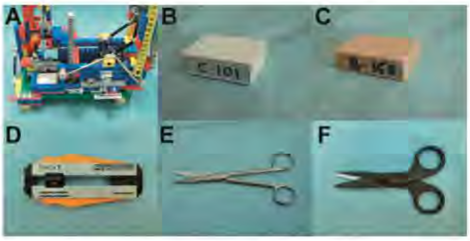


Figure 1. *A,* automated laser testing system with artificial stone inserted before immersion in saline filled tank and laser emission. *B,* plaster of Paris artificial stone. *C,* BegoStone Plus artificial stone. *D,* laser fiber stripper. *E,* metal surgical scissors. *F,* ceramic scissors.

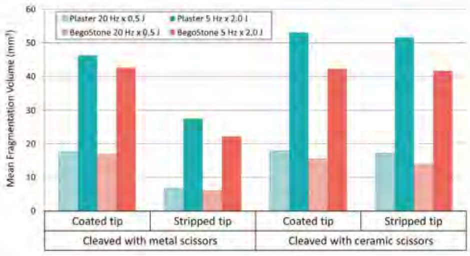


Figure 2. Mean fragmentation volume of 2 artificial stone types using 4 fiber tip preparations at HiFr-LoPE 20 Hz and 0.5 J settings, and LoFr-HiPE at 5 Hz and 2.0 J settings.

depth of focus of a calibrated Will-Wetzlar BX 300 optical microscope (Wilhelm Will, Wetzlar, Germany).[11] Fissure width was measured from high resolution photos using tangential lighting. After photographic calibration and image processing with ImageJ 1.48p (http://imagej.nih.gov/ij/index.html) we calculated fissure depth, width and volume. The volume measurement served as the primary measure of ablation efficiency. Fissure width and depth served as secondary measures.

Statistical Analysis

Statistical analysis was performed with StatEL 2.6 (AD Science, Paris, France). The Student t-test was used to compare stripped vs coated fibers, fibers cut with metal vs ceramic scissors, plaster of Paris vs BegoStone Plus and high vs low frequency settings. Statistical significance was considered at $p < 0.05$.

RESULTS

Figure 2 shows experimental data on the 4 laser fiber tip preparations. Regardless of scissor type, stone material or lithotripter settings coated laser fiber tips always achieved a higher ablation volume than stripped laser fiber tips ($p < 0.00001$). Compared to coated laser fiber tips the stripped fiber tips yielded an average 29.2% smaller ablation volume. When metal scissors were used to cleave stripped fibers, ablation volume decreased by 53.7% compared to when metal scissors were used to cleave coated fibers ($p < 0.00001$). In contrast, ceramic scissors decreased the ablation volume achieved by stripped fibers by an average of only 4.7% compared to when ceramic scissors were used to cleave coated fibers ($p = 0.1$).

Comparison of the effect of metal and ceramic scissors on coated fibers revealed that overall these scissors did not influence ablation volume ($p = 0.16$). Only in 1 condition (plaster of Paris and LoFr-HiPE settings) did metal scissors result in poorer performance than ceramic scissors with a 12.9% smaller ablation volume ($p < 0.05$). In all other conditions (the remaining 75% of experiments) metal scissors improved ablation volume by an average of 2.7% relative to ceramic scissors, although this difference did not attain statistical significance ($p = 0.56$). Comparison of the effect of metal and ceramic scissors on stripped fiber tips revealed that metal scissors reduced the ablation volume of the tips by an average of 52.8% regardless of stone material or lithotripter settings ($p < 0.00001$).

Plaster of Paris was always associated with a higher ablation volume than BegoStone Plus regardless of stripping, scissor type or lithotripter settings ($p < 0.00001$). Ablation volume increased an average of 20.7% and 14.7% for LoFr-HiPE and HiFr-LoPE settings, respectively, compared to those using BegoStone Plus.

At the same 10 W power level LoFr-HiPE lithotripsy achieved a higher fragmentation volume than HiFr-LoPE regardless of fiber stripping, scissor type or stone type with an average ablation volume that was threefold greater ($p < 0.00001$).

Analysis of fissure width and depth revealed that these variables showed relationships similar to those of mean fragmentation volume. Thus, coated fibers, plaster of Paris and LoFr-HiPE were always associated with significantly deeper fissures than stripped fibers, BegoStone Plus and HiFr-LoPE, respectively (each $p < 0.00001$). Coated fibers and LoFr-HiPE settings were similarly always associated with significantly wider fissures than stripped fibers and HiFr-LoPE, respectively (each $p < 0.00001$). Metal scissors with coated fibers outperformed most experimental combinations in terms of fissure width.

Photographic analysis of the fiber tips before and after lithotripsy generated several findings. 1) Coated fibers (fig. 3, *I*, *K*, *M* and *O*) showed less glassy fiber component degradation during LoFr-HiPE lithotripsy than stripped fibers (fig. 3, *J*, *L*, *N* and *P*, respectively). 2) Stripped fibers cut with metal scissors (fig. 3, *B*, *F*, *J* and *N*) showed more cladding damage than stripped fibers cut with ceramic scissors (fig. 3, *D*, *H*, *L* and P, respectively). 3) High pulse energy settings (fig. 3, *A* to *H*) induced more damage to the fiber tip (ie opacification and burn back of the fiber core) than low pulse energy settings (fig. 3, *I* to *P*, respectively) regardless of scissor type, stone type or coating presence. 4) Fiber tip degradation was more pronounced when BegoStone Plus was used (fig. 3, *A* to *D* and *I* to *L*) vs not used (fig. 3, *E* to *H* and *M* to *P*, respectively)

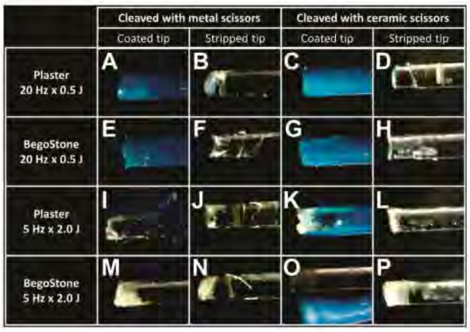


Figure 3. *A* to *P*, microscopic photographs show laser fiber tips after laser emission. Note tip degradation characteristics associated with different fiber tip preparation methods, lithotripter settings and stone materials.

regardless of scissor type, lithotripsy settings and coating presence.

DISCUSSION

There is a widespread belief that the tip of laser fibers should be stripped to achieve better lithotripsy performance. Indeed, new laser fibers come with the laser fiber tip already stripped of its plastic coating. This practice is described in specialty guidebooks[3] and is recommended by experts in the field.[4,12] As a result, major laser fiber manufacturers have purposely included a specialized laser fiber stripper in their sales catalogues.[13–17]

However, our study revealed that regardless of how the tip was cut, how hard the stone was and which power setting was used coated fibers always generated higher ablation volumes than stripped fibers (fig. 2). The performance of the stripped tips was particularly affected when the stripped fiber was cleaved with metal scissors. This sometimes reduced the mean ablation volume more than 60% compared to when coated tips were cut with metal scissors. Even ceramic scissors decreased stripped fiber performance up to 10% compared to coated fibers cut with ceramic scissors. In addition, photographic analysis revealed that after use coated fibers showed less degradation of the glassy fiber components (cladding plus core) than stripped fibers. This was particularly evident in tests performed with LoFr-HiPE since markedly more chipping of the cladding or opacification of the fiber tip was observed with stripped than with coated fibers. As expected, the increased ablation volume observed with coated fibers was also accompanied by increases in the secondary measurements of fissure width and fissure depth.

The laser fiber stripper may also damage the cladding of the laser fiber during the stripping process. The opening of the laser fiber stripper should exactly match the cladding diameter of the fiber. This is important, given the recent controversy regarding mislabeling of laser fiber diameters, which were in fact thicker than advertised.[18] Such mislabeling makes it more likely that stripping will damage the fiber. If the opening is too large, the stripper will not strip the fiber and if it is too narrow, the cladding may be damaged and poor lithotripsy performance may ensue. Figure 4, *A* shows an example of such damage.

Another argument favoring coated laser fibers is that they are easier to see than stripped fibers. The translucent components at the end of a stripped fiber are difficult to see during the operation and this problem is greatly exacerbated when the surrounding medium becomes clouded with debris or blood.[19] In contrast, coated fibers are much easier

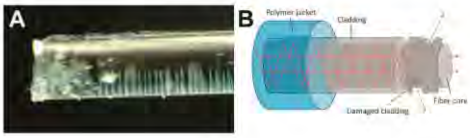


Figure 4. *A*, microscopic photograph shows fiber tip exemplifying cladding damage generated by poorly adjusted fiber stripper. Note extensive scratch marks. *B*, reflective behavior of laser rays in laser fiber. In contrast to straight laser rays (solid red lines), other laser rays (dashed red lines) depend on internal reflection at core-cladding interface to reach fiber tip. If cladding is damaged, laser ray reflection at these locations is compromised. This could result in laser ray leakage that could reduce ablation performance or cause unintentional laser damage, eg to patient tissue or surgical instruments.

to distinguish from the surrounding medium, enabling their position in relation to the target to be determined more swiftly and precisely. This in turn helps prevent any accidental tissue or even scope damage. Therefore, such visibility issues of stripped fibers could potentially be associated with longer operative time and a higher risk of operative damage.

During laser lithotripsy the fiber tip is damaged, for example burn back effects can lead to tip damage.[4,20,21] Such damage can impair fiber efficiency. This is particularly true for reusable laser fibers, which must be reprocessed to restore their performance.[12,22] Regardless of whether a fiber is single use or reusable, fiber tip repair is simply achieved by cleaving off the damaged portion. Like stripping, this practice was also advocated by many specialists.[4,23] Moreover, specialized tools such as ceramic scissors are recommended and also provided by most laser fiber manufacturers.[3,13–15,17] Indeed, only 1 manufacturer has advised against using ceramic scissors.[16]

Analysis of the effect of using metal or ceramic scissors to cleave coated fibers, which our results showed are surgically more convenient and more ablative than stripped fibers, revealed that metal scissors were generally as good as ceramic scissors regardless of stone material or lithotripter settings. In only 1 condition with coated fibers were ceramic scissors superior to metal scissors, namely when the stone material was soft and LoFR-HiPE settings were used. In contrast, when metal scissors were used to cleave stripped fibers, ablation volume was significantly reduced compared to using ceramic scissors.

Photographic analysis showed that these stripped fibers cut by metal scissors also had the most severe cladding damage, suggesting that metal scissors further weaken the cladding in stripped fibers and promote its deterioration. Since the cladding-core interface acts as a reflector that helps keep laser rays in the fiber core,[22] any damage to the cladding can jeopardize this reflective function and result in leakage of laser energy before the laser rays reach the fiber tip (fig. 4, *B*). This may explain why stripped fibers cut with metal scissors performed so weakly. Moreover, the release of laser energy from any location other than the distal end of the fiber core can at least theoretically cause unintentional damage to the surrounding tissues and instruments.

Thus, we believe that retaining the plastic coating that envelops the cladding will 1) eliminate possible initial cladding damage caused by stripping, 2) prevent damage caused by tip cleavage and 3) avoid or at least delay the cladding from breaking off during lithotripsy.

It was previously reported that softer stone material is easier to ablate than harder stone material at the same laser lithotripter settings.[10,24] The current study confirmed this association. Higher ablation rates were achieved when artificial stones were made of plaster of Paris than when they were made of BegoStone Plus. However, photographic analysis of the tips after use also showed that the harder stone material was associated with increased fiber tip deterioration, as indicated by more extensive opacification of the fiber tip and/or flaking off of the cladding. A study using plaster of Paris artificial stones showed that at the same power levels LoFr-HiPE settings were much more efficient and ablated considerably more stone volume than HiFr-LoPE settings.[6] Our study supports these results. At the same power level LoFr-HiPE achieved significantly higher fragmentation volumes than HiFr-LoPE regardless of the cleavage method or whether stripping was performed. The current study further extended these observations by showing that LoFr-HiPE was also more efficient than HiFr-LoPE for harder stone material, as indicated by the BegoStone Plus experiments.

Notably another group reported that higher energy settings resulted in more intense laser fiber damage as well as decreased stone fragmentation efficiency.[25] We also found that LoFr-HiPE resulted in more fiber tip damage than HiFr-LoPE. However, decreased efficiency was not observed. In fact the fragmentation volume sometimes even quadrupled when LoFr-HiPE settings were used.

In view of these findings we believe that laser fiber tips should remain fully coated. This would guarantee the highest ablation volume, thereby saving operative time. It would also result in less fiber tip degradation and less clutter on the operating table. Finally, it would provide better visualization of the fiber tip during use, thus, avoiding unintended tissue or instrument damage.

The method by which the fiber tip is cleaved, whether with simple metal scissors or costly ceramic scissors, is of no importance as long the fiber remains coated. However, should anyone continue to strip the laser fiber, we recommend cleaving the fiber with ceramic scissors because this was associated with a smaller reduction in ablation volume. Following these guidelines would ensure the best laser fiber tip performance and more efficient lithotripsy regardless of stone material or laser lithotripter settings.

Limitations of the current study include the short lithotripsy time (30 seconds), the artificial stone material and the fiber tip preparation tools. Lengthier experiments with a similar reliable automated testing system that ensures reproducibility are needed to assess whether the observed ablation-volume relationships persist when longer periods are used, or whether fiber tip performance degrades after a certain time. Knowing and identifying such intervals would prevent urologists from wasting time with a less efficient fiber and ensure that they re-prepare the laser fiber tip during the procedure.

While the artificial stones used in this study mimicked several features of actual stone material, other investigations using human stones with their particular shapes, textures and physical properties are needed to confirm our results. Moreover, although for the sake of reproducibility we did not assess using a scalpel to strip and/or cleave the laser fiber tip (a method used by some colleagues), future studies are warranted of the effect on ablation volume of other cleaving tools and methods, such as diamond scorers.

CONCLUSIONS

The current study demonstrates that coated laser fibers yielded better lithotripsy performance than laser fibers stripped by current methods as shown by higher ablation volume and less fiber tip degradation. Using metal scissors to cleave coated laser fibers did not significantly influence fiber performance compared to ceramic scissors. This new knowledge may improve and simplify the way that laser lithotripsy procedures are done worldwide.

ACKNOWLEDGMENTS

Jérémie Berg, Hôpital Tenon, Paris, France, assisted with the experiments. Rocamed provided the lithotripter and laser fibers.

REFERENCES

1. Gross AJ and Herrmann TRW: History of lasers. World J Urol 2007; **25:** 217.
2. Turney BW, Reynard JM, Noble JG et al: Trends in urological stone disease. BJU Int 2012; **109:** 1082.
3. Bagley DH and Das A: Endourologic Use of the Holmium Laser. Jackson, Wyoming: Teton NewMedia 2001.
4. Mues AC, Teichman JMH and Knudsen BE: Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol 2009; **23:** 1425.
5. Sung C, Singh H, Schwartz M et al: Evaluation of efficacy of novel optically activated digital endoscope protection system against laser energy damage. Urology 2008; **72:** 57.
6. Kronenberg P and Traxer O: In vitro fragmentation efficiency of holmium:YAG laser lithotripsy—a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 2013; **114:** 261.
7. Auge BK, Sekula JJ, Springhart WP et al: In vitro comparison of fragmentation efficiency of flexible pneumatic lithotripsy using 2 flexible ureteroscopes. J Urol 2004; **172:** 967.
8. Esch E, Simmons W, Sankin G et al: A simple method for fabricating artificial kidney stones of different physical properties. Urol Res 2010; **38:** 315.
9. Marguet CG, Sung JC, Springhart WP et al: In vitro comparison of stone retropulsion and fragmentation of the frequency doubled, double pulse Nd:YAG laser and the holmium:YAG laser. J Urol 2005; **173:** 1797.
10. Liu Y and Zhong P: BegoStone—a new stone phantom for shock wave lithotripsy research. J Acoust Soc Am 2002; **112:** 1265.
11. Liu J. Measurement of channel depth by using a general microscope based on depth of focus. EJAC 2007; **1:** 12.
12. Knudsen BE, Pedro R, Hinck B et al: Durability of reusable holmium:YAG laser fibers: a multicenter study. J Urol 2011; **185:** 160.
13. Quanta System: Diode Laser Series: High Power Diode Lasers. Available at http://www.quantasystem.com/root/brochure/QUANTADIODELASER-rev003-ROTW-LD.pdf. Accessed April 11, 2014.
14. Lumenis: VersaPulse® PowerSuite™ Accessories. Available at http://www.surgical.lumenis.com/VersaPulsePowerSuite%20accessories%20PBS000012%20Rev%20D.pdf. Accessed April 11, 2014.
15. Boston Scientific: Holmium Laser Accessories. Available at http://www.bostonscientific.com/urology-resources/products/holmium-laser-accessories.html. Accessed April 11, 2014.
16. American Medical Systems: SureFlex™ Laser Fiber: Reusable—Instructions for Use. Available at http://www.amselabeling.com/assets/files/0138-0410-C_ReusableSureFlexIFU_1110.pdf. Accessed April 11, 2014.
17. Richard Wolf: Mega Pulse. Available at http://www.richard-wolf.com/broschueren/Urology/D_690_MegaPulse30plus_IV12_GB.pdf. Accessed April 11, 2014.
18. Kronenberg P and Traxer O: E60 The truth about laser fiber diameters. Eur Urol, suppl., 2013; **12:** 50.
19. Geavlete P, Seyed Aghamiri SA and Multescu R: Retrograde flexible ureteroscopic approach for pyelocaliceal calculi. Urol J 2006; **3:** 15.
20. Khemees TA, Shore DM, Antiporda M et al: Evaluation of a new 240-μm single-use holmium:YAG optical fiber for flexible ureteroscopy. J Endourol 2013; **27:** 475.
21. Blackmon RL, Irby PB and Fried NM: Thulium fiber laser lithotripsy using tapered fibers. Lasers Surg Med 2010; **42:** 45.
22. Nazif OA, Teichman JMH, Glickman RD et al: Review of laser fibers: a practical guide for urologists. J Endourol 2004; **18:** 818.
23. Vassar GJ, Teichman JMH and Glickman RD: Holmium: YAG lithotripsy efficiency varies with energy density. J Urol 1998; **160:** 471.
24. Wezel F, Häcker A, Gross AJ et al: Effect of pulse energy, frequency and length on holmium:yttrium-aluminum-garnet laser fragmentation efficiency in non-floating artificial urinary calculi. J Endourol 2010; **24:** 1135.
25. Delvecchio FC, Auge BK, Brizuela RM et al: In vitro analysis of stone fragmentation ability of the FREDDY laser. J Endourol 2003; **17:** 177.

Article 4: Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers

World J Urol
DOI 10.1007/s00345-014-1395-1

TOPIC PAPER

Update on lasers in urology 2014: current assessment on holmium:yttrium–aluminum–garnet (Ho:YAG) laser lithotripter settings and laser fibers

Peter Kronenberg · Olivier Traxer

Received: 7 August 2014 / Accepted: 26 August 2014

Abstract

Purpose The purpose of the study was to review the existing literature on holmium:yttrium–aluminum–garnet laser lithotripsy regarding lithotripter settings and laser fibers.

Methods An online search of current and past peer-reviewed literature on holmium laser lithotripsy was performed on several databases, including PubMed, SciElo, and Google Scholar. Relevant studies and original articles about lithotripter settings and laser fibers were examined, and the most important information is summarized and presented here.

Results We examine how the choice of lithotripter settings and laser fibers influences the performance of holmium laser lithotripsy. Traditional laser lithotripter settings are analyzed, including pulse energy, pulse frequency, and power levels, as well as newly developed long-pulse modes. The impact of these settings on ablation volume, fragment size, and retropulsion is also examined. Advantages of small- and large-diameter laser fibers are discussed, and controversies are highlighted. Additionally, the influence of the laser fiber is examined, specifically the fiber tip preparation and the lithotripter settings' influence on tip degradation.

Conclusions Many technical factors influence the performance of holmium laser lithotripsy. Knowing and understanding these controllable parameters allows the urologist to perform a laser lithotripsy procedure safely, efficiently, and with few complications.

P. Kronenberg (✉)
Hospital Professor Doutor Fernando Fonseca, Amadora, Portugal
e-mail: peterkronenberg@gmail.com

O. Traxer
Hôpital Tenon, Université Pierre et Marie Curie – Paris VI, Paris, France

Keywords Laser lithotripsy · Holmium laser · Lithotripter settings · Laser fibers · Laser fiber preparation · Fragmentation efficiency

Review

More than half a century has passed since the construction of the first working laser emitter [1], then the world's first urological laser procedure [2], and the introduction of the first commercial laser lithotripter in the 1980s [3].

The current and widespread use of holmium laser lithotripsy of urinary stones has produced many debates [4, 5]. The best laser lithotripter settings and the most appropriate laser fibers to achieve the best lithotripsy performance are still being refined [6, 7]; hence, a review of the existing literature on lithotripter settings and laser fibers for holmium laser lithotripsy is in order.

To have a better idea of the wide-ranging field of holmium laser lithotripsy and the role of urologists in it, we performed a search on Medline (on July 14, 2014) for the expression "laser lithotripsy" with or without urology-related terms, starting from the first articles published in 1985 until 2013. A total of 1,037 articles were found on laser lithotripsy, and 768 (74.1 %) of the articles had a urological background.

Figure 1 shows the evolution of laser lithotripsy articles that were related to urology and other specialty fields. During the period examined, urology has always been at the center of laser lithotripsy development: since the first medical laser lithotripsy papers appeared in 1985, urology-related applications have accounted for at least half of the articles published on lithotripsy [8–11]. The first urological reports and clinical series on laser lithotripsy appeared almost simultaneously with the launch of the first

Published online: 04 September 2014

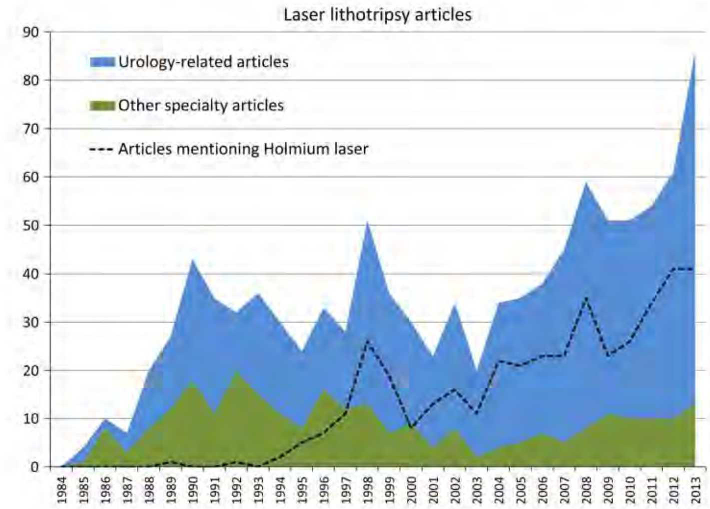


Fig. 1 Number of articles indexed in PubMed relating to laser lithotripsy in urology and other medical fields. The *dashed line* represents those articles pertaining to the holmium laser, a technology developed several years after the first mention of laser lithotripsy

commercial laser lithotripter in 1988, and with the increase in urological laser lithotripsy in the mid-1990s, urological applications in the literature quickly overshadowed the use of laser lithotripsy in all other medical fields, such as gastroenterology, general surgery, or ENT, to treat, for example, biliary, pancreatic, or salivary stones [3, 12–14]. Currently, laser lithotripsy is established primarily as a urological specialty, with 85–90 % of the articles published in the last 10 years authored by urology-affiliated investigators (Fig. 1). Holmium laser lithotripters were developed several years after the first references to laser lithotripsy. The presence of holmium lasers increased gradually at the turn of the century, and these lasers became highly associated with lithotripsy [15–18]. In contrast to other lasers, holmium laser lithotripters can efficiently fragment any type of urinary stone, and their wavelength of 2,100 nm is almost completely absorbed by water within 0.4 mm of the laser fiber tip, making the Ho:YAG one of the safest lasers to use in an endourological setting [19–21]. The efficacy and safety of the Ho:YAG laser led it to be one of the urologists' most popular tools for lithotripsy and other urological applications [22].

Laser lithotripter settings

Existing holmium laser lithotripters allow the urologist to control the main parameters, i.e., pulse energy and pulse frequency, and consequently control the total power output, which results from the product of these two parameters: Total Power (W) = Pulse energy (J) × Pulse frequency (Hz). By adjusting these parameters, the urologist decides the energy intensity that is delivered at the tip of the laser fiber to ablate the stone.

Studies have shown that increased pulse energy increased the ablation volume of stones tested in elementary experiments [23–25] and in more elaborate, automated studies [26]. Using different experimental approaches, whether increasing total power [6] or keeping the same total power [26, 27], when the pulse energy rose so did the ablation volume of these stones.

Increased pulse frequency and, consequently, increased total power are expected to increase ablation volume. Some laser lithotripter manufacturers claim that high-frequency settings and high-frequency lithotripters are more ablative [28]; however, experimental results have not verified these claims. Several studies did not measure any significant increase in ablation volume with an increase in pulse frequency [6, 29]. In a more recent study where total power was kept constant, low frequency using high-pulse energy (LoFr–HiPE) settings showed a statistically significant favorable difference over high frequency using low-pulse energy (HiFr–LoPE) settings. Besides showing a directly proportional increase in ablation volume as pulse energy rises, that study also showed how at the same power levels, LoFr–HiPE settings were up to six times more ablative than HiFr–LoPE settings (Fig. 2). In fact, comparison of LoFr–HiPE settings with others using high frequency with significantly higher total power levels showed that even at very high-power settings, these were surpassed by LoFr–HiPE using lower total power settings [26]. Hence, pulse

Fig. 2 Comparison of the results of different lithotripter settings using the same total power level (6 W) and the same laser fiber (200 µm fiber core). **a** Uses a high-frequency and low-pulse energy (HiFr–LoPE) at 30 Hz × 0.2 J, while **b** employs a low frequency using high-pulse energy (LoFr–HiPE) at 5 Hz × 1.2 J

energy was the most important factor that determined ablation volume, with pulse frequency and total power playing a less important role.

More recently, long-pulse lithotripsy has become available. In newer lithotripter models, the urologist can choose different pulse durations, i.e., the traditional short-pulse mode and the new long-pulse mode [30, 31]. Other laser lithotripter settings remain the same, with the same pulse frequency, the same pulse energy, the same power level, and therefore, the same amount of energy delivered per unit of time. In the short-pulse mode, the energy delivered by a single laser pulse occurs during a certain period of time, while in long-pulse mode, that same amount of energy is distributed over a longer period of time. We have compared short-pulse mode with long-pulse mode (180–330 vs. 650–1,215 µs) at different pulse frequencies and pulse energies (HiFr–LoPE at 20 Hz × 0.5 J vs. LoFr–HiPE at 5 Hz × 2.0 J) and using different stone materials (artificial stones made of plaster of Paris vs. BegoStone). Figure 3 shows that the short-pulse mode was significantly more ablative than the long-pulse mode ($p < 0.0001$): short-pulse mode ablated 25.0 and 9.9 % more on average than long-pulse mode at LoFr–HiPE and HiFr–LoPE settings, respectively. Additionally, in long-pulse mode, LoFr–HiPE settings ablated significantly more than HiFr–LoPE settings. In that same study, we found harder stone material to be more difficult to ablate than softer stone material no matter what the pulse duration was, corroborating our previous studies [26, 32, 33]. Some of these relationships have also been verified by other authors such as Wezel et al. [27].

Debate continues about the fragment size resulting from one laser lithotripter setting or another. Some argue that low-pulse energy, like HiFr–LoPE settings, produces smaller stone fragments (the so-called "dusting effect") than high-pulse energy, such as LoFr–HiPE settings [5, 6, 34]; however, most of these studies used irregular or hand-held approaches. By contrast, automated and reproducible testing systems, similar to the one we use, failed to retrieve any measurable fragments in any of the studies to date. Fragment size may be less related to laser lithotripter settings and more dependent on the surgical technique employed, i.e., how the surgeon approaches the stone with the laser, and whether the stone is repeatedly perforated, chipped, or fragmented, in comparison with worked on at the surface, by "dancing" or "painting" it with the laser [35, 36]. This remains to be investigated. Nevertheless, whichever laser lithotripter setting or ablation technique is used, surgeons must pay attention to the resulting stone fragment size. Numerous large fragments may significantly increase the operating time, require the use of an expensive stone-removal device or of a specific laser lithotripsy technique, such as the "popcorn effect," to reduce the stone burden [26, 29].

Fig. 3 Comparison of the traditional short-pulse mode with the recently developed long-pulse mode of new laser lithotripters (in this case of a Rocamed™-MH 01-ROCA FTS 30 laser lithotripter). Regardless of laser settings or stone material, the traditional short-pulse mode is significantly more ablative than the long-pulse mode

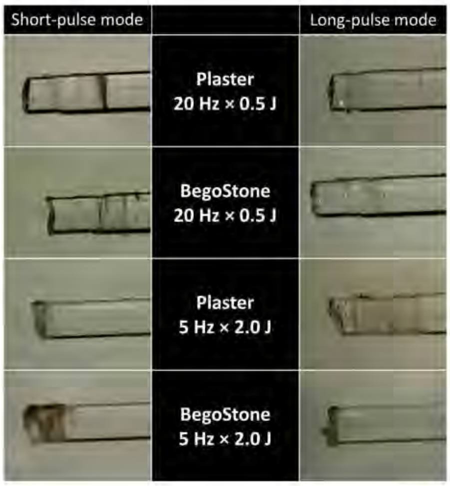


Fig. 4 Fiber tip degradation using short-pulse or long-pulse mode. Both modes show more tip degradation with higher pulse energy settings, and with harder stone material, regardless of lithotripter settings [33]. The long-pulse mode seems to spare the cladding and the fiber tip, showing less cladding degradation as well as less fiber tip opacification

Laser lithotripter settings also affect retropulsion. Retropulsion is known to reduce lithotripsy efficacy, increase operating time and, sometimes, making ureteral calculi inaccessible by pushing them into the renal pelvis [37]. Higher pulse energy levels, as well as the traditional short-pulse mode, increase retropulsion [37–40]. In situations where retropulsion needs to be minimized, lowering the pulse energy or changing to long-pulse mode would decrease the retropulsion effect but would also affect ablation efficiency negatively. When calculi are only slightly influenced or completely unaffected by retropulsion, due to their size, location, being fixed or impacted, more efficient LoFr–HiPE settings can be safely used to accelerate the procedure [26].

Laser fibers

The laser fiber also plays a fundamental role in the lithotripsy procedure. Several components and properties of the laser fiber, such as its diameter, the preparation or shape of its tip, or even its degradation, affect the direct ablation of the calculi and the intervening instruments, e.g., the ureterorenoscopes.

Contradictory reports have emerged concerning fiber diameter and lithotripsy performance, where some authors claim that larger-diameter fibers ablate more than smaller-diameter fibers [38], while others claim that larger fibers ablate less than smaller fibers [24]. Some researchers found no relationship between fiber size and ablation volume [27, 40]. Our previous research showed that larger-diameter fibers do indeed create wider ablation fissures ($p < 0.00001$), while smaller-diameter fibers generate deeper ablation fissures ($p < 0.00001$), but neither surpassed the other in terms of ablation volume ($p = 0.81$) [26]. There is only one particular condition in which large fibers may be less ablative, that is, if very low-pulse energies are employed (e.g., 0.2 J), the energy density may be too low to exceed the ablation threshold. Therefore, a larger-diameter fiber with a larger fiber tip surface area may be significantly less ablative than a smaller-diameter fiber [26, 39]. In addition, larger fibers also increase the retropulsion effect when compared to smaller fibers [37].

Larger laser fibers have another limitation when considering the setting that they are most frequently used in, i.e., inserted inside the small working channels of ureterorenoscopes. Larger laser fibers affect the degree of scope deflection negatively and limit the range of a flexible scope and its ability to reach difficult intrarenal locations, like lower calices [4, 41]. Additionally, larger laser fibers inside narrow working channels influence irrigation rates negatively, which can impair the surgeons' visualization of structures and, therefore, influence operating time [41, 42].

A recent and awarded abstract presentation casted some serious doubt on the reliability of the laser fibers' advertised diameters [43–45]. Multiple laser fibers from different manufacturers were measured, and none of the tested fibers matched the advertised diameter. Some fibers were more than double as thick as advertised, and fibers from different manufacturers advertised with the same diameter were in fact significantly different. Ambiguous information has also arisen from industry representatives of the laser fibers that were evaluated; hence, the authors concluded that most information conveyed to urologists regarding laser fiber diameter may be incorrect [45]. Few authors noticed this fiber diameter discrepancy and even less foresaw its severe implications [46, 47]. Considering the previously described influence that laser fiber diameter exerts on the lithotripsy procedure, this misinformation about laser fiber diameter has a critical impact.

Similarly to other working tools and materials, laser fibers do also wear off. During laser emission, the laser fiber tip degrades because of the "burn-back effect" [46, 48, 49]. High-pulse energy and small-diameter laser fibers are also known to increase the burn-back of the fiber [48]. During our research, we confirmed that high-pulse energy settings are more deleterious to the fiber tip than low-pulse energy settings. Additionally, we found that harder stone material promotes more fiber tip degradation by opacification and

Table 1 This overview table shows how changes in one parameter (in red) affect other variables involved in the lithotripsy procedure

Changeable parameters						Parameter-dependable variables				
Defined by user					Defined by nature					
Lithotripter settings				Fiber diameter	Stone type	Effects on calculi		Effects on instruments		
Power (W)	Pulse energy (J)	Pulse frequency (Hz)	Pulse mode			Ablation volume	Retropulsion	Fiber tip degradation	Scope deflection	Irrigation
↑	↑	-	-	-	-	↑	↑	↑	n/a	n/a
↓	↓	-	-	-	-	↓	↓	↓	n/a	n/a
↑	-	↑	-	-	-	↑	=/↑	↑	n/a	n/a
↓	-	↓	-	-	-	↓	=/↑	↓	n/a	n/a
=†	↑	↓	-	-	-	↑	↑	↑	n/a	n/a
=†	↓	↑	-	-	-	↓	↓	↓	n/a	n/a
-	-	-	Short-pulse	-	-	↑	↑	↑	n/a	n/a
-	-	-	Long-pulse	-	-	↓	↓	↓	n/a	n/a
-	-	-	-	↑	-	=‡	↑	↓	↓	↓
-	-	-	-	↓	-	=	↓	↑	↑	↑
-	-	-	-	-	Hard stone	↓	N/K*	↑	n/a	n/a
-	-	-	-	-	Soft stone	↑	N/K*	↓	n/a	n/a

Fragment size was not included since to date, no relevant reproducible and continuous lithotripsy studies have been performed that demonstrated advantages of using one or another specific parameter in order to obtain smaller stone fragments

n/a not affected, *N/K* not known, ↑ Increase, ↓Decrease, = comparably the same

* Although increasing stone mass is known to reduce retropulsion [53], to our knowledge, no study has so far evaluated the influence of stone composition on retropulsion

† For comparison purposes, total power was kept constant

‡ At very low-pulse energies, ablation volume might decrease with larger fibers

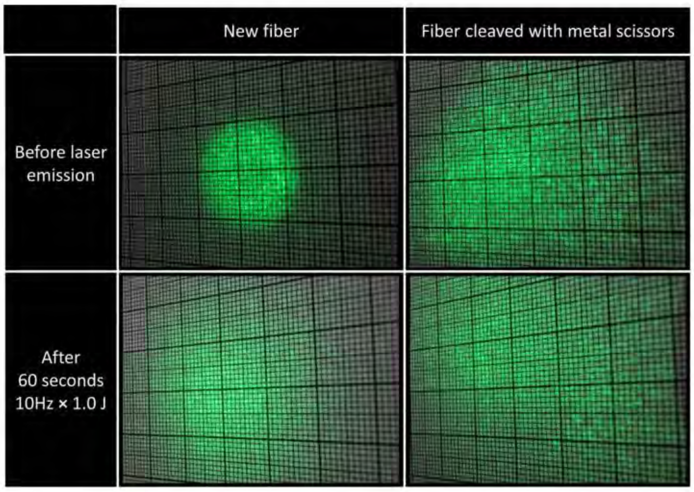


Fig. 5 Laser light scattering patterns comparing a newly, untouched fiber with a fiber cleaved with metal scissors. After a short time of laser emission, both fibers scatter the laser light and are almost undistinguishable from one another

burn-back of the fiber tip [33]. When comparing the effect of pulse length on the fiber, damage to the laser fiber tip is considerably less evident if long-pulse mode is used instead of short-pulse mode (Fig. 4) [32].

An overview of the previous laser lithotripter settings and laser fiber-related evidence is presented and summarized in Table 1.

Another important issue regarding the laser fiber tip concerns its preparation before use. Current practice is to cleave the laser fiber tip with specialized tools and strip several millimeters from the terminal portion of the polymer coating. This preparation ensures the reusability of the laser fiber and prevents any possible performance degradation from previous laser emission, which urologists believe results in better lithotripsy performance [48, 50, 51]. We recently performed a study analyzing the benefits of stripping the laser fiber or leaving the laser fiber-coated, and compared the difference between cleaving the laser fiber with specialized ceramic scissors and using simple metal scissors. Results were recently presented [32] and published [33], and showed that stripping the laser fiber reduces ablation efficiency significantly ($p < 0.00001$), and no differences were found between metal and specialized ceramic scissors, as long as the fiber tip remained coated. These startling results raise many doubts about the current and widespread practice of laser fiber tip preparation.

One abstract presentation at the 2014 meeting of the American Urological Association by Vassantachart et al. [52] examined the energy output at the tip of laser fibers that were prepared with different cleaving techniques. The authors showed that energy transmission at the fiber tip was best when the fiber tip was new or when special cleaving tools were used. The lowest energy transmission occurred when suture scissors were used to cleave the laser fiber. Unfortunately, this study did not validate the findings of lithotripsy studies using real stones. We performed a similar study analyzing laser light dispersion patterns of new fibers and fibers prepared with metal (suture) scissors, and examined these patterns before and after lithotripsy. As expected, and in accordance with our previous experiments, the light dispersion patterns of different fibers after lithotripsy were almost undistinguishable from one another (Fig. 5), further putting into question the importance of specialized and time-consuming fiber tip preparation.

In summary, there are many controllable factors influencing the outcome of laser lithotripsy procedures, but some are more relevant than others. Pulse energy is one of the key elements that affect ablation and procedure speed, especially if the total power remains at the same level. On the contrary, higher power levels and high frequency lithotripsy are not necessarily associated with a better ablation performance. Recently developed long-pulse settings are significantly less ablative than traditional short-pulse lithotripter settings, but also cause less fiber tip degradation. So far, no reliable study has proven that any particular lithotripter setting is better than another with respect to the avoidance of large stone fragment generation. Concerning laser fibers, most of the information regarding their advertised diameter seems to be incorrect. Although small-diameter fibers ablate as much as their large-diameter counterparts, they are more prone to fiber tip degradation. However, this disadvantage is largely compensated for by better irrigation, better scope deflection, and less retropulsion, which lead to less bothersome procedures with fewer complications. Current fiber tip preparation methods, including stripping and cleaving with specialized tools, are redundant and sometimes counterproductive, and reduce ablation efficacy. Further research using reproducible testing methods is needed to increase our understanding of laser lithotripsy.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard The manuscript does not contain clinical studies or patient data.

References

1. Maiman TH (1960) Stimulated optical radiation in ruby. Nature 187(4736):493–494
2. Parsons RL, Campbell JL, Thomley MW (1968) Carcinoma of the penis treated by the ruby laser. J Urol 100(1):38–39
3. U.S. Corporate news: news from candela corporation. laser medicine and surgery news and advances (1988) 6(5):24–5
4. Kuo RL, Aslan P, Zhong P et al (1998) Impact of holmium laser settings and fiber diameter on stone fragmentation and endoscope deflection. J Endourol 12(6):523–527
5. Spore SS, Teichman JM, Corbin NS et al (1999) Holmium: YAG lithotripsy: optimal power settings. J Endourol 13(8):559–566
6. Sea J, Jonat LM, Chew BH et al (2012) Optimal power settings for holmium:YAG lithotripsy. J Urol 187(3):914–919
7. Patel AP, Knudsen BE (2014) Optimizing use of the holmium:YAG laser for surgical management of urinary lithiasis. Curr Urol Rep 15(4):397
8. Hofstetter A (1985) Laser–science fiction or a new dimension in medicine? Urologe A 24(6):310–312
9. Li AA (1985) Physical methods in the treatment of patients with kidney and ureteral calculi. Vopr Kurortol Fizioter Lech Fiz Kult 4:65–68
10. Schmidt-Kloiber H, Reichel E, Schoffmann H (1985) Laser-induced shock-wave lithotripsy (LISL). Biomed Tech (Berl) 30(7–8):173–181
11. Zhang QL, Fujita R, Satake Y (1985) Laser-beam lithotripsy for bile duct stone via percutaneous-transhepatic cholangioscopy. Chin Med J (Engl) 98(9):638–642
12. Coptcoat MJ, Ison KT, Watson G et al (1988) Lasertripsy for ureteric stones in 120 cases: lessons learned. Br J Urol 61(6):487–489
13. Hofmann R, Hartung R (1988) Use of pulsed Nd:YAG laser in the ureter. Urol Clin N Am 15(3):369–375
14. Ritchey M, Patterson DE, Kelalis PP et al (1988) A case of pediatric ureteroscopic lasertripsy. J Urol 139(6):1272–1274

15. Adkins WC, Dulabon DA, Chorazy ZJ et al (1994) Consider Ho:YAG for low-cost, effective laser lithotripsy. Clin Laser Mon 12(9):139–141
16. Denstedt JD, Razvi HA, Sales JL et al (1995) Preliminary experience with holmium: YAG laser lithotripsy. J Endourol 9(3):255–258
17. Matsuoka K, Iida S, Nakanami M et al (1995) Holmium: yttrium–aluminum–garnet laser for endoscopic lithotripsy. Urology 45(6):947–952
18. Erhard MJ, Bagley DH (1995) Urologic applications of the holmium laser: preliminary experience. J Endourol 9(5):383–386
19. Leveillee RJ, Lobik L (2003) Intracorporeal lithotripsy: which modality is best? Curr Opin Urol 13(3):249–253
20. Bader MJ, Gratzke C, Hecht V et al (2011) Impact of collateral damage to endourologic tools during laser lithotripsy—in vitro comparison of three different clinical laser systems. J Endourol 25(4):667–672
21. Floratos DL, La de Rosette JJ (1999) Lasers in urology. BJU Int 84(2):204–211
22. Vicente Rodríguez JJ, Fernández González I, Hernández Fernández C et al (2006) Láser en urología. Actas Urológicas Españolas 30:879–895
23. Teichman JM, Vassar GJ, Glickman RD (1998) Holmium:yttrium–aluminum–garnet lithotripsy efficiency varies with stone composition. Urology 52(3):392–397
24. Vassar GJ, Teichman JM, Glickman RD (1998) Holmium:YAG lithotripsy efficiency varies with energy density. J Urol 160(2):471–476
25. Jelinkova H, Köhler O, Miyagi M et al (2009) Comparison of Ho:YAG and Er:YAG lasers for lithotripsy. Photon Ther Diagn V 7161(1):71611H
26. Kronenberg P, Traxer O (2014) In vitro fragmentation efficiency of holmium: yttrium–aluminum–garnet (YAG) laser lithotripsy: a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 114(2):261–267
27. Wezel F, Häcker A, Gross AJ et al (2010) Effect of pulse energy, frequency and length on holmium:yttrium–aluminum–garnet laser fragmentation efficiency in non-floating artificial urinary calculi. J Endourol 24(7):1135–1140
28. Lumenis (2013) VersaPulse PowerSuite Brochure; PB-1106750 Rev B 2013 [cited 2014 Jun 19]. http://www.surgical.lumenis.com/pdf/PB-1106750_rB_VPPS_P20v_br_LowRes%20(1).pdf
29. Chawla SN, Chang MF, Chang A et al (2008) Effectiveness of high-frequency holmium:YAG laser stone fragmentation: the "popcorn effect". J Endourol 22(4):645–650
30. Electro Medical Systems (2012) Swiss Laserclast Brochure; FA-398 [cited 2014 Jun 19]. http://www.ems-company.com/media/PDF%20NEW/FA-398_EN_Ed_08-2012_LaserClast%20Brochure_single.pdf
31. Rocamed (2013) MH01 Laser Lithotripter Brochure; V.Uk.2 [cited 2014 Jun 19]. http://www.rocamed-urology.com/images/stories/doc/br.uk.v2.laser.pdf
32. Kronenberg P, Traxer O (2014) V-10 Strippers, scissors and laser fiber tips. Video presentation at the 4th international meeting challenges in endourology, Paris [cited 2014 Jun 19]
33. Kronenberg P, Traxer O (2014) Are we all doing it wrong?—Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol in press; accepted 2014 Jul 28; published online 2014 Aug 04. doi:10.1016/j.juro.2014.07.110
34. Corbin NS, Teichman JM, Nguyen T et al (2000) Laser lithotripsy and cyanide. J Endourol 14(2):169–173
35. Al-Kandari AM, Desai M, Shokeir AA et al (2013) Difficult cases in endourology. Springer, London
36. Hecht SL, Wolf JS (2013) JR. techniques for holmium laser lithotripsy of intrarenal calculi. Urology 81(2):442–445
37. Kronenberg P, Traxer O (2013) V1718 laser fibers, pulse energy and retropulsion-what we can see and what we can't. J Urol 189(4):e707
38. Kang HW, Lee H, Teichman JMH et al (2006) Dependence of calculus retropulsion on pulse duration during Ho: YAG laser lithotripsy. Lasers Surg Med 38(8):762–772
39. Blackmon RL, Irby PB, Fried NM (2011) Comparison of holmium:YAG and thulium fiber laser lithotripsy: ablation thresholds, ablation rates, and retropulsion effects. J Biomed Opt 16(7):71403
40. Lee H, Ryan RT, Kim J et al (2004) Dependence of calculus retropulsion dynamics on fiber size and radiant exposure during Ho:YAG lithotripsy. J Biomech Eng 126(4):506–515
41. Pasqui F, Dubosq F, Tchala K et al (2004) Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. Eur Urol 45(1):58–64
42. Bach T, Geavlete B, Herrmann TRW et al (2008) Working tools in flexible ureterorenoscopy–influence on flow and deflection: what does matter? J Endourol 22(8):1639–1643
43. Kronenberg P, Traxer O (2013) E60 the truth about laser fiber diameters. Eur Urol Suppl 12(3):50
44. European Association of Urology (2013) Information conveyed to urologists regarding laser fiber diameter is incorrect. ScienceDaily 2013 Sep 17 [cited 2014 Jul 17]. http://www.sciencedaily.com/releases/2013/09/130917124821.htm
45. Kronenberg P, Traxer O (2014) The truth about laser fiber diameters. Urology in press; accepted 2014 Aug 18
46. Khemees TA, Shore DM, Antiporda M et al (2013) Evaluation of a new 240-μm single-use holmium:YAG optical fiber for flexible ureteroscopy. J Endourol 27(4):475–479
47. Monga M (2013) Ureteroscopy: indications, instrumentation & technique. Totowa, NJ: Humana Press; 2013. (Curr Clin Urol)
48. Mues AC, Teichman JMH, Knudsen BE (2009) Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol 23(9):1425–1428
49. Blackmon RL, Irby PB, Fried NM (2010) Thulium fiber laser lithotripsy using tapered fibers. Lasers Surg Med 42(1):45–50
50. Bagley DH, Das A (2001) Endourologic use of the holmium laser. Teton NewMedia, Jackson
51. Knudsen BE, Pedro R, Hinck B et al (2011) Durability of reusable holmium:YAG laser fibers: a multicenter study. J Urol 185(1):160–163
52. Vassantachart J, Lightfoot M, Maldonado J et al (2014) PD7-11 laser fiber cleaving techniques–the effect upon energy output and tip morphology. J Urol 191(4 Supplement):e187–e188
53. Robinson M, Teichman JMH (2013) 1063 laser lithotripsy retropulsion varies with stone mass. Eur Urol Suppl 12(1):e1063

Article 5: Lithotripsy Performance of Specially Designed Laser Fiber Tips

Lithotripsy Performance of Specially Designed Laser Fiber Tips

Peter Kronenberg* and Olivier Traxer

From the Hospital Professor Doutor Fernando Fonseca, Amadora, Portugal, and Université Paris 6 Pierre et Marie Curie-Hôpital Tenon (OT), Paris, France

Abbreviations and Acronyms

BT = ball-shaped tip

HiFr-LoPE = high frequency, low pulse energy

LoFr-HiPE = low frequency, high pulse energy

PT = polished tip

Accepted for publication October 25, 2015.

No direct or indirect commercial incentive associated with publishing this article.

The corresponding author certifies that, when applicable, a statement(s) has been included in the manuscript documenting institutional review board, ethics committee or ethical review board study approval; principles of Helsinki Declaration were followed in lieu of formal ethics committee approval; institutional animal care and use committee approval; all human subjects provided written informed consent with guarantees of confidentiality; IRB approved protocol number; animal approved project number.

* Correspondence: Hospital Professor Doutor Fernando Fonseca, Amadora, Lisbon, Portugal (e-mail: peterkronenberg@gmail.com).

Purpose: We evaluated and compared a standard laser lithotripsy fiber to laser fibers claimed to have lithotripsy performance enhancing features.

Materials and Methods: A special AccuMax™ 200 polished tip fiber and an AccuTrac™ ball-shaped tip fiber, each with an approximately 240 μm core, were compared to a standard 272 μm core fiber (Rocamed™). The polished and ball-shaped tip fibers were used and reused without preparation. The standard fiber was stripped and cleaved according to manufacturer instructions after each experiment. An automated laser fragmentation testing system was used to perform multiple 30-second laser lithotripsy experiments. To mimic most typical lithotripsy conditions soft and hard stone materials were used with high frequency, low pulse energy (20 Hz and 0.5 J) or with low frequency, high pulse energy (5 Hz and 2.0 J) lithotripter settings. Ablation volumes and laser fiber tip photographs before and after lithotripsy were compared.

Results: The standard and ball-shaped tip fibers did not differ in ablation volume ($p = 0.72$) but they ablated 174% and 188% more stone, respectively, than the polished tip fiber ($p < 0.0001$). The ball-shaped tip showed remarkable fiber tip degradation after short-term use at low frequency, high pulse energy settings. When high pulse energy settings were applied first even for short-term use, the ablation volume achieved by the polished and ball-shaped tip fibers at high frequency, low pulse energy settings decreased more than 20%.

Conclusions: The standard laser fiber was as good as and sometimes better than the specially designed fibers. Rapid degradation of the specially designed laser fiber tips strongly limits their general usefulness but ball-shaped tip fibers may be useful in specific situations.

Key Words: calculi; lithotripsy; lasers, solid-state; surgical instruments; equipment reuse

After the early pioneering efforts of urologists in particular, minimally invasive surgery is now being performed in most medical specialties.[1–3] The widespread success of endourological laser lithotripsy procedures has led to further research into and improvements of existing tools, including laser fibers.[4,5] Some laser fibers include novel features such as special connectors, coatings or fiber tip preparations (eg polished or ball-shaped fiber tips), which it is claimed boost ablation performance and/or facilitate passage of the laser fiber through the endoscope.[6–8]

To our knowledge studies comparing the ablation efficiency of these fibers to that of ordinary laser lithotripsy fibers have not yet been published. We performed the current study to compare the lithotripsy

0022-5347/16/1956-1606/0
THE JOURNAL OF UROLOGY®

http://dx.doi.org/10.1016/j.juro.2015.10.135
Vol. 195, 1606-1612, May 2016
Printed in U.S.A.

performance of 2 special fibers, including 1 with a special PT and 1 with a BT, to that of a standard laser lithotripsy fiber.

MATERIALS AND METHODS

Automated Laser Fragmentation Testing System

To guarantee the accuracy of our evaluations the experiments were performed using an automated testing system constructed of Lego® Technic (fig. 1, *D*). The reproducibility and reliability of this system have been proven and widely reported.[9–12] The system fires the immovable laser fiber for 30 seconds on the surface of an artificial stone, which moves along an axis at constant velocity. As a result the fiber engraves a fissure on the stone surface. Experiments were done at Hôpital Tenon, Paris, France.

Artificial Stones

To assess lithotripsy performance most real-life conditions that are encountered during this procedure were simulated using 2 types of 30 × 20 × 10 mm artificial stones. One type was made of plaster of Paris with a powder-to-water ratio of 1.5:1 by weight and the other was made of BegoStone plus (BEGO Bremer Goldschlägerei Wilh. Herbst, Bremen, Germany) with a powder-to-water ratio of 5:1 by weight. The stones were left to dry for at least 96 hours at room temperature before use.[13] These materials have physical properties similar to those of actual urinary stones. Plaster mimics soft urinary calculi (eg struvite stones)[14] while BegoStone plus simulates harder urinary stones (eg calcium oxalate monohydrate stones).[15]

Laser Fibers

Three universal single use laser fibers were tested, including 1) an approximately 240 μm core AccuMax 200 fiber with a special polished output tip,[8] designated the PT fiber, 2) an approximately 240 μm AccuTrac core fiber with a ball-shaped output tip,[7] designated the BT fiber, and 3) a standard 272 μm core fiber (No. MF272ST, Rocamed™) devoid of any special ablation enhancing features,[16] designated the standard fiber (fig. 1, *A* to *C*). All fibers were new before testing started.

The PT and BT fibers were used and reused without preparation. The standard fiber was stripped and cleaved before each experiment according to manufacturer instructions.[17] Before and after each experiment photographs were obtained of each laser fiber tip under a No. 5201000 microscope (Bresser, Rhede, Germany).

Lithotripter and Lithotripsy Settings

HiFr-LoPE and LoFr-HiPE lithotripter settings mimic the limits of most typical lithotripsy conditions.[9] HiFr-LoPE tests were performed at 20 Hz and 0.5 J, and LoFr-HiPE tests were performed at 5 Hz and 2.0 J. Each

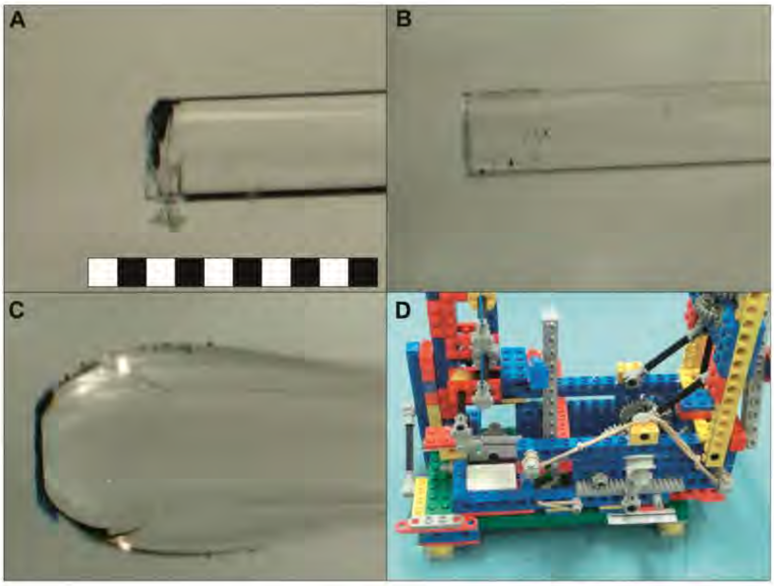


Figure 1. Tips of 3 laser fibers tested and automated testing system. *A*, standard MF272ST laser fiber after being stripped and cleaved according to manufacturer instructions. *B*, AccuMax 200 PT fiber. *C*, AccuTrac BT fiber. Scale bar indicates 10 × 100 μm (*A* to C). *D*, automated laser fragmentation testing system can be used for precise reproducible lithotripsy experiments. All experiments were performed in tank filled with 0.9% saline.

setting used short pulse lithotripsy with an average pulse duration of 180 and 330 µs, respectively. Thus the 3 fibers were tested with 2 stone types at 2 lithotripter settings, meaning that there were 12 experimental conditions (fig. 2). The lithotripter used was the MH01 ROCA FTS 30 (Rocamed).

Fissure Measurements

As previously described[9,11] the depth of focus of a calibrated Will BX300 optical microscope (Wilhelm Will, Wetzlar, Germany) was used to measure fissure depth. Fissure width was measured from high resolution photographs obtained under tangential lighting. After photographic calibration and application of ImageJ, version 1.48p image processing software (http://imagej.nih.gov/ij/) the fissure depth, width and volume were calculated. Ablation volume was the primary measure of lithotripsy performance. Fissure width and depth served as secondary measures.

Statistical Analysis

Statistical analysis was performed with StatEL, version 2.6 (AD Science, Paris, France). The fibers, 2 stone materials and 2 lithotripter settings were compared in terms of lithotripsy performance values by the Friedman test, the Student t-test and the Wilcoxon test with $p < 0.05$ considered statistically significant.

RESULTS

The standard and BT fibers did not differ significantly from each other ($p = 0.72$), although the standard fiber ablated an average of 4.8% less volume (range 0.4% to 8.5%) than the BT fiber (fig. 2). Regardless of stone material or lithotripter settings the standard and BT fibers ablated much higher volumes than the PT fiber (174% and 188% more, respectively, each $p < 0.0001$). Similarly compared to the PT fiber the standard and BT fibers produced 49.6% and 54.7% wider fissures, and 72.5% and 76.6% deeper fissures, respectively (each $p < 0.0001$). Although the standard fiber made −3.3% narrower and −1.9% shallower fissures than the BT fiber, these differences did not achieve statistical significance.

The softer stone material was always easier to ablate than the harder stone material regardless of fiber type or lithotripter setting. The average ablation volume with soft stone was 25.7% higher than that with hard stone ($p < 0.0001$). LoFr-HiPE settings were also up to threefold more ablative than HiFr-LoPE settings regardless of fiber type or stone material. Average ablation volume was 218% higher using LoFr-HiPE settings ($p < 0.00001$).

Photograph analysis revealed that the initial HiFr-LoPE settings were associated with minor tip changes in all fibers (fig. 3). After an additional 60 seconds of LoFr-HiPE laser emission the BT fiber showed intense fiber tip degradation. The PT fiber showed some cladding degradation and fiber tip opacification after 60 seconds of high pulse energy.

When high pulse energy settings had been used previously even in the short term, the PT and BT

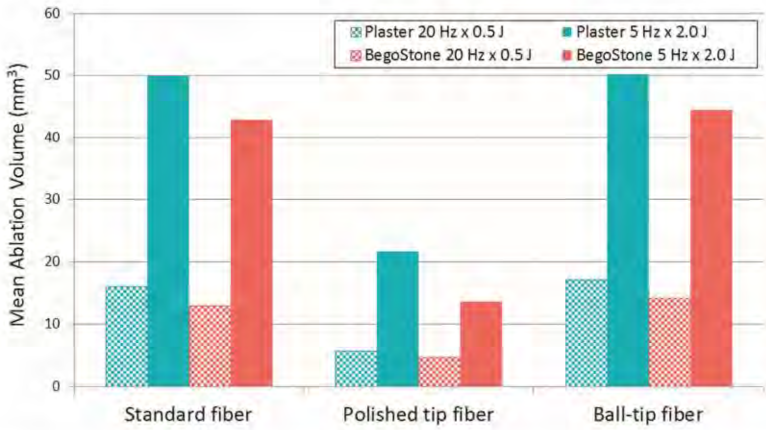


Figure 2. Ablation volumes of 3 laser fibers tested using soft and hard stone material at HiFr-LoPE and LoFr-HiPE settings. Standard and BT fibers did not differ in ablation volume but each was superior to PT fiber by factor of almost 3. Plaster of Paris was always associated with higher ablation volume than BegoStone. Comparison of low (hatched columns) and high (solid columns) pulse energy settings revealed that high pulse settings were several fold more ablative at same 10 W power level regardless of fiber type or stone material.

Figure 3. Microscopic analysis of fiber tip changed during course of experiments. Three tips showed minor tip changes after low pulse energy settings. When LoFr-HiPE laser emission was used, BT fiber showed intense degradation, which caused it to lose ball-shaped appearance, acquire menacing appearance and become undistinguishable from other fibers. PT fiber showed only cladding degradation and fiber tip opacification. Standard fiber was not subjected to gradual microscopic degradation analysis because it was always prepared again after each experimental run according to manufacturer instructions. Scale bar indicates 10 × 100 μm.

fibers produced significantly smaller ablation volumes at low pulse energy settings. Average ablation volumes were 23.0% (maximum 40.0% reduction) and 23.4% (maximum 39.5% reduction) lower, respectively, than those of new fibers ($p < 0.01$). In contrast low pulse energy settings before high pulse energy settings did not significantly affect ablation volumes of the latter ($p = 0.53$).

DISCUSSION

There is almost no literature on ball-shaped or special polished tip fibers and only a few abstract presentations have been published.[18–21] These fibers are advertised as having special features that enhance performance relative to that of standard laser fibers.[6–8] However at least with regard to ablation efficiency we did not find that these fibers were better than standard fibers. Indeed the standard fiber was not only as good as the BT fiber but also markedly better than the PT fiber. The standard fiber sometimes ablated threefold greater volumes than the PT fiber (fig. 2). This raises questions about the reliability of the information being advertised. This issue was previously the subject of controversy in other series.[22,23]

Additionally the experiments in our study were done in ideal laboratory conditions. If under ideal conditions there are already considerable performance differences among the different fibers, it is only plausible to assume that under clinical conditions with many uncontrollable and unforeseeable variables (eg uneven stone surfaces, manual laser fiber movements and patient respiratory movements) these differences will be at least as great if not substantially greater.

Notably although the BT fiber was as good as the standard fiber in terms of ablation volume, the tip of this fiber showed surprisingly intense degradation after short-term use, especially after high pulse energy settings. Figure 3 shows these effects. Fiber tip degradation due to burn-back effects is a known issue in laser lithotripsy.[24] However Shin et al reported that the BT fiber is robust and shows only minimal burn-back and degradation during laser lithotripsy.[21] This may reflect the fact that Shin et al repositioned the fibers relative to the stone surface at regular intervals. In contrast in the automated testing system used in our study (and indeed in real-life lithotripsy) all fibers were continuously in contact with the stone surface at the same orientation.

Knudsen et al also found that while higher energy levels correlated with BT fiber degradation, more than half of the fiber tips still had an intact ball shape at the end of the procedure.[19] However, the total energy delivered as well as the stone burden per procedure in that study was minimal.[19]

These observations led us to reanalyze our original data set according to preceding pulse energy settings. We found that if the BT and PT fibers had been previously applied at high pulse energy settings, all following lithotripsy experiments at low pulse yielded significantly lower ablation volumes (average 23% lower with a maximum 40% reduction) than new fibers. Since all existing laser fibers are made of the same core material (eg silica) and to our knowledge a fiber material resistant to burn-back effects has yet to be invented, it is likely that any other future fiber with a comparable ball-shaped tip morphology would show a degradation pattern similar to the one observed in this study.

The standard fiber did not demonstrate a statistically significant reduction in performance during the course of the experiment regardless of the preceding lithotripsy settings. This was probably because the tip of the standard fiber was always stripped and cleaved after each experiment. In contrast the PT and BT fibers were not prepared in such a manner before each new experiment. Giving the standard fiber but not the other fibers a fresh start each time could be considered a study limitation that biased results in favor of the standard fiber. However the study procedure was designed to be consistent with the recommendations of the manufacturers as it was thought that this approach would best reveal differences among the fibers. In fact it would have been inappropriate to prepare the BT and PT fiber tips by stripping/cleaving because this would have eliminated the only feature that makes these fibers unique, namely the tip.

We recently reported that traditional laser fiber tip preparation (ie customary stripping of the distal fiber coating and cleaving of the tip with specialized tools) is at best futile and at worst has a negative impact on performance.[11] We found that stripping standard laser fibers is always associated with lower ablation volumes. Based on these observations we speculate that the metal scissor cleaved standard laser fibers without stripping would yield better performance than the specially tipped fibers.

It has also been argued that specially designed, factory prepared laser fiber tips and single use laser fibers are superior to standard fibers because they yield perfect energy transmission.[6,8] One manufacturer even laser polishes its laser fiber tips instead of using mechanical polishing to achieve such flawless laser energy delivery.[6] New fibers in fact have high light transmission properties and perfect-looking fiber tips transmit 99% to 100% of the light.[25] Our previous light dispersion analysis also revealed that new fibers indeed kept the light focused on a single spot while fibers that were reprepared (eg cleaved with metal scissors) showed an unfocused light dispersion pattern.[5] However after only a few seconds of laser lithotripsy the new and reprepared fibers demonstrated the same blurred light dispersion pattern.[5]

Because the PT and BT fibers have fast tip degradation, which eliminates their special feature within a few seconds of lithotripsy and results in rapid loss of light focusing abilities during laser lithotripsy similar to standard fibers, the usefulness of the special tips can be questioned. The average price of the PT, BT and standard (single use) fibers is \$170, \$250 and \$150, respectively. Therefore using standard fibers could decrease laser fiber costs by 11% to 40% from a strictly economic point of view regardless of ablation performance.

Our observations also support the use of reusable fibers. These fibers show exactly the same tip morphology and degradation as new standard fibers and they can be reused as long as they are not damaged along the length or at the connector with a performance guarantee. Although standard reusable fibers are more expensive than standard single use fibers (\$570 vs \$150), reusable fibers decrease cost after the third use with additional cost reductions of 5% to 62% depending on the number of times (range 4 to 10) that they are reused.

The current study reveals that the lithotripsy performance of the PT and BT fibers decreased significantly after high pulse energy use. This suggests that if one wants to use lower pulse energy settings (eg HiFr-LoPE) with a fiber tip that was previously used at high pulse energy settings, laser fiber tip preparation should perhaps be performed as this will maximize ablation efficiency and prevent an unnecessary reduction in lithotripsy performance. Notably we also observed that prior use of a fiber tip at low pulse energy settings did not affect the performance of the tip at subsequent higher pulse energy settings. To our knowledge this is the first report of the effect of prior lithotripsy on fiber tip performance. It also suggests that when a urologist is going to increase pulse energy settings, there might be no advantage in preparing the fiber tip again.

Regardless of fiber type or manufacturer all laser fibers tested in this study shared a common component, namely the SMA-905 connector that allows these universal fibers to be used in similar fashion with different lithotripter models.[26] The information brochures of the PT and BT fibers state that these fibers have a special, custom guided SMA-905 connector that provides high output efficiency and decreases the chance of guiding laser energy toward the wrong direction, thus guaranteeing perfect energy transmission.[7,8] One would assume that these features would confer better lithotripsy performance compared to standard fibers. This notion is contradicted by the current study, which demonstrated that the standard fiber with its standard SMA-905 connector was as good as the BT fiber and several times better than the PT fiber. Thus, the custom connectors of the BT and PT fibers do not seem to confer any additional advantage. Even if other lithotripters were used, absolute ablation volume values could vary. However they would only reflect differences among the lithotripters. The relative performance of each individual fiber in relation to the other fibers would remain unchanged.

It should be emphasized that the PT fiber brand name erroneously indicates that it has a 200 μm core. This discrepancy between the actual and the advertised core size of the BT fiber and other fibers has been noted previously by others, further suggesting that lithotripsy fiber manufacturer advertising information should be treated with caution.[23,27]

Laser fibers with sharp edges can scratch and damage the working channel during insertion, especially if the distal end of the scope is deflected.[28] Moreover laser fibers are known to decrease the deflection angle of ureterorenoscopes and hinder them from reaching the lower kidney calyces.[29] In addition, if the ureterorenoscope has a protruding laser fiber tip and it is manipulated in the kidney, it may injure the urothelium and cause bleeding, thus making the surgery even more challenging or even impossible.

In these settings the BT fiber has some clear advantages over the PT and standard fibers. 1) Because of its smooth round tip surface it passes more easily through the working channel. Straining or tearing the inner surface of the channel is prevented, reducing damage and maintenance costs. 2) The urologist can maneuver the scope in the kidney until the desired spot is reached without concern that subsequent insertion of the BT fiber will be complicated by major resistance or loss of deflection angle. Thus in these specific situations the BT fiber is superior to all other fibers in that it permits successful surgery in cases in which surgery with another fiber may not be possible.

However these advantages are lost after the first laser emission due to almost immediate BT fiber tip degradation, especially at high pulse energy settings. Thus subsequent passages of such a changed fiber tip will be more difficult, as acknowledged by the manufacturer.[7] Indeed given the menacing appearance of the BT tip in the microscope photographs (fig. 3), it is quite possible that it may damage a deflected working channel more severely than other fibers. Notably other groups have warned that damaged BT fibers can become side firing[30] and thus potentially dangerous to the scope or even to nearby tissues. To assess the safety of these fibers we need more studies of working channel durability when using these new fibers.

The cores of the PT and BT fibers had slightly smaller diameters (240 μm) than the core of the standard fiber (272 μm), which could possibly be considered a limitation of the study. However this slight difference is unlikely to have biased study results as different-sized cores have been reported to yield similar ablation volumes at the range of the lithotripter settings used in this series.[5,9]

Another study limitation was that we only compared 2 laser fibers with special tips to a single standard laser fiber. This limitation was unavoidable because few laser fiber manufacturers have and advertise special laser fiber tips.[6–8] We also did not want to compare multiple standard laser fibers with each other because it would be beyond the scope of this study. In any case the current series indicates the need to carefully test claims regarding new fibers, including those with novel tips.

CONCLUSIONS

The standard laser fiber was as good as and sometimes better than the novel fibers with specially designed tips. Moreover the specially designed fiber tips showed marked degradation after only a few seconds. This in effect eliminates their unique feature and makes their usefulness questionable. However, ball-shaped laser fibers may be useful or even essential in specific surgical situations. The current study also suggests that the urologist may be justified in preparing the fiber tip again by cleavage if lithotripter settings are changed from high to low pulse energy as this may ensure better lithotripsy performance.

REFERENCES

1. Civiale J. On lithotrity, and the peculiar dispositions that prevent its employment. Continental and British Medical Review, or Monthly Therapeutical Journal 1837; p 150.
2. Alcock NG: Prostatic resection and surgical prostatectomy: comparison of immediate results in two equal consecutive series of cases chairman's address. JAMA 1933; **101:** 1355.
3. Iribarne A, Easterwood R, Chan EYH et al: The golden age of minimally invasive cardiothoracic surgery: current and future perspectives. Future Cardiol 2011; **7:** 333.
4. Recent News: IPG Photonics. Boston: Reynders McVeigh Capital Management 2013.
5. Kronenberg P and Traxer O: Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 2015; **33:** 463.
6. American Medical Systems: SureFlex™ Laser Fiber Brochure: Instructions for Use. No. 0138–0410 Rev C (11/10), 2010. Available at http://www.amselabeling.com/assets/files/0138-0410-C_ReusableSureFlexIFU_1110.pdf. Accessed April 11, 2014.
7. Boston Scientific: AccuTrac™ Flexiva™ TracTip Brochure. BVU2640, 2011. Available at https://www.bostonscientific.com/content/dam/bostonscientific/uro-wh/portfolio-group/lithotripsy/tractip/AccuTrac_Flexiva_TracTip_Brochure.pdf. Accessed July 16, 2014.
8. AccuMax Single-Use Holmium Laser Fiber URO-93705-AA. Natick: Boston Scientific 2012.
9. Kronenberg P and Traxer O: In vitro fragmentation efficiency of holmium: yttrium-aluminum-garnet (YAG) laser lithotripsy - a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 2014; **114:** 261.
10. Kronenberg P and Traxer O: Myths, doubts, and facts about laser lithotripsy. J Endourol Part B Videourol 2014; p 2.
11. Kronenberg P and Traxer O: Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol 2015; **193:** 1030.
12. Knoll T: Scientific souvenirs: urolithiasis and treatment. Presented at annual meeting of European Association of Urology, Madrid, Spain, March 20-24, 2015.
13. Esch E, Simmons W, Sankin G et al: A simple method for fabricating artificial kidney stones of different physical properties. Urol Res 2010; **38:** 315.
14. Marguet CG, Sung JC, Springhart WP et al: In vitro comparison of stone retropulsion and fragmentation of the frequency doubled, double pulse ND:YAG laser and the holmium:yag laser. J Urol 2005; **173:** 1797.
15. Liu Y and Zhong P: BegoStone—a new stone phantom for shock wave lithotripsy research. J Acoust Soc Am 2002; **112:** 1265.
16. Rocamed: Product Catalogue Brochure, EN.2.1, 2014. Available at http://www.rocamed-urology.com/images/stories/doc/products%20catalogue%20oct%202014.pdf. Accessed February 13, 2015.
17. Rocamed: MH01 Laser Lithotripter Brochure, V.Uk.2, 2013. Available at http://www.rocamed-urology.com/images/stories/doc/br.uk.v2.laser.pdf. Accessed June 19, 2014.
18. Knudsen B: 18-Ball-tip holmium:YAG optical fiber. Presented at annual meeting of Engineering and Urological Society, Washington, D.C., May 14, 2011, abstract 33.
19. Knudsen B, De S and Monga M: PD37-05 ball tipped holmium:YAG optical fiber: pulse energy settings increase degradation during clinical use. J Urol, suppl., 2014; **191:** e947.
20. Shin R, Cabrera F, Shami C et al: MP20-04 ball-tip holmium laser fiber may reduce flexible ureteroscope damage. J Urol, suppl., 2014; **191:** e197.
21. Shin R, Lautz J, Cabrera F et al: PD37-04 ball-tip holmium laser fiber: in vitro stone comminution and fiber tip degradation. J Urol, suppl., 2014; **191:** e947.
22. Barros JA: A (des)informação sobre medicamentos: o duplo padrão de conduta das empresas farmacêuticas. Cad Saude Publica 2000; **16:** 421.
23. Kronenberg P and Traxer O: The truth about laser fiber diameters. Urology 2014; **84:** 1301.
24. Mues AC, Teichman JMH and Knudsen BE: Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol 2009; **23:** 1425.
25. Vassantachart JM, Lightfoot M, Yeo A et al: Laser fiber cleaving techniques: effects on tip morphology and power output. J Endourol 2015; **29:** 84.
26. Verdaasdonk R and van Swol CFP: Laser light delivery systems for medical applications. Phys Med Biol 1997; **42:** 869.
27. Monga M: Ureteroscopy: Indications, Instrumentation and Technique. Current Clinical Urology. Totowa: Humana Press 2013.
28. Seto C, Ishiura Y, Egawa M et al: Durability of working channel in flexible ureteroscopes when inserting ureteroscopic devices. J Endourol 2006; **20:** 223.
29. Pasqui F, Dubosq F, Tchala K et al: Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. Eur Urol 2004; **45:** 58.
30. Verdaasdonk R, Klaessens J, Roode R de et al: Dynamic change of characteristics of (modified) fiber tips used with microsecond pulsed lasers in a liquid environment influencing the effectiveness and safety of treatment. Proc SPIEE 6435, February 7, 2007, p 64350S.

Article 6: Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an Ex Vivo Animal Model on Pig Eyes

JOURNAL OF ENDOUROLOGY
Volume 30, Number 3, March 2016
© Mary Ann Liebert, Inc.
Pp. 332–337
DOI: 10.1089/end.2015.0232

Do We Really Need to Wear Proper Eye Protection When Using Holmium:YAG Laser During Endourologic Procedures? Results from an *Ex Vivo* Animal Model on Pig Eyes

Luca Villa, MD,[1,2] Jonathan Cloutier, MD,[1] Eva Compérat, MD,[3] Peter Kronemberg, MD,[4] Frederic Charlotte, MD,[3] Laurent Berthe, PhD,[5] Yann Rouchausse, DEng,[5] Andrea Salonia, MD, PhD,[2,6] Francesco Montorsi, MD, FRCS,[2,6] and Olivier Traxer, MD[1]

Abstract

Purpose: We sought to evaluate the effect of holmium:yttrium–aluminum–garnet (Ho:YAG) laser exposure on *ex vivo* pig eyes and to test the protective action of different glasses in preventing eye lesions in case of accident.
Materials and Methods: We pointed the tip of a Ho:YAG laser fiber from different distances (0, 3, 5, 8, 10, and 20 cm, respectively) toward the center of the pupil of the pig eye. The Ho:YAG laser was activated for 1 or 5 seconds at three different settings (0.5 J-20 Hz, 1 J-10 Hz, and 2 J-10 Hz, respectively). The experiment was repeated using laser safety glasses and eyeglasses. A total of 78 pig eyes were used. The effects of the Ho:YAG laser on pig eyes were assessed by histopathology. Comparable laser emission experiments were performed on thermal paper at different distances using different pulse energies.
Results: Ho:YAG laser-induced corneal lesions were observed in unprotected eyes, ranging from superficial burning lesions to full-thickness necrotic areas, and were directly related to pulse energy and time of exposure and inversely related to the distance from the eye. When the laser was placed 5 cm or more, no corneal damage was observed regardless of the laser setting and the time of exposure. Similar distance/energy level relationships were observed on thermal paper. No damage was observed to the lens or the retina in any of the Ho-YAG laser-treated eyes or in any of the eyes protected by laser safety and eyeglasses.
Conclusions: Ho:YAG lasers can cause damage when set to high energy, but only to the cornea, from close distances (0–5 cm) and in the absence of eye protection. Eyeglasses are equally effective in preventing laser damage as laser safety glasses.

Introduction

Over the last two decades, the holmium:yttrium–aluminum–garnet (Ho:YAG) laser has been gaining increasing popularity in the urologic community because it offers effective treatment for various pathologies requiring endourologic procedures.[1]

In the context of the upper urinary tract, the use of the Ho:YAG laser is actually recommended for several pathologies such as intracorporeal lithotripsy during flexible ureteroscopy in patients with kidney stones,[2] conservative treatment for upper urinary tract tumors,[3] and the endoscopic incision of strictures of the ureter or the ureteropelvic junction.[1]

Despite its effectiveness, some concerns exist regarding laser safety. In particular, Ho:YAG laser manufacturers[4–6] and the guidelines of European Association of Urology on laser and technologies[1] recommend all intraoperative personnel to wear proper eye protection to avoid any corneal or retinal damage in case of unintentional laser exposure.

A recent study reporting adverse events resulting from lasers used in urology in the United States showed that out of 433 total adverse events, 46% resulted from generator failure

[1]Department of Urology, Tenon Hospital, Pierre and Marie Curie University, Paris, France.
[2]Division of Experimental Oncology/Unit of Urology, URI, IRCCS Ospedale San Raffaele, Milan, Italy.
[3]Department of Pathology, Pitié-Salpêtrière Hospital, Pierre and Marie Curie University, Paris, France.
[4]Department of Urology, Hospital Prof. Doutor Fernando Fonseca, Amadora, Portugal.
[5]Process and Engineering in Mechanics and Materials Laboratory (PIMM), UMR CNRS/ENSAM 8006, Paris, France.
[6]Università Vita-Salute San Raffaele, IRCCS Ospedale San Raffaele, Milan, Italy.

or fiber tip breakage and 37.8% were eye injuries associated with the use of neodymium:yttrium–aluminum–garnet (Nd:YAG), potassium titanyl phosphate (KTP), and diode lasers with improper eye protection. Interestingly, no eye injuries were reported with the use of Ho:YAG lasers.[7]

To clarify the potential harmful effects of a Ho:YAG laser when the laser beam accidentally hits the surface of the eyes, we conducted an *ex vivo* animal study on pig eyes to evaluate the effect of a Ho:YAG laser, set at the most commonly used parameters and at different distances, on different eye structures.

In addition, we determined the real protection offered by laser safety glasses and eyeglasses in preventing eye lesions, and we assessed the photothermal effect of the Ho:YAG laser transmitted in air on thermal paper at different distances to implement the results obtained in the first part of the study.

Materials and Methods

All experiments included in the current study were conducted in the laboratory of the "Ecole Nationale Supérieure d'Arts et Métiers ParisTech" (Paris, France) in July 2014 using a 30-W Ho:YAG laser (Rocamed™-MH 01-ROCA FTS 30 [Serial No. LHT0661-0813, Monaco] and a 272-μm-core-diameter laser fiber (Rocamed™-MF272STs).

Evaluation of Ho:YAG laser effect on pig eyes

Overall, 78 pig eyes were used. The potential detrimental effect of the Ho:YAG laser on the different eye structures was evaluated by pointing the laser fiber toward the center of the pupil of the pig eyes. We decided to use such an *ex vivo* animal model because pig eyes share many similarities with human eyes not only in terms of size but also for some specific histologic and physiologic features.[8]

Three different laser settings were examined, which approximately represent the ideal conditions in which clinicians should work to (1) obtain small stone fragments—the so-called "dusting effect"—(i.e., 0.5 J at 20 Hz, long pulse),[9,10] (2) reduce the stone burden when numerous large fragments are present—the so-called "popcorn effect"—(i.e., 1 J at 10 Hz, short pulse),[11,12] and (3) achieve a higher fragmentation volume by increasing the pulse energy (i.e., 2 J at 10 Hz, short pulse).[12,13]

Because we sought to reproduce the condition of a beam-related adverse event that could occur in the daily clinical practice during any endourologic procedure requiring the use of a Ho:YAG laser, we assumed that if the tip of the laser fiber was accidentally pointed toward the eye of any person present in the operating theater, the exposure to the eye should last no more than some fraction of a second considering the blink reflex. Therefore, we established that activating the laser fiber in the direction of the pig eyes for 1 second would make the experiments reproducible and reliable, thus reflecting an unfavorable condition that would simulate an accidental injury.

We, in addition, tested a fourth laser lithotripter setting to evaluate an extreme condition by activating the laser fiber set at the highest energy (2 J at 10 Hz, short pulse) for 5 seconds.

The tip of the laser fiber was placed and activated in contact (0 cm) and at different distances from the eyes (3, 5, 8, 10, and 20 cm, respectively) (Fig. 1). Each eye was used to evaluate the effect of each laser setting at each different distance.

The experiment was repeated using laser safety glasses, eyeglasses, and without any eye protection. Six eyes served as nontreated controls. Eyes were fixed in 10% formol, after fixation embedded in paraffin and stained by hematein–eosin–saffron (HES). Cuts were 3 μm thick. The analysis was conducted by two independent pathologists who focused their attention on the cornea, lens, retina, and optic nerve of each eye. In the case of discordant findings, consensus lecture was undertaken.

Evaluation of Ho:YAG laser effect on thermal paper

The photothermal effect of the Ho:YAG laser was evaluated by using a thermal paper (Thermal Print Media, UPP-210HD; Sony Corporation, Tokyo, Japan). The laser fiber tip was positioned perpendicularly to the surface of the thermal paper at different distances for each test (1, 1.5, 5, 10, and 20 cm). Pulse energies included 0.5, 1, 1.5, and 2 J using the traditional short-pulse mode. For each distance/pulse-energy combination, laser emission was sustained for 3 seconds at 5 Hz. After laser emission, the darkened stains produced on the thermal paper were visually compared.

Results

Pathologic findings from the pig eyes exposed to Ho:YAG laser emission in the different situations are shown in Tables 1–3. Compared to the nontreated controls (Fig. 2A), when the laser was set either at 0.5 J-20 Hz or 1 J-10 Hz, a superficial burning lesion with a loss of surface epithelium was observed on the HES on the cornea of the unprotected eye in contact with the laser fiber (Fig. 2B), whereas no effect was observed when the eye was placed at a distance greater than 3 cm from the laser fiber (Tables 1 and 2). When the laser was set at 2 J-10 Hz, eyes in contact or within 3 cm of the laser without any glasses showed an increase in corneal thickness,

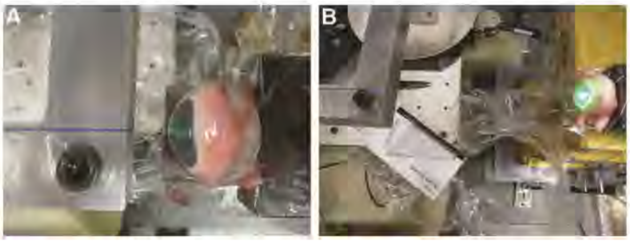


FIG. 1. Two hundred seventy-two-micrometer-diameter laser fiber (Rocamed™-MF272STs) pointed toward a pig eye and placed in contact with the cornea **(A)** and at 20 cm **(B)** just before activation. Color images available online at www.liebertpub.com/end

TABLE 1. PATHOLOGIC FINDINGS OF THE PIG EYES EXPOSED TO HO:YAG LASER FIBER ACTIVATION SET AT 0.5 J-20 HZ FOR 1 SECOND

Eye protection device	*Distance from the eye (cm)*	*Cornea*	*Lens*	*Retina*	*Optic nerve*
Laser safety glasses	0	—	—	—	MP
"	3	—	—	—	—
"	5	—	—	—	—
"	8	—	—	—	—
"	10	—	—	—	—
"	20	—	—	—	—
Eyeglasses	0	—	—	—	—
"	3	—	—	—	—
"	5	—	—	—	—
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	—
Nothing	0	SBL, LSE	—	—	—
"	3	—	—	—	—
"	5	—	—	—	—
"	8	—	—	—	—
"	10	—	—	—	MP
"	20	—	—	—	MP

Ho:YAG = holmium:yttrium–aluminum–garnet; LSE = loss of surface epithelium; MP = melanophages; SBL = superficial burning lesion.

with necrotic areas in the anterior region and a complete loss of corneal epithelium (Fig. 2C). A superficial burning lesion was observed at 5 cm, and no relevant effect was observed from 8 cm onward. No damage was detected on the lens and on the retina in any of the Ho:YAG laser-treated eyes and in any of the eyes protected by laser safety and eyeglasses, regardless of the laser setting and the distance from the laser fiber (Tables 1–3). Nevertheless, significant damage directly related to the pulse energy and inversely related to the distance from the laser tip was detected on both laser safety glasses and eyeglasses (Fig. 3).

TABLE 2. PATHOLOGIC FINDINGS OF THE PIG EYES EXPOSED TO HO:YAG LASER FIBER ACTIVATION SET AT 1 J-10 HZ FOR 1 SECOND

Eye protection device	*Distance from the eye (cm)*	*Cornea*	*Lens*	*Retina*	*Optic nerve*
Laser safety glasses	0	—	—	—	MP
"	3	—	—	—	—
"	5	—	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	—
Eyeglasses	0	—	—	—	MP
"	3	—	—	—	—
"	5	—	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	—
Nothing	0	SBL, LSE	—	—	—
"	3	—	—	—	—
"	5	—	—	—	MP
"	8	—	—	—	—
"	10	—	—	—	—
"	20	—	—	—	—

Ho:YAG = holmium:yttrium–aluminum–garnet; LSE = loss of surface epithelium; MP = melanophages; SBL = superficial burning lesion.

TABLE 3. PATHOLOGIC FINDINGS OF THE PIG EYES EXPOSED TO HO:YAG LASER FIBER ACTIVATION SET AT 2 J-10 HZ FOR 1 SECOND

Eye protection device	*Distance from the eye (cm)*	*Cornea*	*Lens*	*Retina*	*Optic nerve*
Laser safety glasses	0	—	—	—	MP
"	3	—	—	—	MP
"	5	—	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	—
Eyeglasses	0	—	—	—	—
"	3	—	—	—	—
"	5	—	—	—	MP
"	8	—	—	—	—
"	10	—	—	—	—
"	20	—	—	—	MP
Nothing	0	NA, LSE ++, ICT	—	—	—
"	3	NA, LSE ++, ICT	—	—	MP
"	5	SBL, LSE	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	—

Ho:YAG = holmium:yttrium–aluminum–garnet; LSE = loss of surface epithelium; MP = melanophages; SBL = superficial burning lesion; ICT = increased corneal thickness; NA = necrotic areas.

In the extreme condition, a 2 J-10 Hz activation of the laser fiber for 5 seconds at contact (0 cm) and at 3 cm from the eyes caused full-thickness necrotic areas on the cornea, a complete loss of superficial epithelium, and an increase in corneal thickness (Fig. 2D), with no lesion on the lens, the retina, or the optic nerve. A superficial burning lesion was observed on the cornea at 5 cm, and no significant effect was found from 8 cm onward. No changes were observed in any of the eyes protected by either laser safety or eyeglasses (Table 4).

Both the eyes exposed to the Ho:YAG laser and the non-treated control eyes showed the presence of melanophages on the optic nerve, compatible with chronic non-Ho:YAG laser exposure-related events. No other changes were documented in the control group (Tables 1–4).

Concerning the evaluation of Ho:YAG laser effect on thermal paper, we observed that both pulse-energy level and distance from the paper were determinants of a considerable increase in the darkening effect or burn damage on the thermal paper.

Thermal paper was not affected by laser emission at a distance of 10 or 20 cm, regardless of the energy level used (Fig. 4).

Effects of laser emission began to be observed when the distance from the fiber tip to the paper surface was reduced to

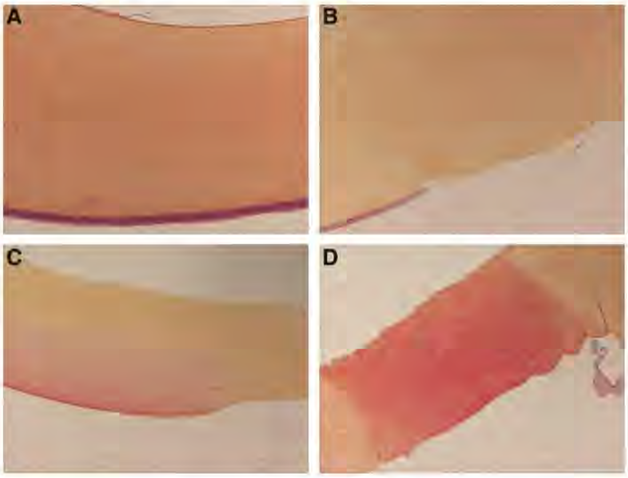


FIG. 2. Hematein–eosin–saffron section of the cornea: **(A)** the normal structure of a control eye; **(B)** the loss of surface epithelium after 1 second of holmium:yttrium–aluminum–garnet (Ho:YAG) laser exposure at 0.5 J-20 Hz; **(C)** an increase in corneal thickness, with necrotic areas in the anterior region and a complete loss of corneal epithelium after 1 second of Ho:YAG laser exposure at 2 J-10 Hz; and **(D)** full-thickness necrotic areas on the cornea, a complete loss of superficial epithelium, and an increase in corneal thickness after 5 seconds of Ho:YAG laser exposure at 2 J-10 Hz, when the tip of the laser fiber was placed in contact with the eye. Color images available online at www.liebertpub.com/end

5 cm or less: at 5 cm, only high pulse-energy levels of 1.5 and 2 J were able to darken the paper, whereas at shorter distances of 2.5 or 1 cm, all energy levels (0.5 up to 2 J) darkened the thermal paper. Moreover, at 1 cm distance, all pulse levels caused a significant burning of the thermal paper in an energy-dependent manner.

Discussion

Therapeutic applications of Ho:YAG laser in ophthalmology for the correction of hyperopia are well known.[14,15] Wearing proper laser eye protection is strongly recommended for all persons present in the operating theater when lasers are used for any kind of surgery, because there are case reports in the literature describing eye injury with significant loss of visual acuity due to unfavorable accidents after laser exposure.[16] However, a recent study investigating the rate of laser-induced adverse events showed that all eye injuries occurred when ND:YAG, KTP, and diode lasers were used, whereas Ho:YAG lasers caused only minor skin burns.[7] Our study analyzed for the first time in an *ex vivo* animal model the potential impairments of different eye structures following Ho:YAG laser exposure. We found that that the cornea of the pig eyes was the only layer damaged by laser exposure when no protective devices were used. In this context, the greater the pulse energy, moving from 0.5 to 2 J, the more severe the corneal injuries, ranging from superficial burning lesions with a loss of surface epithelium to full-thickness necrotic areas with increased corneal thickness and a loss of normal microarchitecture, when the laser tip was in contact or 3 cm from the eyes (Fig. 2B–D and Tables 1–3). Similarly, Schmitz-Valckenberg et al. used an animal model to investigate the effect of Nd:YAG laser exposure on rat eyes.[17] They detected *in vivo* retinal cells undergoing apoptosis in a dose-dependent manner, with greater retinal burns for longer exposures (500 mS *vs* 300 mS) and at higher power levels (500 mW *vs* 300 mW). Conversely, our findings showed that neither the lens nor the retina was impaired regardless of the laser settings adopted. This difference seems to be explained by the intrinsic characteristics of the Ho:YAG laser, which has a wavelength of 2140 nm, is absorbed by water, and has a depth of tissue penetration of 0.4 mm; in contrast, Nd:YAG is absorbed by oxyhemoglobin, has a shorter wavelength (1064 nm), and has a higher depth of tissue penetration (4–18 mm).[1,18]

A further interesting finding concerns the concept of distance: when the laser tip was more than 5 cm away from the cornea, Ho:YAG laser emission impaired neither the deeper eye structures nor more superficial ones; indeed, no superficial burning lesion or loss of surface epithelium was observed

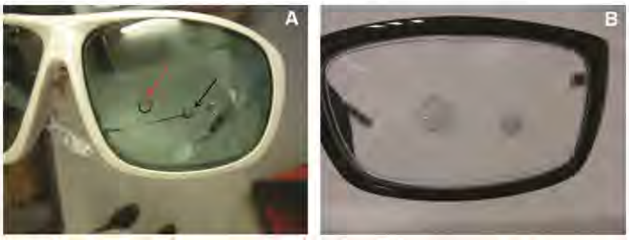


FIG. 3. **(A)** Laser safety glasses and **(B)** eyeglasses after 1 second (*black arrow*) and 5 seconds (*red arrow*) of Ho:YAG laser exposure at 2 J and 10 Hz with the laser fiber tip in contact with the glasses. Color images available online at www.liebertpub.com/end

Table 4. Pathologic Findings of the Pig Eyes Exposed to Ho:YAG Laser Fiber Activation Set at 2 J-10 Hz for 5 Seconds

Eye protection device	*Distance from the eye (cm)*	*Cornea*	*Lens*	*Retina*	*Optic nerve*
Laser safety glasses	0	—	—	—	MP
"	3	—	—	—	MP
"	5	—	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	MP
Eyeglasses	0	—	—	—	MP
"	3	—	—	—	MP
"	5	—	—	—	—
"	8	—	—	—	MP
"	10	—	—	—	MP
"	20	—	—	—	MP
Nothing	0	NA ++, LSE ++, ICT	—	—	—
"	3	NA +, LSE ++, ICT	—	—	MP
"	5	SBL, LSE	—	—	MP
"	8	—	—	—	MP
"	10	—	—	—	—
"	20	—	—	—	MP

Ho:YAG = holmium:yttrium–aluminum–garnet; LSE = loss of surface epithelium; MP = melanophages; SBL = superficial burning lesion; ICT = increased corneal thickness; NA = necrotic areas.

on the cornea, independent of the laser setting (low- or high-power energy), thus resulting in normal pathologic findings comparable to the nontreated controls.

The key role of power energy and distance in affecting the potential detrimental effect of the Ho:YAG laser in the case of accident has been confirmed by the experiments on thermal paper. Acute thermal injury is known to occur at temperatures of 65°C and above, even for brief periods of time.[19] The thermal sensitivity threshold of thermal paper is similar, starting at 60°C to 70°C.[20,21] Any significant thermal variation above that threshold would show up as darkened stains on the paper, such as in our experiments. Our results showed that unintentional Ho:YAG laser emission in air over distances of more than 5 cm may not be harmful, even if high pulse energies such as 2 J are used and for accidental emission periods of up to 3 seconds.

The distance to the terminal laser source, that is, the laser fiber tip, and power of the laser lithotripter, including pulse energy, are known factors that crucially influence the risk of laser injury.[22] The findings of the current study support this evidence, demonstrating that the damage caused by laser emission correlates directly with the pulse-energy level and inversely with the distance to the laser fiber tip. Of note, using high pulse energy (i.e., 2 J) is often not necessary and could be counterproductive, because it increases stone retropulsion, produces larger stone fragments, and induces greater fiber tip degradation.[12,23,24]

In addition, we showed that laser safety glasses protect the eye's surface against all Ho:YAG laser exposure, even in the worst case scenario (i.e., small distance, high pulse energy, and long exposure duration—Table 4). Laser safety glasses for Ho:YAG lasers are certainly effective and do not cause any distortion of color perception,[25] thus not affecting the quality of view and the performance of the surgeon. Interestingly, regular eyeglasses act equally well in counteracting the potentially harmful effects of Ho:YAG laser exposure to the cornea. Taken together, the current data show that Ho:YAG laser emission can have detrimental effects on eyes only at small distances (no more than 5 cm from the laser source) and that regular eyeglasses are just as effective as laser safety glasses at protecting the eyes from these effects. However, because the current study systematically investigates for the first time the interaction between the Ho:YAG laser and eye structures in an *ex vivo* animal model, further *in vivo* studies are necessary to overcome the inability to evaluate the response of living tissues in terms of inflammatory events or late apoptosis occurring after Ho:YAG laser exposure, which could not be taken into consideration in the current study.

Moreover, it must be carefully considered that the human eye is highly radiosensitive, and prolonged radiation exposure increases the risk of developing cataracts. Taylor et al.[26] showed that the mean radiation dose received during 28 endourologic procedures was 0.208 mSv. Considering a threshold of 2500 mSv as the minimum fractionated long-term dose required to initiate cataract formation and an average of 20 endourologic cases per month, they stated that it takes about 50 years to reach that threshold and to start developing cataracts.

Overall, the benefit of wearing lead-lined glasses should be considered for young urologists and high-volume surgeons and compared with the usefulness of laser safety glasses, the protective effect of which against radiation exposure has never been proven.

Therefore, we may translationally suggest that wearing laser safety rather than lead-lined glasses during all endourologic procedures requiring the use of Ho:YAG lasers and X-ray should be a personal decision of the surgeon and the intra-operative personnel.

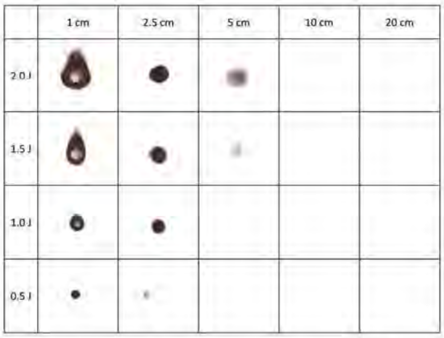


FIG. 4. Effect of Ho:YAG laser exposure on a thermal paper (Thermal Print Media, UPP-210HD; Sony Corporation) according to the distance from the laser fiber tip (1–20 cm) and the pulse-energy setting (0.5–2 J). Color images available online at www.liebertpub.com/end

Conclusions

In the event of an accident during endourologic procedures, the Ho:YAG laser does not provoke injury to the lens or the retina of the eye. It can cause corneal lesions, but only in the absence of eye protection and only when set to high energy (2 J) and experienced from a short distance (0–5 cm). Eyeglasses are equally effective in counteracting harmful laser effects to the cornea as laser safety glasses. Although the risk of eye injury is minimal, the use of laser safety glasses or at least eyeglasses during endourologic procedures requiring Ho:YAG laser should be recommended to all intraoperative personnel who are close to the laser source.

Author Disclosure Statement

No competing financial interests exist.

References

1. Herrmann TR, Liatsikos EN, Nagele U, Traxer O, Merseburger AS. EAU guidelines panel on lasers, technologies. EAU guidelines on laser technologies. Eur Urol 2012;61:783–795.
2. Türk C, Knoll T, Petrik A, et al. EAU Guidelines on Urolithiasis. Guidelines on Urolithiasis. European Association of Urology 2015. Available from http://uroweb.org/guideline/urolithiasis/ (accessed January 20, 2015).
3. Rouprêt M, Babjuk M, Compérat E, et al. European guidelines on upper tract urothelial carcinomas: 2013 update. Eur Urol 2013;63:1059–1071.
4. Lumenis. (2013). VersaPulse PowerSuite Brochure; PB-1106750 Rev B 2013. Available from www.surgical.lumenis.com/pdf/PB-1106750_rB_VPPS_P20v_br_LowRes%20%281%29.pdf (accessed February 8, 2015).
5. Electro Medical Systems. (2012). Swiss Laserclast Brochure; FA-398. Available from www.ems-company.com/media/PDF%20NEW/FA-398_EN_Ed_08-2012_LaserClast%20Brochure_single.pdf (accessed February 8, 2015).
6. Rocamed (2013) MH01 Laser Lithotripter Brochure; V.Uk.2. Available from www.rocamed-urology.com/images/stories/doc/br.uk.v2.laser.pdf (accessed February 8, 2015).
7. Althunayan AM, Elkoushy MA, Elhilali MM, Andonian S. Adverse events resulting from lasers used in urology. J Endourol 2014;28:256–260.
8. Guduric-Fuchs J, Ringland LJ, Gu P, Dellett M, Archer DB, Cogliati T. Immunohistochemical study of pig retinal development. Mol Vis 2009;15:1915–1928.
9. Spore SS, Teichman JM, Corbin NS, et al. Holmium: YAG lithotripsy: Optimal power settings. J Endourol 1999; 13:559–566.
10. Sea J, Jonat LM, Chew BH, et al. Optimal power settings for holmium:YAG lithotripsy. J Urol 2012;187:914–919.
11. Chawla SN, Chang MF, Chang A, et al. Effectiveness of high-frequency holmium:YAG laser stone fragmentation: The "popcorn effect." J Endourol 2008;22:645–650.
12. Kronenberg P, Traxer O. *In vitro* fragmentation efficiency of holmium:yttrium-aluminum-garnet (YAG) laser lithotripsy: A comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 2014;114:261–267.
13. Kronenberg P, Traxer O. Update on lasers in urology 2014: Current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 2015;33:463–469.
14. Rocha G, Castillo JM, Sánchez-Thorin JC, Johnston J, Cartagena RG. Two-year follow-up of noncontact holmium laser thermokeratoplasty for the correction of low hyperopia. Can J Ophthalmol 2003;38:385–392.
15. Eggink CA, Bardak Y, Cuypers MH, Deutman AF. Treatment of hyperopia with contact Ho:YAG laser thermal keratoplasty. J Refract Surg 1999;15:16–22.
16. Fernandez MP, Modi YS, John VJ, Berrocal AM. Accidental Nd:YAG laser-induced macular hole in a pediatric patient. Ophthalmic Surg Lasers Imaging Retina 2013;44 Online(6):e7–e10.
17. Schmitz-Valckenberg S, Guo L, Maass A, et al. Real-time *in vivo* imaging of retinal cell apoptosis after laser exposure. Invest Ophthalmol Vis Sci 2008;49:2773–2780.
18. Teichmann HO, Herrmann TR, Bach T. Technical aspects of lasers. World J Urol 2007;25:221–225.
19. Henriques FC, Moritz AR. Studies of thermal injury: I. The conduction of heat to and through skin and the temperatures attained therein. A theoretical and an experimental investigation. Am J Pathol 1947;23:530–549.
20. Koehler Paper Group. Thermal Paper KT 70 HS: Technical Data Sheet. Oberkirch, Germany; 2012 Nov 1 [cited 2015 Jan 11]. Available from www.koehlerpaper.com/media/docs/en/product-information/KT-70-HS-Techn_Datenblatt_Rev5_GB.pdf (accessed February 10, 2015).
21. Torraspapel. Technical Knowledge; Sensitivity of thermal papers. Barcelona, Spain; 2011 Jan 1 [cited 2015 Jan 11]. Available from www.torraspapel.com/Conocimiento%20Tcnico/ThermalSensitivity.pdf (accessed February 10, 2015).
22. Smalley PJ. Laser safety: Risks, hazards, and control measures. Laser Ther 2011;20:95–106.
23. Kronenberg P, Traxer O. V1718 LASER fibers, pulse energy and retropulsion-what we can see and what we can't. J Urol 2013;189:e707.
24. Kronenberg P, Traxer O. Are we all doing it wrong?—Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol 2015;193:1030–1035.
25. Teichman JM, Johnson AJ, Yates JT, et al. Color vision deficits during laser lithotripsy using safety goggles for coumarin green or alexandrite but not with holmium:YAG laser safety goggles. J Urol 1998;159:683–689.
26. Taylor ER, Kramer B, Frye TP, Wang S, Schwartz BF, Köhler TS. Ocular radiation exposure in modern urological practice. J Urol 2013;190:139–143.

Address correspondence to:
Olivier Traxer, MD
Department of Urology
Tenon Hospital
Pierre and Marie Curie University
4 rue de la Chine
Paris 75020
France

E-mail: olivier.traxer@tnn.aphp.fr

Abbreviations Used

Ho:YAG = holmium:yttrium–aluminum–garnet
ICT = increased corneal thickness
KTP = potassium titanyl phosphate
LSE = loss of surface epithelium
MP = melanophages
NA = necrotic areas
Nd:YAG = neodymium:yttrium–aluminum–garnet
SBL = superficial burning lesion

Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey et al.

JOURNAL OF ENDOUROLOGY
Volume 32, Number 4, April 2018
© Mary Ann Liebert, Inc.
P. 296
DOI: 10.1089/end.2018.0152

Editorial Comment on: Ureteroscopic High-Frequency Dusting Utilizing a 120-W Holmium Laser by Tracey *et al.*

Peter Kronenberg, MD[1–3]

In the past years, there is an increasing trend among urologists to use dusting techniques instead of fragmentation during (holmium) laser lithotripsy. Dusting has shown to favorably decrease several parameters such as operative time, ureteral access sheath usage, fragment retrieval, and basket-associated complications.[1] This article analyzes a case series about laser lithotripsy using high-frequency dusting, in particular, with frequencies higher than 50 Hz, using a high-power laser. Besides the description of the new lithotripter that allows this high-frequency lithotripsy, there are other features in this article that stand out.

Considering the average stone size of 12.5 mm, and the average operative time of 53 minutes reported in this article, one noticeable characteristic is that of the mean laser usage, which was only 5.2 kJ per case (mainly with dusting settings), which corresponds to only 5 minutes of laser lithotripsy time. It is a considerable achievement, being able to ablate that average stone size in such a short time, thus occupying only 10% of the surgical time with pure laser lithotripsy, leaving the remaining 90% of theater time for auxiliary surgical steps. Obviously, one must consider that this new technology might be indeed a breakthrough, shortening the average lithotripsy time substantially. This might also be related to the fact that this series was based on the work of a single and experienced high-volume surgeon. In addition, by scrutinizing the work of a single surgeon, the authors were able to exclude interuser variability bias, which further enhances the quality of this article.

Despite this excellent performance, the average stone-free rate (SFR) was only 67.4%, sometimes even as low as 39%, depending on the patient group. This could be considered a low value in comparison with other series.[2] However, the definition of SFR is very variable among articles: although the present article classified patients to be stone free only without any trace of residual fragments on CT, there are publications that even considered patients with residual fragments up to 3 mm to be stone free as well. Thus, the performance herein reported could be considered substantially better, depending on the definition.

As with any surgical procedure, some low-grade postoperative complications were reported, which were easily resolved, deeming this high-frequency dusting technique with this new laser, a safe technology. However, one must bear in mind that such high-power systems deliver much energy, in small enclosed spaces to the surrounding medium and in a very short period of time. Furthermore, recent evidence has emerged that even at low energy settings, very high temperatures are locally achieved, which might pose a danger to the patients' tissues, in particular with low irrigation.[3,4] Hence more attention must be paid whenever a high-power laser is used.

Considering the ever faster technological advances and increasing availability of newer and more powerful laser lithotripters, these and other issues will surely pose future challenges for us urologists. Therefore, what applies for kings, rulers, and other leaders also applies to us: "With greater power comes greater responsibility…"

References

1. Matlaga BR, Chew B, Eisner B, et al. Ureteroscopic laser lithotripsy: A review of dusting vs fragmentation with extraction. J Endourol 2018;32:1–6.
2. Santiago JE, Hollander AB, Soni SD, et al. To dust or not to dust: A systematic review of ureteroscopic laser lithotripsy techniques. Curr Urol Rep 2017;18:32.
3. Butticè S, Sener TE, Proietti S, et al. Temperature changes inside the kidney: What happens during holmium:yttrium-aluminium-garnet laser usage? J Endourol 2016;30:574–579.
4. Wollin DA, Carlos EC, Tom WR, et al. Effect of laser settings and irrigation rates on ureteral temperature during holmium laser lithotripsy, an in vitro model. J Endourol 2018;32:59–63.

Address correspondence to:
Peter Kronenberg, MD
Department of Urology
Hospital Prof. Doutor Fernando Fonseca
IC-19
Amadora 2720-276
Portugal

E-mail: peterkronenberg@gmail.com

[1]Department of Urology, Hospital Prof. Doutor Fernando Fonseca, Amadora, Portugal.
[2]PETRA UroGroup (Progress in Endourology, Technology and Research Association).
[3]Fellow of the European Board of Urology.

Article 7: Advances in Lasers for the Treatment of Stones – a Systematic Review

Current Urology Reports (2018) 19: 45
https://doi.org/10.1007/s11934-018-0807-y

ENDOUROLOGY (P MUCKSAVAGE, SECTION EDITOR)

Advances in Lasers for the Treatment of Stones—a Systematic Review

Peter Kronenberg[1] · Bhaskar Somani[2]

Published online: 17 May 2018

Abstract

Purpose of Review Laser lithotripsy is increasingly used worldwide and is a continuously evolving field with new and extensive research being published every year.

Recent Findings Variable pulse length Ho:YAG lithotripters allow new lithotripsy parameters to be manipulated, and there is an effort to integrate new technologies into lithotripters. Pulsed thulium lasers seem to be a viable alternative to holmium lasers. The performance of similar laser fibers varies from manufacturer to manufacturer. Special laser fibers and "cleaving only" fiber tip preparation can be beneficial for the lithotripsy procedure. Different laser settings and the surgical technique employed can have significant impact on the success of laser lithotripsy. When safely done, complications of laser lithotripsy are rare and concern the endoscopic nature of procedure, not the technology itself, making laser lithotripsy one of the safest tools in urology.

Summary Laser lithotripsy has had several new developments and more insight has been gained in recent years with many more advances expected in the future.

Keywords Laser lithotripsy · Endourology · Pulsed thulium lasers

Introduction

This year is the 50th birthday when lasers first made their debut in urology [1], as well as the 30th birthday when urinary laser lithotripsy began establishing itself as a method of urinary stone treatment [2, 3]. Similar to most technological advancements, laser lithotripsy has also advanced with ongoing new developments. We therefore review the latest advances in laser lithotripsy to keep up to date with them.

Material and Methods

A PubMed search was performed (December 2017) for papers including the terms "laser(s)" or "holmium" in association with any of the following terms "lithotripsy," "lithiasis," "stone(s)," "calculus," "calculi," "lithotripter(s)," "lithotrite(s)," "fiber(s)," "(endo)urology," (endo)urologic(al)," or "intrarenal" in their title and published between the years 2015 and 2017, as well as 2018, to include already accepted, but not yet published papers. Additionally, the medical sections of ScienceDirect, Wiley, SpringerLink, and Mary Ann Liebert publishers where also searched for abstract presentations published in that time frame that were not indexed on PubMed. Moreover, key papers and other important studies on the subject were also included and cross-referenced, if they were considered noteworthy, despite being published before 2015. The authors adhered to PRISMA guidelines for this review [4]. All relevant data was identified, selected, and has been summarized below.

This article is part of the Topical Collection on *Endourology*

✉ Bhaskar Somani
b.k.somani@soton.ac.uk

Peter Kronenberg
peterkronenberg@gmail.com

1 Hospital Prof. Doutor Fernando Fonseca, Amadora, Portugal
2 University Hospital Southampton NHS Trust, Southampton, UK

Bibliographic Search Results

The PubMed search returned 1255 articles. Most of these articles (845) relate to basic laser research not necessarily related to medicine. They include research of new laser media and fiber production, soliton and quantum research, down to communications, nanotubes, and random bit generators created with lasers, all of them published in journals specialized in the wide-raging field of optics, and hence indexed in PubMed. Other 108 articles relate to the use of lasers in non-urological medical specialties such as ophthalmology, gastroenterology, ENT, vascular and general surgery, interventional radiology, and pneumology, as well as dermatology. The other 302 articles relate to urology-related fields, of which 150 concern the use of lasers in a non-lithotripsy-related setting, such as HoLEP, Greenlight laser, or other laser ablative techniques. Finally, the last 152 articles relate to urological laser lithotripsy. More than half of these papers are about case series, single-surgeon series, and comparisons of laser lithotripsy to other lithotripsy methods or case reports.

The search in the medical sections of ScienceDirect, Wiley, SpringerLink, and Mary Ann Liebert returned 12,454 papers or abstract presentations, 759 of them related to urinary stone treatments, some of them already picked up in the PubMed search. All abstract presentations of the major urology congresses were also reviewed and included [5–16].

The relevant data of the publications and abstracts have been categorized into the following four main groups: laser lithotripters, laser fibers, laser settings and technique, and laser safety and related complications (Table 1).

Laser Lithotripters

Laser technology was foreseen in 1917 and has been available and developed for 60 years [1, 17–19]. Most of the (initial) lasers emitted their laser energy in a continuous mode which has not been shown to be suited for lithotripsy [20], besides producing heat that can be harmful. On the contrary, pulsed lasers, e.g., the holmium:yttrium–aluminum–garnet (Ho:YAG) or the frequency-doubled double-pulse neodymium:YAG (FREDDY) laser [21, 22], deliver their energy in packets (pulses) that are suddenly released and very efficient at stone lithotripsy. Nevertheless, there are anecdotal reports of using Greenlight lasers for lithotripsy [23]. The reason for this difference in lithotripsy capabilities between continuous and pulsed lasers can be explained using the electric drill machine analogy: while trying to drill a hole in a wall, a continuous rotating drill is less efficient in perforating that wall and also generates much heat; on the contrary, a similar powered impact or percussion drill machine is much faster and efficient and also produces lower levels of heat. These features, together with its excellent safety profile, established and made the Ho:YAG laser ideal for laser lithotripsy in the last 30 years [2, 24, 25, 26••].

Despite the launch of more powerful and high-frequency Ho:YAG lithotripters over the years [27], they still only allowed the urologist to manipulate two parameters: pulse energy and pulse frequency. It took more than 20 years for holmium laser lithotripters to get their first, true technological upgrade, i.e., the ability to change pulse length, aka pulse duration or pulse width [26••]. Standard Ho:YAG lithotripters were restricted to short pulse lengths, while the newer lithotripters, besides short pulse, were now also capable of doing long-pulse lithotripsy (Fig. 1). Although all other lithotripter parameters (pulse energy, pulse frequency, and consequently total energy delivered) remain unchanged, in short-pulse mode, the energy delivered by a single laser pulse occurs during a short period of time (approximately 300 μs), while in long-pulse mode, that same amount of energy is distributed over a longer period of time (approximately 600 μs or more) [26••]. Pulse length was shown to be inversely correlated with ablation volume, i.e., the shorter the pulse length, the more ablative is the setting. Extreme pulse length comparisons of ultra-short and long-pulse mode (150 vs 800 μs) showed an average 60.6% higher ablation volume difference favoring ultra-short-pulse mode [28]. Despite this apparent lower efficiency, long-pulse mode showed to produce less fiber tip degradation and stone retropulsion [26••, 29, 30, 31•]. However, there is still some controversy in the subject, with some authors considering long pulse to be as ablative as short pulse [32•], or studies showing short-pulse lithotripters producing less retropulsion than more powerful long-pulse lithotripters [33]. There is also the general belief that long pulse produces smaller residual fragments and promotes a more "dusting" technique.

Regardless of the Ho:YAG lithotripsy domination, thulium laser technology, known for its usefulness in prostate ablation using continuous laser emission, and consequently considered unsuited for lithotripsy, has evolved and is now capable of pulsed laser emission. Although its usefulness in lithotripsy was demonstrated back in 2005 [34], only recently has it gained more attention. It has shown to be 2- to 4-fold faster without any significant heat increase and also producing three times less retropulsion, sometimes none at all, in comparison to Ho:YAG lithotripsy [35–37, 38•]. Pulsed thulium lithotripsy looks promising; however, true clinical studies are still lacking.

There is a new technology developed for a high-power 120-W Ho:YAG lithotripter, called the Moses effect. The theory is that this lithotripsy mode emits a modulated laser pulse whose first part divides the water between laser fiber tip and the stone, allowing the second part of the pulse to hit the stone unobstructed, more efficiently and with less retropulsion. However, on a closer look at the official high-speed videos, it reveals to be made of two separate laser pulses with a short time interval between them, rather than a single "modulated" laser pulse. Surgical opinions and in vitro experiments have indeed shown that this Moses effect reduced retropulsion [39, 40] and is significantly more ablative; however, in vivo experiments did not show any significant differences in terms of lasing and procedural times between regular and Moses lithotripsy techniques [40].

Recently, a novel Ho:YAG laser lithotripsy mode has been developed: burst laser lithotripsy (Fig. 1). Each burst consists of three individual laser pulses, the first one being the more energy intense while the last one the least energy intense, having successive increasing pulse lengths and which are emitted in a rapid succession after one another [41•, 42, 43]. The novel burst mode is significantly more ablative, achieving 60% higher ablation volumes than standard lithotripsy at similar power and energy settings

Table 1 Summary of the advances or technical aspects of laser lithotripsy, its complications, and their prevention

	Advancement or technical aspect	Benefit	Verdict
Laser lithotripters	Long pulse length (pulse duration or pulse width)	• Less fiber tip degradation • Less stone retropulsion • Smaller residual fragments • Ideal for "dusting"	Gradual rise in its use
	Moses effect (modulated laser pulse)	• More ablative (in vitro) • Less retropulsion	• No significant difference between lasing and procedural time in vivo • Limited availability (one manufacturer) • Costly
	Burst laser lithotripsy	• Greater ablation volume	• Likely to be used more often • Limited availability (one manufacturer)
	Thulium laser (pulsed)	• More ablative than Ho:YAG • Less retropulsion	• New technology • Very limited availability • Lack of clinical studies
Laser fibers	Ball tip fiber	• Easier insertion in deflected scope	• Initial benefit lost after a few seconds with degradation
	Tip cleaving tools	• All were equivalent	• Simple scissors are equally effective
	Leaving fibers coated	• Greater stone ablation • Easier to pass in the scope • Safer than stripped fiber	• More advantageous than stripped fibers in several categories
	Stripping of fibers	• Debatable higher stone ablation	• Significantly less advantages than coated fibers
Laser settings and technique	Fragmentation technique	• Faster ablation of primary stone	• Excellent for bladder or PCNL
	Dusting technique	• No fragments (dust) • No basketing • Decreased ureteral access sheath use	• Ablation itself takes more time, compensated by other time gains • Ultra-high-frequency lithotripters further shorten surgical time
	Pop-corning	• Ideal for multiple smaller stone fragments in an enclosed space Avoids endless chase of fragments	Helpful technique, complementing other lithotripsy methods
	Pop-dusting	• Similar to pop-corning, but creating more dust	• Helpful technique, complementing other lithotripsy methods
	Complication	*Prevention*	
Laser safety and related complications	Fever, subcapsular hematoma	• Reduce operative time • Use low-pressure ureterorenoscopy Confirm negative urine culture	
	Local thermal damage	• Never close irrigation • Intermittent laser use • Cooled irrigation if necessary	
	Eye damage	• Use eye glasses (simple ones will do) • Avoid laser fibers near eyes	
	Collateral instrument damage	• Keep fibers coated for better identification and regularly cleave them • Respect the safety distance between scope and laser fiber tip • Avoid passage of fibers through deflected scopes or else use BT fiber or at least a coated fiber	

[41•]. Possibly, the synchronized continuous variation of pulse energy and pulse length of high-frequency burst pulses, throughout the same lithotripter setting, might improve and speed up laser lithotripsy procedures in the future.

There have been also some efforts to incorporate useful auxiliary technologies into laser lithotripters. These include real-time stone/tissue differentiation using autofluorescence preventing the laser from firing against any structure other than the stone surface [44], or the attempt of in vivo analysis of urinary stone composition [45]. Some manufacturers are also trying to make carefully designed user interfaces, because most lithotripters are not as user friendly [46•].

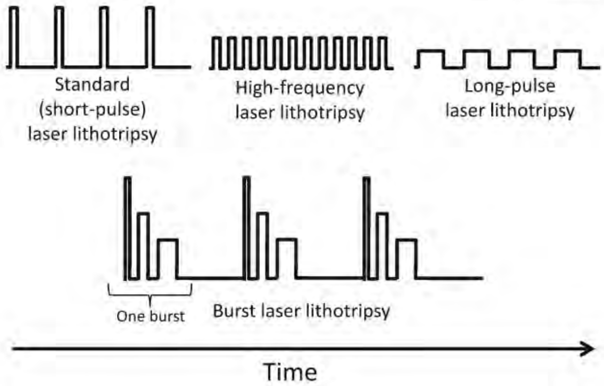


Fig. 1 Graphic representation of differences between standard (short-pulse) laser lithotripsy, high-frequency laser lithotripsy, long-pulse laser lithotripsy, and burst laser lithotripsy over time

Laser Fibers

Besides the lithotripter, the laser fiber used also plays a vital role in the lithotripsy procedure. It is already known that larger laser fibers hinder the flow of irrigation fluid, limit the flexibility of instruments, and produce more retropulsion as well as larger stone fragments [26••, 47, 48•, 49, 50]; hence, the urologists prefer for small-diameter laser fibers, especially in flexible ureterorenoscopy. Additionally, there is emerging evidence about significant performance differences (e.g., on flexibility, degradation, ablation capabilities) among laser fiber manufacturers and no single fiber seems to be an ideal performer in every situation [51••, 52••] corroborating older studies on the subject [53•]. These performance differences should also be considered together with the manufacturers' misinformation and mislabeling issues about laser fiber diameters, which were discussed not so long ago and these issues are far from being settled [48•, 54]. Even small-diameter changes can have a critical impact, because they indirectly affect accessibility, visibility, efficiency, total surgical time, and the lithotripsy procedure as a whole [48•]. On the other hand, pulsed thulium lasers are able to use smaller diameter laser fibers, than the ones used with the Ho:YAG lasers, representing a clear advantage and affecting favorably on the abovementioned aspects [55].

Lately, much attention has been given to ball-shaped tip (BT) laser fibers. BT laser fibers are particularly interesting because of their reduced insertion force in a completely deflected working channel without damaging it [56]. However, those features are lost as soon as laser emission occurs, because of the laser fiber tip degradation, the so called "burn-back" effect. Hence, most of these BT fibers should be only used once for a single, deflected working channel passage and at the very beginning of the surgery, because after several seconds of laser emission, they exhibit exactly the same characteristics as standard laser fibers [57]. Additionally, no better ablation properties where found on these special (and more costly) designed fiber tips in comparison to single-use standard fibers [56, 57]. Regarding reusable fibers, they show exactly the same tip morphology and degradation as new single-use standard fibers, as well as similar performances as long as they are not damaged along their length or at the connector. Although reusable fibers are more expensive than standard single-use fibers, they decrease fiber costs after the third and subsequent uses [57]. Yet other authors have shown that the use of single-use laser fibers can help decrease the overall cost of flexible ureterorenoscopy [58].

Still, laser fiber degradation, fiber fracture with smaller bend diameters or burn-back at its tip, affects every fiber, regardless of its shape or type (single-use or reusable fibers). It has been demonstrated that higher pulse energies, shorter pulse lengths, or harder stone material are more detrimental to laser fibers, in particular to their tips [26••, 29, 59•]. But there are also some conflicting results from other authors claiming that there is a trend for less fiber fracture with higher pulse energies [52••].

Related to these degradation issues is laser fiber tip preparation. This old, but still current practice of laser fiber preparation can be done before and during the procedure (to "renew" the fiber tip) and consists of stripping off the terminal portion of the plastic fiber coating and then cleaving several millimeters off the end of the glassy fiber components using special instruments (e.g., laser fiber stripper, ceramic scissors) [60–62, 63••]. One publication compared several cleaving methods, demonstrating that the "scribe pen" cleaving tool produced the highest average power output. However, these measurements were done without any laser emission, thus without considering any degradation issues over time [64]. Another paper analyzed the influence of stripping and cleaving methods of laser fibers on lithotripsy performance. The authors concluded that coated fibers outperformed stripped fibers; were not exposed to possible initial cladding damage caused by stripping; prevented damage caused by tip cleavage; and avoided cladding or other silica components to break off during lithotripsy as well as being more visible during the treatment. They also concluded that simple cleaving methods such as using a metallic surgical scissor were as good as more costly methods, as long as the fibers remain coated [63••]. Some of these results favoring coated fibers have been confirmed by other researchers [65]. Another advantage of keeping the fibers coated is that most of these fibers are able to pass through all angles of deflections in most scopes, while stripped fibers cannot without being harmful to the scopes' working channel [66]. However, there is also evidence that initial advantages of certain cleaving methods over another level themselves out and the fibers become quite similar in performance in the first minutes of lithotripsy, because of equal, short-term fiber degradation [65, 67, 68•]. However, even over this topic, there is controversy among researchers, with some advocating against routine cleaving [67], others endorsing fiber tip preparation and renewal after 15 min or 10,000 J of laser emission, which is also important for reusable fibers [63••, 68•, 69], while still others claim that stripped fibers achieve greater stone ablation [65].

There are also other developments that can change the laser fiber as we know it. One of them is a miniaturized integrated thulium laser fiber and a stone basket. This device may minimize stone retropulsion, increase scope flexibility, allow higher saline irrigation rates through the working channel, reduce material degradation compared with separate fiber and basket manipulation, and reduce laser-induced nitinol wire damage [70]. The other is a more peculiar development: a fiber optic muzzle brake tip made of stainless steel to apply on thulium laser fibers. Similar to muzzle brakes used in rifles and artillery canons to reduce recoil and redirect propellant gases sideways, this laser fiber muzzle brake not only reduces stone retropulsion by 85%, but also provides minimal fiber degradation and an efficient stone ablation [71].

Laser Settings and Technique

Most experts agree that fragmentation settings with higher pulse energies (> 0.5 J) and shorter pulse lengths have advantages, because they speed up the process of breaking up a large stone into smaller pieces. This can be speedy and useful in the bladder or in kidney stones with a large caliber percutaneous approach. However in ureterorenoscopy, this technique may also turn a single large problem into multiple, more time-consuming smaller problems. This is the reason why many urologists prefer to use a "dusting" technique [72–74]. Although dusting settings with low pulse energies (0.2–0.5 J), higher frequencies, and preferably longer pulse lengths ablate less stone material per unit time, it has several advantages: it decreases the use of ureteral access sheaths and therefore reduces potential ureteral trauma [75••, 76]; basket-associated complications are reduced because dust is naturally eliminated [73]; in the long run, it even reduces operative time by 20–40% by avoiding lengthy extraction procedures [73, 75••, 76]. Besides using low pulse energies for dusting, some authors also recommend keeping the laser fiber slightly away from the stone to "defocus" it and produce smaller fragments [75••]. With the recent arrival of high-powered high-frequency long-pulse Ho:YAG lithotripters, ultra-high pulse frequencies are available (up to 80 Hz), further speeding up the dusting lithotripsy procedure [77–79]. Despite all this evidence, according to an international survey, most urologists still use lithotripter settings around 10 Hz and 0.8 J [80]. However, it must also be acknowledged that if the dust does not evacuate spontaneously, stone-free rates in patients can be lower and this increases the risk of future stone-related events [75••, 81].

All the aforementioned settings and modalities relate to contact lithotripsy, which constitutes the first (and usually the only) stage of the lithotripsy procedure. However, when numerous smaller fragments result, which are still big enough to need treatment, but too time-consuming to chase individually, a second stage (completion) non-contact lithotripsy can be performed. The aim of non-contact lithotripsy is to pulverize these fragments and allow their spontaneous passage [82], preferably in a smaller and enclosed space such as a calix to increase the efficiency [83]. Two different techniques can be employed. One is the "pop-corn" technique, whose optimal settings have been confirmed by using a higher pulse energy (≈ 1.5 J), usually associated with a high-frequency (20–40 Hz), long-pulse mode, as well as a small-diameter laser fiber, and taking as much time as possible to produce clinically insignificant fragments [84•]. The other one is the "pop-dusting" technique, quite similar to the pop-corn technique but using a lower pulse energy (0.5 J), resulting in finer fragments without compromising fiber tip burn-back [82].

However, fragment size may not only be related to laser lithotripter settings, but also on the surgical technique employed, i.e., how the surgeon approaches the stone with the laser, i.e., "perforating," "chipping," "cutting into pieces" vs working uniformly and tangentially on the surface, by "dancing" or "painting" the stone with the laser and taking care not to break off large fragments from the main stone [26••, 75••, 85, 86]. Thus, even the best dusting setting, when used improperly, can produce large stone fragments.

Concerning settings and technique, it is the authors' opinion that one should use lower pulse energy levels, with long pulse length (thus achieving smaller residual fragments and minimizing retropulsion, as well as reducing laser fiber degradation), and very high frequencies as technically possible to "go faster" and speed up the procedure. The laser fiber should be moved uniformly over the stone, without chipping or fragmenting the stone. The surgeon should be aware of the resulting fragment size, and if necessary adjust the settings, or even use a pop-corn technique to finish the procedure.

Laser Safety and Related Complications

Ho:YAG laser lithotripsy is an efficient and safe technology for the treatment of urinary stones in almost any patient group, ranging from young children to adults and older patients, pregnant women to spinal cord injury patients, from solitary to allograft kidneys, or patients on certain medications and anticoagulants. Its safety profile has been largely demonstrated and still is in countless and recent safety-oriented studies [87•, 88•, 89, 90•, 91–98, 99•, 100, 101•]. Yet there are still some direct and indirect complications and safety concerns about laser lithotripsy, which have been recently researched.

The most frequent complication in laser lithotripsy is fever [102]. Renal backflow and infected urine fluid reabsorption can be one of the causes, and curiously retrograde intrarenal surgery (RIRS) has higher total fluid absorption than percutaneous nephrolithotomy (PCNL) procedures [103], which makes sense considering the enclosed space in RIRS. The presence of a preoperative stent, obstructive pyelonephritis, a positive preoperative bladder urine culture result, female gender, increased stone size, or lengthy operating time are significantly associated with postoperative fever and risk of sepsis [104, 105]. Spinal cord injury or patients with severe motor disabilities are in particular risk of sepsis (27%) after laser lithotripsy [106].

Bleeding is also a concern and several cases of renal subcapsular hematomas have been reported with Ho:YAG laser lithotripsy [102, 107, 108]. Yet it is questionable that these infections or bleeding complications were exclusively related to the Ho:YAG technology itself, because they are also known to occur in ureterorenoscopy without the use of laser lithotripsy [109]. On the other hand, one should bear in mind that there are at least three reported mortalities resulting from ureteral perforation and retroperitoneal bleeding using the Ho:YAG laser, although it is not specified if it was during a lithotripsy or endoureterotomy procedure [110]. In any case, the risk of subcapsular hematoma can be reduced by avoiding prolonged endoscopy and performing ureterorenoscopy under low pressure [111, 112], and the importance of always having a negative urine culture before any RIRS cannot be overemphasized.

Lately, attention has been given to local temperature rise at the site of laser lithotripsy, i.e., in the ureter or the kidney. Multiple authors and papers have confirmed that holmium laser emission in long bursts, even at lower power settings, does indeed rise fluid temperatures (up to 70 °C or more), particularly when irrigation is closed, potentially causing tissue injury [113•, 114•, 115•]. Since thulium laser has comparable absorption properties in water, it also shows similar temperature rises as the Ho:YAG laser [116, 117]. Considering that only 4.18 J of energy is needed to rise the temperature of 1 mL of water by 1 °C [118], and that holmium laser energy is highly absorbed by water, it comes as no surprise, that even with modest lithotripter settings providing dozens of Joules per second to a few milliliters of water enclosed in a very small space (e.g., a segment of the ureter or a renal calyx), the temperature is able to rise considerably and literally cook the surrounding tissues. Therefore, an endourologist should be aware of the risk of temperature rise during laser emission and implement a variety of techniques (higher irrigation flow rates, intermittent laser activation, and potentially cooled irrigation fluid) to control and mitigate thermal effects during laser lithotripsy and avoid unnecessary damage of the surrounding tissues [113•, 114•, 119].

In summary, considering the aforementioned issues, and with very few exceptions, patient-related safety and complications are probably less dependent on the laser technology itself, but dependent on multiple other factors relating to the procedure, e.g., the surgeon's skill, the use of ureteral access sheaths, basketing instead of dusting, good intraoperative visibility, and operative time [63••, 73, 75••, 110].

But laser safety is not only about patient-related problems, but also concerns the safety of urologists and other staff in the operating room (OR). Eye injury is one of the main concerns when lasers are used; however, it was demonstrated that Ho:YAG lasers can only cause damage when all the following three conditions are met: high-energy laser settings, at very close distances (0–5 cm), and with no eye protection. Simple eyeglasses are equally effective in preventing laser damage as special laser safety glasses, and should an eye burn still occur, it would be restricted to the cornea [120••]. Not surprisingly, no eye injuries were reported so far with the use of Ho:YAG lasers [110]. Considering all reported adverse events with Ho:YAG lasers, if there is harm, it is to the patient or the surgeon (minor skin burns for the latter), but never to non-medical operators [110].

Radiation exposure for the patient as for the surgeon is a familiar problem in laser lithotripsy. Studies have confirmed the positive correlation between stone burden and radiation exposure during laser lithotripsy. Hence, clinicians should consider strategies to reduce the total radiation exposure, such as using pulsed instead of continuous fluoroscopy [121], although there are even defenders of using no fluoroscopy at all [122].

Material-related safety is also an issue, because laser energy can be harmful to other instruments, in particular to the delicate scopes used in endourology. To prevent accidental material damage, several strategies are recommended: to keep the laser fiber tip coated for better identification and to know its whereabouts [63••] and at a reasonable safety distance from the optical end of the scope (approximately one fourth of the endoscope field of view) [123••]; to regularly cleave the fiber tip to prevent back burns and retrograde laser emission [69]; to avoid passing a laser fiber through a deflected ureterorenoscope, and if inevitable, it is better to opt for an unused BT fiber or a recently cleaved and coated (not stripped) laser fiber [57, 124]; to avoid narrowed scope deflections with active laser fibers, and if inevitable, to change to smaller core fibers since they are less likely to fracture [59•]; and to avoid laser emission adjacent to auxiliary instrument components such as guidewires or basket tip parts since they are susceptible to breakages [125, 126].

Conclusions

After 20 years of few technological developments, with the arrival of variable pulse length Ho:YAG lithotripters, new lithotripsy parameters can be manipulated to their advantage by the endourologist. There is an effort to integrate new lithotripsy modes and helpful technologies into lithotripters, including the use of pulsed thulium lasers instead of the Ho:YAG. Laser fibers from several manufactures perform significantly differently from one another and BT laser fibers have some short-lived advantages that can also be obtained with standard laser fibers. Laser fiber stripping is always detrimental for their performance and fiber cleavage can be done securely with simple metallic scissors. There are several settings for contact and non-contact laser lithotripsy, each with their own advantages and disadvantages, but the importance of the procedural movements of the laser fiber by the surgeon to deliver the laser energy to the stone should not be neglected. There are some reported complications with laser lithotripsy, but most of them are procedure-related and not with the laser technology itself. The remaining few safety issues can be prudently avoided, making laser lithotripters one of the safest instruments urologists can use in any patient group.

Compliance with Ethical Standards

Conflict of Interest Peter Kronenberg and Bhaskar Somani each declares no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Parsons RL, Campbell JL, Thomley MW. Carcinoma of the penis treated by the ruby laser. J Urol. 1968;100(1):38–9.
2. Coptcoat MJ, Ison KT, Watson G, Wickham JE. Lasertripsy for ureteric stones in 120 cases: lessons learned. Br J Urol. 1988;61(6):487–9.
3. Hofmann R, Hartung R. Use of pulsed Nd:YAG laser in the ureter. Urol Clin North Am. 1988;15(3):369–75.
4. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097.
5. EAU15 – 30th Annual Congress of the European Association of Urology Abstracts. Eur Urol Suppl. 2015;14(2):e1-eV77.
6. EAU16 – 31st Annual Congress of the European Association of Urology Abstracts. Eur Urol Suppl. 2016;15(3):e1-eV79.
7. Abstracts EAU17 – 32nd Annual EAU Congress. Eur Urol Suppl. 2017;16(3):e1-e2160.
8. 2015 Annual Meeting Program Abstracts. J Urol. 2015; 193(4): e1-e1118.
9. 2016 Annual Meeting Program Abstracts. J Urol. 2016;195(4):e1-e1192.
10. 2017 Annual Meeting Program Abstracts. J Urol. 2017;197(4):1–1376.
11. SIU 2015 Abstracts. World J Urol 2015;33(Suppl 1):1–256. https://doi.org/10.1007/s00345-015-1684-3.
12. Abstract SIU 2016 Buenos Aires, Argentina book. World J Urol. 2016; 34(Suppl 1):1–248. https://doi.org/10.1007/s00345-016-1931-2.
13. Abstracts from the 37th Congress of the Société Internationale d'Urologie, Centro de Congressos de Lisboa, October 19-22, 2017. World J Urol. 2017;35(Suppl 1):1–360. https://doi.org/10.1007/s00345-017-2090-9.
14. Scientific Program of 33rd World Congress of Endourology & SWL Program Book. J Endourol. 2015;29(Suppl 1):P1-A457. https://doi.org/10.1089/end.2015.29003.abstracts.
15. Scientific Program of 34th World Congress of Endourology & SWL Program Book and Abstracts. J Endourol. 2016;30(S2):P1-A464. https://doi.org/10.1089/end.2016.29020.abstracts.
16. Scientific Program of 35th World Congress of Endourology Program Book and Abstracts. J Endourol. 2017;31(S2):P1-A474. https://doi.org/10.1089/end.2017.29029.abstracts.
17. Einstein A. Zur Quantentheorie der Strahlung. Phys Z. 1917;18:121–8.
18. Schawlow AL, Townes CH. Infrared and optical masers. Phys Rev. 1958;112(6):1940–9. https://doi.org/10.1103/PhysRev.112.1940.
19. Maiman TH. Stimulated optical radiation in ruby. Nature. 1960;187(4736):493–4. https://doi.org/10.1038/187493a0.
20. Pal D, Ghosh A, Sen R, Pal A. Continuous-wave and quasi-continuous wave thulium-doped all-fiber laser: implementation on kidney stone fragmentations. Appl Opt. 2016;55(23):6151–5. https://doi.org/10.1364/AO.55.006151.
21. Zörcher T, Hochberger J, Schrott KM, Kühn R, Schafhauser W. In vitro study concerning the efficiency of the frequency-doubled double-pulse neodymium:YAG laser (FREDDY) for lithotripsy of calculi in the urinary tract. Lasers Surg Med. 1999;25(1):38–42.
22. Banús Gassol JM. Física del láser. Arch Esp Urol. 2008;61(9):961–4.
23. Ow D, Bolton D, Lawrentschuk N, VID.38. Photovaporization of calculi as an alternative approach for vesical urolithiasis. World J Urol. 2015;33(Suppl 1):102–256. https://doi.org/10.1007/s00345-015-1684-3.
24. Floratos DL, de la Rosette JJ. Lasers in urology. BJU Int. 1999;84(2):204–11.
25. Vicente Rodríguez JJ, Fernández González I, Hernández Fernández C, Santos García-Vaquero I, Rosales Bordes A. Láser en Urología. Actas Urol Esp. 2006;30:879–95.

26.•• Kronenberg P, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol. 2015;33(4): 463–9. https://doi.org/10.1007/s00345-014-1395-1. **One of the best reviews on Ho:YAG laser lithotripsy, with a wide-ranging insight into this topic.**
27. Lumenis. VersaPulse PowerSuite Brochure; PB-1106750 Rev. B; 2013 [cited 2014 Jun 19]. Available from: URL:http://www.surgical.lumenis.com/pdf/PB-1106750_rB_VPPS_P20v_br_LowRes%20(1).pdf.
28. Kronenberg P, Traxer O. PI-05 ultra-short, short, medium and long-pulse laser lithotripsy performance. J Urol. 2016;195(4, Supplement):e410. https://doi.org/10.1016/j.juro.2016.02.1210.
29. Wollin DA, Ackerman A, Yang C, Chen T, Simmons WN, Preminger GM, et al. Variable pulse duration from a new holmium: YAG laser: the effect on stone comminution, fiber tip degradation, and retropulsion in a dusting model. Urology. 2017;103: 47–51. https://doi.org/10.1016/j.urology.2017.01.007.
30. Bell JR, Penniston KL, Nakada SY. In vitro comparison of holmium lasers: evidence for shorter fragmentation time and decreased retropulsion using a modern variable-pulse laser. Urology. 2017;107:37–42. https://doi.org/10.1016/j.urology.2017.06.018.
31.• Sroka R, Pongratz T, Scheib G, Khoder W, Stief CG, Herrmann T, et al. Impact of pulse duration on Ho: YAG laser lithotripsy: treatment aspects on the single-pulse level. World J Urol. 2015;33(4): 479–85. https://doi.org/10.1007/s00345-015-1504-9. **One of the two articles demonstrating the benefits of long-pulse lithotripsy.**
32.• Bader MJ, Pongratz T, Khoder W, Stief CG, Herrmann T, Nagele U, et al. Impact of pulse duration on Ho: YAG laser lithotripsy: fragmentation and dusting performance. World J Urol. 2015;33(4):471–7. https://doi.org/10.1007/s00345-014-1429-8. **The second of the two articles demonstrating the benefits of long-pulse lithotripsy.**
33. Bell JR, Penniston KL, Nakada SY. In vitro comparison of stone fragmentation when using various settings with modern variable pulse holmium lasers. J Endourol. 2017;31(10):1067–72. https://doi.org/10.1089/end.2017.0351.
34. Fried NM. Thulium fiber laser lithotripsy: an in vitro analysis of stone fragmentation using a modulated 110-watt thulium fiber laser at 1.94 microm. Lasers Surg Med. 2005;37(1):53–8. https://doi.org/10.1002/lsm.20196.
35. Platonova DV, Zamyatina VA, Dymov AM, Kovalenko AA, Vinarov AZ, Minaev VP. Laser lithotripsy. Urologiia (Moscow, Russia : 1999). 2015;(6):116–21.
36. Kamal W, Kallidonis P, Koukiou G, Amanatides L, Panagopoulos V, Ntasiotis P, et al. Stone retropulsion with Ho: YAG and Tm: YAG lasers: a clinical practice-oriented experimental study. J Endourol. 2016;30(11):1145–9. https://doi.org/10.1089/end.2016.0212.
37. Dymov A, Glybochko P, Alyaev Y, Vinarov A, Altshuler G, Zamyatina V, et al. V11-11 thulium lithotripsy: from experiment to clinical practice. J Urol. 2017;197((4):e1285. https://doi.org/10.1016/j.juro.2017.02.3000.
38.• Glybochko P, Altshuler G, Vinarov A, Rapoport L, Enikeev M, Grigoriev N, et al. 226 Comparison between the possibilities of holmium and thulium laser in lithotripsy in vitro. Eur Urol Suppl. 2017;16(3):e391–2. https://doi.org/10.1016/S1569-9056(17)30292-0. **Although it is a simple abstract presentation, it demonstrates pulsed thulium lasers as promising and viable alternative to the standard Ho:YAG lasers for lithotripsy.**
39. Mullerad M, Aguinaga JRA, Aro T, Kastin A, Goldin O, Kravtsov A, et al. Initial clinical experience with a modulated holmium laser pulse-Moses technology: does it enhance laser lithotripsy efficacy? Rambam Maimonides Med J. 2017;8(4):e0038. https://doi.org/10.5041/RMMJ.10315.
40. Elhilali MM, Badaan S, Ibrahim A, Andonian S. Use of the Moses technology to improve holmium laser lithotripsy outcomes: a preclinical study. J Endourol. 2017;31(6):598–604. https://doi.org/10.1089/end.2017.0050.
41.• Kronenberg P, Traxer O. MP22-13 burst laser lithotripsy—a novel lithotripsy mode. J Urol. 2016;195(4, Supplement):e258. https://doi.org/10.1016/j.juro.2016.02.701. **Sole publication that analyzed the promising burst laser lithotripsy mode in the single-laser lithotripter capable of doing it.**
42. Kronenberg P, Traxer O. Lithotripsie par laser en salves: Un nouveau mode de lithotripsie. Prog Urol. 2016;26(13):697–8. https://doi.org/10.1016/j.purol.2016.07.059.
43. CoolTouch - Syneron Candela. StoneLight 30 brochure: laser therapy. 2016.
44. Lange B, Jocham D, Brinkmann R, Cordes J. Stone/tissue differentiation for holmium laser lithotripsy using autofluorescence: clinical proof of concept study. Lasers Surg Med. 2017;49(4): 361–5. https://doi.org/10.1002/lsm.22611.
45. Miernik A, Eilers Y, Nuese C, Bolwien C, Lambrecht A, Hesse A, et al. Is in vivo analysis of urinary stone composition feasible? Evaluation of an experimental setup of a Raman system coupled to commercial lithotripsy laser fibers. World J Urol. 2015;33(10): 1593–9. https://doi.org/10.1007/s00345-014-1477-0.
46.• Dragos LB, Proietti S, Buttice S, Sener E, Tefik T, Emiliani E, et al. 82 - Lasers in flexible ureterorenoscopy. Are they user friendly enough? Eur Urol Suppl. 2016;15(11):e1449–50. https://doi.org/10.1016/S1569-9056(16)30285-8. **Unique paper about the much neglected aspect of user-friendliness of equipment used by urologists.**
47. Kronenberg P, Traxer O. V1718 laser fibers, pulse energy and retropulsion—what we can see and what we can't. J Urol. 2013;189((4):e707.
48.• Kronenberg P, Traxer O. The truth about laser fiber diameters. Urology. 2014;84(6):1301–7. https://doi.org/10.1016/j.urology.2014.08.017. **Although it is an older paper, it clearly reveals the misinformation among laser fiber and medical device manufacturers that, unfortunately, still prevails today.**
49. Pasqui F, Dubosq F, Tchala K, Tligui M, Gattegno B, Thibault P, et al. Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. Eur Urol. 2004;45(1):58–64.
50. Spore SS, Teichman JM, Corbin NS, Champion PC, Williamson EA, Glickman RD. Holmium: YAG lithotripsy: optimal power settings. J Endourol. 1999;13(8):559–66.
51.•• Akar EC, Knudsen BE. Evaluation of 16 new holmium:yttrium-aluminum-garnet laser optical fibers for ureteroscopy. Urology. 2015;86(2):230–5. https://doi.org/10.1016/j.urology.2015.04.017. **One of the two key papers on the variability of laser fiber performance of different manufacturers.**
52.•• Lusch A, Heidari E, Okhunov Z, Osann K, Landman J. Evaluation of contemporary holmium laser fibers for performance characteristics. J Endourol. 2016;30(5):567–73. https://doi.org/10.1089/end.2015.0600. **The second key paper on the variability of laser fiber performance of different manufacturers.**
53.• Mues AC, Teichman JMH, Knudsen BE. Evaluation of 24 holmium:YAG laser optical fibers for flexible ureteroscopy. J Urol. 2009;182(1):348–54. https://doi.org/10.1016/j.juro.2009.02.112. **Another older paper laying bare the variability among laser fiber manufacturers.**
54. European Association of Urology. Information conveyed to urologists regarding laser fiber diameter is incorrect. ScienceDaily 2013 Sep 17 [cited 2014 Jul 17]. Available from: URL:http://www.sciencedaily.com/releases/2013/09/130917124821.htm.
55. Wilson CR, Hardy LA, Kennedy JD, Irby PB, Fried NM. Miniature ball-tip optical fibers for use in thulium fiber laser

ablation of kidney stones. J Biomed Opt. 2016;21(1):18003. https://doi.org/10.1117/1.JBO.21.1.018003.

56. Shin RH, Lautz JM, Cabrera FJ, Shami CJ, Goldsmith ZG, Kuntz NJ, et al. Evaluation of novel ball-tip holmium laser Fiber: impact on ureteroscope performance and fragmentation efficiency. J Endourol. 2016;30(2):189–94. https://doi.org/10.1089/end.2015.0300.

57. Kronenberg P, Traxer O. Lithotripsy performance of specially designed laser fiber tips. J Urol. 2016;195(5):1606–12. https://doi.org/10.1016/j.juro.2015.10.135.

58. Chapman RA, Somani BK, Robertson A, Healy S, Kata SG. Decreasing cost of flexible ureterorenoscopy: single-use laser fiber cost analysis. Urology. 2014;83(5):1003–5. https://doi.org/10.1016/j.urology.2013.12.019.

59.• Haddad M, Emiliani E, Rouchausse Y, Coste F, Doizi S, Berthe L, et al. Impact of the curve diameter and laser settings on laser fiber fracture. J Endourol. 2017;31(9):918–21. https://doi.org/10.1089/end.2017.0006. **Important paper showing the relation between ureterorenoscope deflection and fiber fracture.**

60. Bagley DH, Das A. Endourologic use of the holmium laser. Teton NewMedia: Jackson; 2001.

61. Mues AC, Teichman JMH, Knudsen BE. Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol. 2009;23(9):1425–8. https://doi.org/10.1089/end.2009.0384.

62. Sung C, Singh H, Schwartz M, Mirabile G, Hruby GW, Ryan CD, et al. Evaluation of efficacy of novel optically activated digital endoscope protection system against laser energy damage. Urology. 2008;72(1):57–60. https://doi.org/10.1016/j.urology.2008.01.011.

63.•• Kronenberg P, Traxer O. Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol. 2015;193(3):1030–5. https://doi.org/10.1016/j.juro.2014.07.110. **Key paper with world-wide impact, showing that the long rooted habit of laser fiber stripping is detrimental for the fiber, its performance, and safety, as well as showing that metal scissors are as good as special tools to cleave laser fibers.**

64. Vassantachart JM, Lightfoot M, Yeo A, Maldonado J, Li R, Alsyouf M, et al. Laser fiber cleaving techniques: effects on tip morphology and power output. J Endourol. 2015;29(1):84–9. https://doi.org/10.1089/end.2014.0175.

65. Ritchie C, Yang P, Peplinski B, Keheila M, Cheriyan S, Abourbih S, et al. Jackets off: the impact of laser fiber stripping on power output and stone degradation. J Endourol. 2017;31(8):780–5. https://doi.org/10.1089/end.2017.0160.

66. Baghdadi M, Emiliani E, Talso M, Servián P, Barreiro A, Orosa A, et al. Comparison of laser fiber passage in ureteroscopic maximum deflection and their influence on deflection and irrigation: do we really need the ball tip concept? World J Urol. 2017;35(2):313–8. https://doi.org/10.1007/s00345-016-1873-8.

67. Peplinski B, Faaborg D, Miao E, Alsyouf M, Myklak K, Kelln W, et al. The effect of laser fiber cleave technique and lithotripsy time on power output. J Endourol. 2016;30(6):678–84. https://doi.org/10.1089/end.2015.0835.

68.• Haddad M, Emiliani E, Rouchausse Y, Coste F, Berthe L, Doizi S, et al. Impact of laser fiber tip cleavage on power output for ureteroscopy and stone treatment. World J Urol. 2017;35(11):1765–70. https://doi.org/10.1007/s00345-017-2053-1. **Another key paper further demystifying the importance of laser fiber stripping and cleaving.**

69. Haddad M, Emiliani E, Traxer O. Re: The effect of laser fiber cleave technique and lithotripsy time on power output. J Endourol. 2016; https://doi.org/10.1089/end.2016.0492.

70. Wilson CR, Hutchens TC, Hardy LA, Irby PB, Fried NM. A miniaturized, 1.9F integrated optical fiber and stone basket for use in thulium fiber laser lithotripsy. J Endourol. 2015;29(10):1110–4. https://doi.org/10.1089/end.2015.0124.

71. Hutchens TC, Gonzalez DA, Irby PB, Fried NM. Fiber optic muzzle brake tip for reducing fiber burnback and stone retropulsion during thulium fiber laser lithotripsy. J Biomed Opt. 2017;22(1):18001. https://doi.org/10.1117/1.JBO.22.1.018001.

72. Wu Z, Gao P, Feng C, Wang L, Mao S, Ding Q, et al. MP-04.10 flexible ureteroscopic stone dusting with holmium: YAG laser for treatment of renal stones. World J Urol. 2016;34(Suppl 1):19. https://doi.org/10.1007/s00345-016-1931-2.

73. Gamal W, Mamdouh A. MP28-04 flexible URS holmium laser stone dusting VS fragmentaion for 2 cm single renal stone. J Urol. 2015;193(4):e312–3. https://doi.org/10.1016/j.juro.2015.02.1227.

74. Singh A, Sabnis R, Ganpule A, Chhabra J, Desai M. MP-04.11 initial experience of using high power holmium laser for dusting of large bulk renal stones by RIRS. World J Urol. 2016;34(Suppl 1):20–248. https://doi.org/10.1007/s00345-016-1931-2.

75.•• Matlaga BR, Chew B, Eisner B, Humphreys M, Knudsen B, Krambeck A, et al. Ureteroscopic laser lithotripsy: a review of dusting vs fragmentation with extraction. J Endourol. 2017; https://doi.org/10.1089/end.2017.0641. **Key paper on dusting laser lithotripsy and its numerous advantages, as well as focusing on its technique.**

76. Santiago JE, Hollander AB, Soni SD, Link RE, Mayer WA. To dust or not to dust: a systematic review of ureteroscopic laser lithotripsy techniques. Curr Urol Rep. 2017;18(4):32. https://doi.org/10.1007/s11934-017-0677-8.

77. Tracey J, Gagin G, Morhardt D, Hollingsworth J, Ghani K. MP51-07 flexible ureteroscopy and laser lithotripsy for renal stones using 'pop-dusting': comparison of outcomes between traditional dusting settings versus ultra-high frequency settings. J Urol. 2016;195(4, Supplement):e683. https://doi.org/10.1016/j.juro.2016.02.462.

78. Tracey JM, Gagin G, Morhardt D, Hollingsworth JM, Ghani KR. Ureteroscopic high frequency dusting utilizing a 120-watt holmium laser. J Endourol. 2017; https://doi.org/10.1089/end.2017.0220.

79. Teichman JMH. Editorial comment on: In vitro comparison of stone fragmentation when using various settings with modern variable pulse holmium lasers by Bell et al. (from: Bell JR, Penniston KL, Nakada SY, J Endourol 2017;31:1067-1072). J Endourol. 2017;31(12):1345–6. https://doi.org/10.1089/end.2017.0711.

80. Bell J, Philip J, Rane A, Nakada SY. MP39-16 international holmium laser lithotripsy settings: an international survey of endourologists. J Endourol. 2016;30(S2):A336–464. https://doi.org/10.1089/end.2016.29020.abstracts.

81. Shah O, Chew B, Humphreys M, Sur R, Knudsen BE, Matlaga B, et al. MP46-13 dusting vs basketing during ureteroscopic lithotripsy—what is more efficacious? A multi-centre prospective trial from the EDGE Research Consortium. J Endourol. 2015;29(Suppl 1):A351. https://doi.org/10.1089/end.2015.29003.abstracts.

82. Aldoukhi AH, Roberts WW, Hall TL, Ghani KR. Holmium laser lithotripsy in the new stone age: dust or bust? Front Surg. 2017;4:57. https://doi.org/10.3389/fsurg.2017.00057.

83. Wollin D, Jiang R, Tom W, Radvak D, Simmons WN, Preminger G, et al. PD35-05 how do you like your popcorn? An evaluation of laser settings and location in the efficiency of the popcorn effect. J Urol. 2017;197(4, Supplement):e664. https://doi.org/10.1016/j.juro.2017.02.1541.

84.• Emiliani E, Talso M, Cho S-Y, Baghdadi M, Mahmoud S, Pinheiro H, et al. Optimal settings for the noncontact holmium: YAG stone fragmentation popcorn technique. J Urol. 2017;198(3):702–6. https://doi.org/10.1016/j.juro.2017.02.3371. **Important paper, testing and establishing objectively the best settings for the pop-corn technique.**

85. Al-Kandari AM, Desai M, Shokeir AA, Shoma AM, Smith AD. Difficult cases in endourology. London: Springer; 2013.
86. Hecht SL, Wolf JS Jr. Techniques for holmium laser lithotripsy of intrarenal calculi. Urology. 2013;81(2):442–5. https://doi.org/10.1016/j.urology.2012.11.021.
87.• Ishii H, Griffin S, Somani BK. Ureteroscopy for stone disease in the paediatric population: a systematic review. BJU Int. 2015;115(6):867–73. https://doi.org/10.1111/bju.12927. **One of the several key papers on the safety of ureterorenoscopy and laser lithotripsy for specific patient populations.**
88.• Ghosh A, Somani BK. Safety and feasibility of day case ureteroscopy and laser lithotripsy (URSL) in patients with a solitary kidney. Centr Eur J Urol. 2016;69(1):91–5. https://doi.org/10.5173/ceju.2016.709. **One of the several key papers on the safety of ureterorenoscopy and laser lithotripsy for specific patient populations.**
89. El-Nahas AR, Elshal AM, El-Tabey NA, El-Assmy AM, Shokeir AA. Percutaneous nephrolithotomy for staghorn stones: a randomised trial comparing high-power holmium laser versus ultrasonic lithotripsy. BJU Int. 2016;118(2):307–12. https://doi.org/10.1111/bju.13418.
90.• Ishii H, Aboumarzouk OM, Somani BK. Current status of ureteroscopy for stone disease in pregnancy. Urolithiasis. 2014;42(1):1–7. https://doi.org/10.1007/s00240-013-0635-y. **One of the several key papers on the safety of ureterorenoscopy and laser lithotripsy for specific patient populations.**
91. Aboulela W, ElSheemy MS, Shoukry AI, Shouman AM, Elshenoufy A, Daw K, et al. Transurethral holmium laser cystolithotripsy in children: single center experience. J Endourol. 2015;29(6):661–5. https://doi.org/10.1089/end.2014.0636.
92. Altay B, Erkurt B, Albayrak S. A review study to evaluate holmium:YAG laser lithotripsy with flexible ureteroscopy in patients on ongoing oral anticoagulant therapy. Lasers Med Sci. 2017;32(7):1615–9. https://doi.org/10.1007/s10103-017-2289-4.
93. Bujons A, Millán F, Centeno C, Emiliani E, Sánchez Martín F, Angerri O, et al. Mini-percutaneous nephrolithotomy with high-power holmium YAG laser in pediatric patients with staghorn and complex calculi. J Pediatr Urol. 2016;12(4):253.e1–5. https://doi.org/10.1016/j.jpurol.2016.04.027.
94. Ilic P, Djordjevic M, Kojovic V, Dzambasanovic S. Laser lithotripsy in the treatment of renal stones in children. A single-center experience. Ann Ital Chir. 2016;87:326–32.
95. Sevinc C, Balaban M, Ozkaptan O, Karadeniz T. Flexible ureterorenoscopy and laser lithotripsy for the treatment of allograft kidney lithiasis. Transplant Proc. 2015;47(6):1766–71. https://doi.org/10.1016/j.transproceed.2015.06.020.
96. Dołowy Ł, Krajewski W, Dembowski J, Zdrojowy R, Kołodziej A. The role of lasers in modern urology. Centr Eur J Urol. 2015;68(2):175–82. https://doi.org/10.5173/ceju.2015.537.
97. Abedi AR, Allameh F, Razzaghi MR, Fadavi B, Qashqai H, Najafi S, et al. The efficacy and safety of laser lithotripsy in pregnancy. J Lasers Med Sci. 2017;8(2):84–7. https://doi.org/10.15171/jlms.2017.15.
98. Tepeler A, Sninsky BC, Nakada SY. Flexible ureteroscopic laser lithotripsy for upper urinary tract stone disease in patients with spinal cord injury. Urolithiasis. 2015;43(6):501–5. https://doi.org/10.1007/s00240-015-0786-0.
99.• Prattley S, Cheng S, Voss J, Geraghty R, Jones P, Somani BK. Ureteroscopy and stone treatment in the elderly (≥70 years): prospective outcomes over 5-years with a review of literature. Int Braz J Urol. 2018; (In Press). **One of the several key papers on the safety of ureterorenoscopy and laser lithotripsy for specific patient populations.**
100. Yoshioka T, Otsuki H, Uehara S, Shimizu T, Murao W, Fujio K, et al. Effectiveness and safety of ureteroscopic holmium laser lithotripsy for upper urinary tract calculi in elderly patients. Acta Med Okayama. 2016;70(3):159–66. https://doi.org/10.18926/AMO/54414.
101.• Sharaf A, Amer T, Somani BK, Aboumarzouk OM. Ureteroscopy in patients with bleeding diatheses, anticoagulated, and on antiplatelet agents: a systematic review and meta-analysis of the literature. J Endourol. 2017;31(12):1217–25. https://doi.org/10.1089/end.2017.0253. **One of the several key papers on the safety of ureterorenoscopy and laser lithotripsy for specific patient populations.**
102. Zhang P, Hu W-L. Sudden onset of a huge subcapsular renal hematoma following minimally invasive ureteroscopic holmium laser lithotripsy: a case report. Exp Ther Med. 2015;10(1):335–7. https://doi.org/10.3892/etm.2015.2460.
103. Guzelburc V, Balasar M, Colakogullari M, Guven S, Kandemir A, Ozturk A, et al. Comparison of absorbed irrigation fluid volumes during retrograde intrarenal surgery and percutaneous nephrolithotomy for the treatment of kidney stones larger than 2 cm. SpringerPlus. 2016;5(1):1707. https://doi.org/10.1186/s40064-016-3383-y.
104. Uchida Y, Takazawa R, Kitayama S, Tsujii T. Predictive risk factors for systemic inflammatory response syndrome following ureteroscopic laser lithotripsy. Urolithiasis. 2017; https://doi.org/10.1007/s00240-017-1000-3.
105. Fan S, Gong B, Hao Z, Zhang L, Zhou J, Zhang Y, et al. Risk factors of infectious complications following flexible ureteroscope with a holmium laser: a retrospective study. Int J Clin Exp Med. 2015;8(7):11252–9.
106. Madec F-X, Suply E, Luyckx F, Nedelec M, Chowaniec Y, Branchereau J, et al. L'urétérorénoscopie souple avec fragmentation laser dans le traitement des calculs du haut appareil urinaire chez les patients atteints d'une maladie du système nerveux avec un handicap moteur sévère. Prog Urol. 2017;27(6):369–74. https://doi.org/10.1016/j.purol.2017.03.002.
107. Tao W, Cai CJ, Sun CY, Xue BX, Shan YX. Subcapsular renal hematoma after ureteroscopy with holmium:yttrium-aluminum-garnet laser lithotripsy. Lasers Med Sci. 2015;30(5):1527–32. https://doi.org/10.1007/s10103-015-1760-3.
108. Paiva MM, da Silva RD, Jaworski P, Kim FJ, Molina WR. Subcapsular hematoma after ureteroscopy and laser lithotripsy. Can J Urol. 2016;23(4):8385–7.
109. Chouhan JD, Zhao HH, Magee B, McNeil BK. Retroperitoneal hemorrhage after ureteroscopy without laser lithotripsy: an extreme example of an underreported event? Can J Urol. 2016;23(3):8324–8.
110. Althunayan AM, Elkoushy MA, Elhilali MM, Andonian S. Adverse events resulting from lasers used in urology. J Endourol. 2014;28(2):256–60. https://doi.org/10.1089/end.2013.0451.
111. Whitehurst LA, Somani BK. Perirenal hematoma after ureteroscopy: a systematic review. J Endourol. 2017;31(5):438–45. https://doi.org/10.1089/end.2016.0832.
112. Vaidyanathan S, Samsudin A, Singh G, Hughes PL, Soni BM, Selmi F. Large subcapsular hematoma following ureteroscopic laser lithotripsy of renal calculi in a spina bifida patient: lessons we learn. Int Med Case Rep J. 2016;9:253–9. https://doi.org/10.2147/IMCRJ.S99960.
113.• Aldoukhi AH, Ghani KR, Hall TL, Roberts WW. Thermal response to high-power holmium laser lithotripsy. J Endourol. 2017;31(12):1308–12. https://doi.org/10.1089/end.2017.0679. **One of the several scary papers about possible and significantly harmful temperature increases during laser lithotripsy.**
114.• Butticè S, Sener TE, Proietti S, Dragos L, Tefik T, Doizi S, et al. Temperature changes inside the kidney: what happens during holmium:yttrium-aluminium-garnet laser usage? J Endourol.

2016;30(5):574–9. https://doi.org/10.1089/end.2015.0747. **Paper alerting to the possible damages of rising temperature during endoscopic procedures.**

115.• Wollin DA, Carlos EC, Tom WR, Simmons WN, Preminger GM, Lipkin ME. Effect of laser settings and irrigation rates on ureteral temperature during holmium laser lithotripsy, an in vitro model. J Endourol. 2017; https://doi.org/10.1089/end.2017.0658. **One of the several scary papers about possible and significantly harmful temperature increases during laser lithotripsy.**

116. Lange BI, Brendel T, Hüttmann G. Temperature dependence of light absorption in water at holmium and thulium laser wavelengths. Appl Opt. 2002;41(27):5797–803. https://doi.org/10.1364/AO.41.005797.

117. Kallidonis P, Amanatides L, Panagopoulos V, Kyriazis I, Vrettos T, Fligou F, et al. Does the heat generation by the thulium:yttrium aluminum garnet laser in the irrigation fluid allow its use on the upper urinary tract? An experimental study. J Endourol. 2016;30(4):422–7. https://doi.org/10.1089/end.2015.0252.

118. Rossini FD. Excursion in chemical thermodynamics, from the past into the future. Pure Appl Chem. 1964;8(2):95–112. https://doi.org/10.1351/pac196408020095.

119. Gross AJ, Netsch C. Editorial comment on: Thermal response to high-power holmium laser lithotripsy by Aldoukhi et al. J Endourol. 2017;31(12):1313. https://doi.org/10.1089/end.2017.0809.

120.•• Villa L, Cloutier J, Compérat E, Kronemberg P, Charlotte F, Berthe L, et al. Do we really need to wear proper eye protection when using holmium:YAG laser during endourologic procedures? Results from an ex vivo animal model on pig eyes. J Endourol. 2016;30(3):332–7. https://doi.org/10.1089/end.2015.0232. **Paper analyzing and demystifying eye safety issues for the urologists during Ho:YAG laser lithotripsy.**

121. Hadjipavlou M, Lam V, Seth J, Anjum F, Sriprasad S. MP28-18 predicting radiation exposure in ureterorenoscopy and laser lithotripsy: an analysis of patient and stone characteristics. J Urol. 2015;193(4, Supplement):e317. https://doi.org/10.1016/j.juro.2015.02.1241.

122. Aboutaleb H. Fluoroscopy free flexible ureteroscopy with holmium: yttrium-aluminium-garnet laser lithotripsy for removal of renal calculi. Arab J Urol. 2016;14(2):123–30. https://doi.org/10.1016/j.aju.2016.04.004.

123.•• Talso M, Emiliani E, Haddad M, Berthe L, Baghdadi M, Montanari E, et al. Laser fiber and flexible ureterorenoscopy: the safety distance concept. J Endourol. 2016;30(12):1269–74. https://doi.org/10.1089/end.2016.0209. **Key paper analyzing important instrument-related safety issues during Ho:YAG laser lithotripsy.**

124. Emiliani E, Talso M, Traxer O. Re: Evaluation of novel ball-tip holmium laser fiber: impact on ureteroscope performance and fragmentation efficiency (from: Shin RH, Lautz JM, Cabrera FJ, et al. J Endourol 2016;30:189-194). J Endourol. 2017;31(6):618. https://doi.org/10.1089/end.2016.0208.

125. Bagbanci S. Holmium: yttrium aluminum garnet laser and guidewires: is there a durability difference among guidewires against laser energy? An in vitro experimental study. J Endourol. 2017;31(5):528–32. https://doi.org/10.1089/end.2016.0883.

126. Huang Z, Fu F, Zhong Z, Xu R, Zhang L, Deng G, et al. Zebra guidewire damage by holmium: YAG laser and management of removal. Int J Clin Exp Med. 2015;8(8):14251–3.

Article 8: Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy.

World Journal of Urology (2021) 39:1673–1682
https://doi.org/10.1007/s00345-020-03481-9

TOPIC PAPER

Consultation on kidney stones, Copenhagen 2019: aspects of intracorporeal lithotripsy in flexible ureterorenoscopy

Søren Kissow Lildal[1] · Kim Hovgaard Andreassen[2] · Joyce Baard[3] · Marianne Brehmer[4,5] · Matthew Bultitude[6] · Ylva Eriksson[4,5] · Khurshid R. Ghani[7] · Helene Jung[8] · Guido Kamphuis[3] · Peter Kronenberg[9] · Ben Turney[10] · Olivier Traxer[11] · Øyvind Ulvik[12] · Palle Jörn Sloth Osther[8]

Received: 22 August 2020 / Accepted: 1 October 2020 / Published online: 16 October 2020

Abstract

Purpose To summarize current knowledge on intracorporeal laser lithotripsy in flexible ureterorenoscopy (fURS), regarding basics of laser lithotripsy, technical aspects, stone clearance, lithotripsy strategies, laser technologies, endoscopes, and safety.

Methods A scoping review approach was applied to search literature in PubMed, EMBASE, and Web of Science. Consensus was reached through discussions at the Consultation on Kidney Stones held in September 2019 in Copenhagen, Denmark.

Results and conclusions Lasers are widely used for lithotripsy during fURS. The Holmium laser is still the predominant technology, and specific settings for dusting and fragmenting have evolved, which has expanded the role of fURS in stone management. Pulse modulation can increase stone ablation efficacy, possibly by minimizing stone retropulsion. Thulium fibre laser was recently introduced, and this technology may improve laser lithotripsy efficiency. Small fibres give better irrigation, accessibility, and efficiency. To achieve optimal results, laser settings should be adjusted for the individual stone. There is no consensus whether the fragmentation and basketing strategy is preferable to the dusting strategy for increasing stone-free rate. On the contrary, different stone scenarios call for different lithotripsy approaches. Furthermore, for large stone burdens, all laser settings and lithotripsy strategies must be applied to achieve optimal results. Technology for removing dust from the kidney should be in focus in future research and development. Safety concerns about fURS laser lithotripsy include high intrarenal pressures and temperatures, and measures to reduce both those aspects must be taken to avoid complications. Technology to control these parameters should be targeted in further studies.

Keywords Laser lithotripsy · Ureteroscopy · Kidney stones · Endoscopes · Safety · Technology

✉ Palle Jörn Sloth Osther
posther@health.sdu.dk

1 Department of Urology, Aarhus University Hospital, Aarhus, Denmark

2 Department of Urology, Herlev-Gentofte Hospital, University of Copenhagen, Copenhagen, Denmark

3 Department of Urology, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands

4 Department of Surgery and Urology, Danderyd University Hospital, Stockholm, Sweden

5 Department of Clinical Sciences, Karolinska Institutet, Stockholm, Sweden

6 Urology Centre and Stone Unit, Guy's and St. Thomas' NHS Foundation Trust, London, UK

7 Department of Urology, University of Michigan, Ann Arbor, MI, USA

8 Department of Urology, Urological Research Center, Lillebaelt Hospital, University of Southern Denmark, Vejle, Denmark

9 Department of Urology, Hospital CUF Descobertas, Lisbon, Portugal

10 Department of Urology, Churchill Hospital, Oxford University Hospitals NHS Trust, Oxford, UK

11 Department of Urology, Tenon Hospital, Paris, France

12 Department of Urology, Haukeland University Hospital, Bergen, Norway

Springer

Introduction

Flexible ureterorenoscopy (fURS) has evolved as one of the major modalities for upper urinary tract stone management. This development is largely the result of continuing advancements in laser technology for intracorporeal lithotripsy, which is the focus of this review. Most daily clinical practices in the field of kidney stones, including lithotripsy techniques, are not supported by randomized trials and meta-analyses. This is not due to low research activity in this area, but rather to difficulties in designing meaningful trials that reflect daily clinical practice, because stone disease is so diverse. In this context, it is particularly important for practising experts to share their knowledge on clinical applications. The concept of the meeting "Consultation on Kidney Stones", on which this review is based, was to create a forum for transfer and development of clinical expertise.

Methods

To evaluate lithotripsy in fURS regarding the balance between existing evidence, expert opinions, and safety and efficacy of new technological improvements, key opinion leaders in the field were invited to assess and discuss existing evidence at the 2-day meeting entitled "Consultation on Kidney Stones: Aspects of Intracorporeal Lithotripsy" held in Copenhagen, Denmark, in September 2019. The participating experts were assigned different topics and prepared presentations according to scoping reviews using PubMed, EMBASE, and Web of Science to search the literature. The first day of the meeting was open only to the experts, who individually presented their topics, which were then discussed by the whole group. The presentations were subsequently adjusted if necessary. The second day was an open meeting at which all presentations were given to an international audience, and this was followed by free discussions.

Basics of laser lithotripsy

Laser fibre size

The deflection range of a flexible ureteroscope decreases with increased size of the laser fibre inserted [1–3]. The size of the fibre also has an inverse effect on irrigation [1, 2]. An in vitro study of the ablation efficiency of laser fibres showed that large fibres (550 µm) produced wider fissures than small fibres (200 µm), but the fissures made by the small fibres were deeper [4]. Another investigation found that using a larger fibre created more retropulsion of the stone during lithotripsy [5]. Comparison of total fragmentation volume indicated little difference between fibres except at very low pulse energies (0.2 J), at which small fibres were more efficient [4]. These observations suggest that smaller fibres provide the following: better irrigation and thus improved visibility; better deflection and hence increased accessibility; and less retropulsion and thus higher ablation efficiency, and also an overall reduction in operating time [2, 6].

Laser fibre tips

Laser fibres can have a standard flat tip or a polished or ball-shaped tip. The ball-tip fibre is designed to reduce damaging friction forces generated within the working channel of the ureteroscope. It has been shown that this type of fibre can be safely passed through a deflected ureteroscope without causing liner perforation. The same advantage can be achieved by cleaving a standard fibre in such a manner that the coating protects the scope from the laser core [7]. Flat-tip fibres require greater insertion force at all angles and therefore can cause the ureteroscope liner to leak if it is deflected 45°or more [8].

An in vitro study comparing lithotripsy performance of different types of laser fibres found that the standard fibre functioned just as well as specially designed fibres [9]. Kronenberg et al. [10] noted that, compared to fibres stripped off the coating material, coated fibres achieved significantly higher ablation volumes, and there was no difference in performance between coated fibres cleaved with metal or ceramic scissors. However, Aldoukhi et al. [11] observed that single-use fibres and cleaved reusable fibres performed better than fibres with tips cut using Mayor scissors. The difference in efficiency between stripped and coated fibres may be due to the fibre itself being damaged during the stripping off the coating, leading to a dispersion of laser energy [10, 11]. Another downside of such stripping is that a fibre devoid of its coloured coating is difficult to discern in front of the ureteroscope. The above-mentioned factors have not been scientifically evaluated in vivo, and individual surgeons may have different preferences.

Laser settings

Various laser systems have been developed that offer different laser settings, such as high frequency and long-pulse duration. The total power (W) used is equal to the pulse energy (J) multiplied by the pulse frequency (Hz). In an in vitro study, a combination of low frequency and high pulse energy was more effective than the opposite combination with the same total power level, and pulse energy and ablation volume were linearly correlated with the width and depth of fissures observed in the stone material [4]. However, high pulse energy resulted in more stone retropulsion, larger stone fragments, and laser fibre burn-back, all leading to prolonged operating time [4, 12]. Lowering the pulse energy and increasing the frequency give rise to less retropulsion and fibre burn-back, which results in dusting of the stone. Regarding the pulse length, preliminary data from an in vitro study showed that short pulse settings led to significantly higher ablation volumes than long-pulse settings [13], whereas long-pulse lithotripsy was associated with less fibre burn-back, smaller fragments, and more dust. Other investigations have been unable to demonstrate a significant relationship between pulse duration and stone ablation [14, 15].

The Moses technology introduces a pulse-shaped modulation that optimizes energy delivery through water to the target stone. The Moses platform has two settings: Moses contact (MC) mode, for operation at close range (< 2 mm); Moses distance (MD) mode, for lithotripsy at a distance of 2 mm. In a preclinical study, the Moses technology resulted in more efficient laser lithotripsy with significantly reduced stone retropulsion [16]. In an automated in vitro dusting model, compared to long-pulse lithotripsy, Moses holmium:yttrium–aluminum–garnet (Ho:YAG) (Ho:YAG) laser technology provided greater ablation of soft stones when in contact with the stone surface [17]. In an investigation using a three-dimensional positioning system, researchers examined the impact of laser fibre working distance on fragmentation when altering pulse width or modulation [18], which showed that holmium laser lithotripsy was significantly affected by the fibre tip to stone working distance, with the greatest ablation volume obtained with the fibre in contact with the stone.

Considering optimal settings for the lithotriptor, different stone compositions require different settings to achieve the desired effect, and the desired effect may vary in individual situations. The recommendation is to start with a test setting of low pulse energy and low frequency to initially determine how the stone reacts, and thereafter adjust settings accordingly to improve efficiency of the lithotripsy.

Technical aspects of laser lithotripsy and stone clearance during fURS

Various methods for laser lithotripsy have been described, and combining them can lead to more efficient ablation and clearance of stones with different characteristics [19]. The techniques described include dusting (dancing/painting), chipping, fragmentation, popcorning, dustmenting, and popdusting, and all these strategies can be combined in different ways to achieve the desired outcome. Dancing/painting is done by moving the laser fibre from side to side over the surface of the stone, using dusting settings. Chipping entails lasering off small pieces from the edges of the stone leaving small fragments for spontaneous passage, whereas fragmenting involves cutting a stone into larger fragments for subsequent basket removal. The fragmentation and basketing strategy use a setting of low frequency (4–10 Hz) and high pulse energy (0.6–2.0 J); dusting uses a setting of high frequency (15–80 Hz) and low pulse energy (0.2–0.5 J); popcorning stones requires settings of moderate-to-high frequencies (10–20 [40] Hz) and moderate pulse energy (1–1.5 J)[20–23].

Popcorning refers to a non-contact technique in which the laser energy whirls around fragments that come in contact with the laser and breaks them into smaller pieces. Chawla et al. [20] conducted an in vitro investigation of popcorning with different laser settings and observed that 1.5 J and 40 Hz produced the greatest mean decrease in stone burden per amount of time used; however, such a high-power level cannot be recommended in vivo. In that study, settings of 1.0 J and 20 Hz were most efficient with regard to mean stone weight loss per total amount of energy used. Emiliani et al. [24] suggested that a good compromise for popcorning would be using a long pulse of 1.5 J and 20 Hz with a 270 µm laser fibre and taking as much time as possible (> 4 min) to produce clinically insignificant fragments. In another in vitro model, Aldoukhi et al. found that the popcorn te

chnique was more effective when the laser fibre was positioned in contact with the stone as compared to at a distance of 2 mm from the stone, and when performed in a small (11 mm) rather than a larger calyceal model [25]. These in vitro studies do not replicate the clinical environment, and, working in a limited space, surgeons should always aim to choose a safe power level based on the irrigation flow applied and other factors, including outflow (access sheath) and temperature of the irrigation fluid.

Humphreys et al. [26] conducted a non-randomized prospective clinical comparative trial considering dusting versus fragmenting, and they found no statistically significant difference in stone-free rate (SFR) and no difference in complication rates between the two patient groups. However, although stones were significantly larger in the dusting arm (96 vs 63 mm^2, $p < 0.001$) the mean operative time was significantly shorter in that group (36 vs 67 min, $p < 0.001$). This agrees with clinical data showing that, for large stones, it is easier to control the complete stone burden during dusting, whereas fragmenting may result in fragments moving into multiple different calyces in which they must be dealt with, potentially prolonging OR time and reducing SFR.

Ureteroscopic lasering of lower pole stones can be challenging. The anatomy of the lower pole must be considered, because a long infundibular length, a narrow infundibular width, and a steep infundibulo-pelvic angle may have a negative impact on stone clearance, especially if more than one of these aspects is unfavourable [27–30]. Using a basket/grasper to move the stone to another location can be a viable alternative that can facilitate lithotripsy, reduce scope damage, and aid fragment passage [31, 32]. Schuster et al. [33] compared SFR in patients with lower pole stones treated in situ and subjects with relocation of the stone before lithotripsy. For stones > 1 cm in size, complete clearance was obtained in 100% of cases by relocation versus 29% of cases in situ ($p=0.005$); the difference between the two groups was not significant for stones of < 1 cm. Placing the patient in Trendelenburg position during surgery can facilitate stone relocation to the upper pole from other sites by creating a dependent upper pole; two randomized trials have demonstrated that this method results in shorter OR time, better SFR, less flexible ureteroscope manipulation, and less stone migration into the lower pole [34, 35]. If the stone cannot be relocated due to size or anatomy, or if lithotripsy in situ is preferred, a ball-tip laser fibre can be safely introduced through a deflected scope.

The 2020 EAU Urolithiasis Guidelines recommend that only baskets made of Nitinol be used for fURS. A range of different baskets are available, such as triangular baskets, 4-wire baskets, smaller baskets for narrow locations, and larger baskets for strength. Baskets can also vary regarding penetration force, radial dilation force, and opening dynamics, and add different degrees of resistance to scope deflection [36]. Bach et al. [37] tested various sizes of baskets in five different endoscopes and found that, in contrast to laser fibres, the size of the basket did not influence the deflection of the scope, which made relocation of a stone easier than in in situ lithotripsy. However, the size of the basket had an inverse effect on irrigation flow. Conversely, Patel et al. [36] showed some limitation of deflection, which was greater for a 2.2 Fr compared to a 1.5 Fr basket. In practice, these differences will vary depending on the type of ureteroscope employed and how long it has been in use, and the specific basket that is chosen.

Methods for the evacuation of small residual fragments include the glue-clot technique and irrigation/suction systems. In the glue-clot technique, autologous venous blood is injected into a calyx, where it agglutinates with stone fragments to form a clot that can be extracted with a basket [38]. In a randomized pilot study of 47 patients, an automated irrigation/suction pump system was tested and found to reduce mean operating time by 35% ($p=0.04$) and to increase SFR from 69 to 92% ($p=0.048$) compared with the standard pressurized technique [39].

Comparing clinical outcome of different laser lithotripsy strategies

Comparing fragmenting and dusting with regard to clinical outcomes has proven difficult, because the objective metrics for such comparison vary. The studies performed have differed regarding rates of pre-stenting and staged procedures, and ways of reporting complication grades, emergency room visits, intensive care admission, hospitalization, and re-intervention. Reports concerning follow-up also differ with regard to definitions of stone free, imaging modalities, and timing of the follow-up and repeat intervention rate. Stone free has been defined as zero fragment, < 2 mm, or > 4 mm residual fragment. Imaging modality for follow-up varies between computed tomography (CT), kidney–ureter–bladder radiograph (KUB), ultrasound (US), or fluoroscopy at operation, and a large proportion of patients apparently have no follow-up imaging at all [40]. An assessment of administrative data in the United States showed that 39% of patients had no imaging at 12 months post-surgery[41].

A retrospective study demonstrated that fragments > 4 mm in size were associated with significantly higher rates of stone growth leading to complications and need for re-intervention, whereas fragments of > 2 mm were likely to grow, but were not associated with complications or re-intervention [42]. Another retrospective investigation reported that the cumulative repeat surgery rate at 5 years after fURS was proportional to the size of residual fragments on post-operative CT [43]: with no visible residual fragments, fragments < 4 mm, or fragments > 4 mm, the rates were 3.5%, 8.2%, and 46.2%, respectively. CT has been reported to have a sensitivity of 95–100% for residual fragments [44].

Eleven studies comparing spontaneous passage and fragmentation with active retrieval [45] were identified, but most of them could not be compared with each other due to differences in imaging modalities and definitions of SFR. Only three comparative, non-randomized studies of the various disintegration strategies in the treatment of renal stones were pinpointed (Table 1) [26, 46, 47]. Two of those assessments used CT for follow-up, whereas the third used KUB and US. Only one of those three studies reported the power settings for dusting and fragmentation, respectively.

In a randomized, double-blinded clinical trial comparing regular and Moses modes of Ho:YAG laser lithotripsy, Ibrahim et al. showed that the Moses technology was associated with significantly lower fragmentation/pulverization (stone dusting) and procedural times, which the authors explained by less retropulsion of stones during Moses mode lithotripsy [48].

Conclusive evidence for comparing spontaneous passage and active retrieval strategies is limited, and it is difficult to compare existing studies, because they vary regarding disintegration strategy, SFR criteria, and time and modality of imaging at follow-up. Moreover, the investigations have not systematically reported stone density and composition and post-operative complications.

Table 1 Comparative studies regarding SFR with spontaneous passage vs active retrieval during lithotripsy

Cohort	Lee et al. 2016		Humphreys et al. 2018		El-Nahas et al. 2019	
	Spontaneous	Retrieval	Spontaneous	Retrieval	Spontaneous	Retrieval
Study design	Retrospective	Retrospective	Prospective	Prospective	Retrospective	Retrospective
Study period	2010–2015	2010–2015	2013–2016	2013–2016	2015–2017	2015–2017
Cases, *n*	76	172	68	82	51	56
Mean stone size (SD)	11 mm (± 5.2)	11 mm (± 4.8)	11 mm (± 4.3)	8.8 mm (± 3.5)	NS	NS
Laser power (setting)	NS	NS	30–100 W (NS)	30–100 W (NS)	20–60 W (0.3 J/20 Hz)	20–60 W (1.0 J/10 Hz)
OR time	82 min	83 min	36 min	67 min	76 min	91 min
Stenting rate	100%	100%	100%	100%	100%	100%
Complications	11%*	11%*	13.2%*	19.5%**	8%*	9%**
Definition of SFR	< 3 mm	< 3 mm	No fragment	No fragment	No fragment and < 4 mm	No fragment and < 4 mm
Imaging used	CT	CT	KUB, US	KUB, US	CT	CT
Imaging timing	4 weeks	4 weeks	4–6 weeks	4–6 weeks	2 months	2 months
Stone free rate	87%	89%	58%	74%	59% and 86%	79% and 89%

SD standard deviation, *OR* operating room, *SFR* stone-free rate, *CT* computed tomography, *KUB* kidney–ureter–bladder radiograph, *US* ultrasound

Endoscopes and laser lithotripsy

Ureteroscopes vary with respect to location of working channel (Fig. 1), deflection ability and irrigation flow with laser fibre inserted, distance of laser tip from the tip of the endoscope, and optical imaging quality and illumination of the surgical field. All of the listed features have a potential impact on laser lithotripsy, although evidence for this is based mainly on in vitro studies and expert opinions, and very little has been published regarding effects on clinical outcome.

The position of the working channel of the endoscope can influence irrigation flow and thus create differences in the flushing and movement of stone and tissue. The position also dictates location of the laser fibre/basket inserted through the channel and thereby affects the ability to reach stones in certain positions within the kidney [49].

In vitro comparison of single-use and reusable flexible ureteroscopes showed that the latter had bettervision characteristics [50]. It appears that scopes differ regarding occurrence of light flashes during laser lithotripsy, over-illumination of the field, and the speed at which light intensity can be regulated. These phenomena may occur due to automatic light intensity regulation being affected by laser energy flashes or by stone fragments or dust that is flushed around by irrigation and laser pulse pressure waves. The cited in vitro comparison also demonstrated that the flow varied between different flexible ureteroscopes equipped with the same type of laser fibre [50]. The problem of working channel damage can be almost completely overcome by employing single-use flexible ureteroscopes.

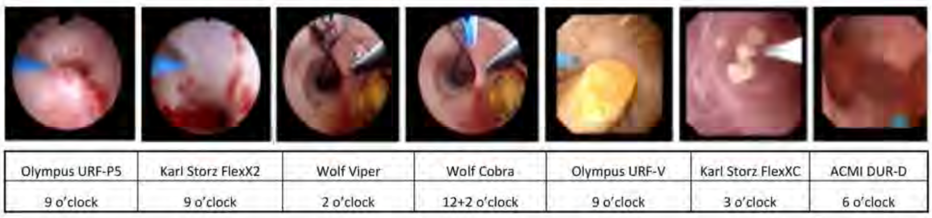


Fig. 1 Different positions of working channel depending on manufacturer and model of ureteroscope

Safety aspects of laser lithotripsy during fURS

Direct contact of the laser can cause local burns on the urothelium. Furthermore, high-flow irrigation for optimal visualization and cooling leads to increased intraluminal pressure, although such irrigation is necessary.

It should also be noted that incorrect handling of lasers may damage the ureteroscope and even harm the surgeon and OR personnel. A safety distance between the tip of the fibre and the tip of the scope should be maintained to minimize the risk of damaging endoscopes. Talso et al. [51] observed that the length of the fibre projecting from ureteroscopes was 1–2 mm at first appearance in the camera image, whereas it was 3–4 mm when reaching one-fourth of the screen, and in that position, the laser bubble was never in contact with the tip of the ureteroscope and was therefore protected from damage.

The incidence of ureteral perforation during ureterorenoscopy has been reported to be 0.4–6.3%, and the risk factors identified included size of ureteroscope, prolonged operation time, surgeon's lack of experience, stone characteristics, lack of pre-stenting, and high laser energy [52, 53]. Possible complications of perforation are extravasation, haematoma, sepsis, pain, obstruction, stricture, and loss of kidney function [52–55]. Use of laser during intracorporeal lithotripsy has been observed to be an independent risk factor, with a 3.6% risk of Post-ureteroscopic Lesion Scale (PULS; [56] grade 1 lesions and 3.1% risk of PULS grade 2 lesions. To avoid ureteral perforation, it is recommended that optimal visualization be secured by irrigation and that a safety distance of at least 1 mm be maintained between laser tip and urothelium.

During laser lithotripsy, visualization can be impaired by stone dust and debris. Increasing irrigation to solve this problem unequivocally raises the intrarenal pressure, potentially leading to tubular, venous, and lymphatic backflow. Baseline intrarenal pressure is approximately 10 mmHg, and the threshold for backflow is 30–35 mmHg. Intrarenal pressure levels during fURS and holmium laser usage have been noted to be as high as 50–350 mmHg [57, 58]. Intrarenal pressures above 30 mmHg for more than 10 min have been shown to significantly increase the incidence of septicaemia in percutaneous nephrolithotomy [59]. Although several studies have suggested that complications such as sepsis and post-operative pain leading to longer hospitalization are related to high intrarenal pressure, no definitive causal data exist [60–63]. Intrarenal pressure during fURS may be reduced by the use of a ureteral access sheath (UAS) [64]. If a UAS is to be applied, it must have a larger diameter than the scope, which make the UAS a double-edged sword: on one hand, it reduces intrarenal pressure and potential septic complications, and on the other hand, it may increase the risk of strain-induced lesions to the ureter [65]. Therefore, it is important to use the smallest UAS compatible with the ureteroscope chosen to ensure both safe placement without significant friction and sufficient outflow, and thereby achieve both low intrarenal pressure and sufficient flow for visualization during lithotripsy [66].

High intrarenal temperatures have been observed during laser lithotripsy, especially at high total power settings (> 30 W) [67]. High temperatures can lead to thermal ablation of kidney tissue, resulting in permanent kidney damage. Overall, such tissue damage is dependent on temperature, time, and blood flow [68]. In the ureter, the threshold for tissue damage has been shown to be around 43 °C for 120 min, which is equivalent to approximately 50 °C for 56 s or 56 °C for 0.9 s [69–71]. In an in vitro model, Wollin et al. achieved temperatures of > 43 °C at all laser settings within 1 min without irrigation, and the maximum temperature reached was 100 °C at fragmentation settings [69]. Aldoukhi et al. recorded temperatures in a pig kidney during high-power holmium laser lithotripsy at 0.5 J and 80 Hz and different irrigation flows, and found that only high irrigation flow (38–40 ml/min) could keep the caliceal temperature at ≤ 43 °C [72]. To reduce heating, it is important to have secured continuous flow irrigation and consider use of room temperature or even cooled irrigation fluid. Lasering should be carried out intermittently to allow cooling in low-flow areas.

Comparison of different laser technologies for intracorporeal lithotripsy

The past and current standard for laser lithotripsy is the Ho:YAG laser, which has revolutionized retrograde stone management. Introduction of high-power Ho:YAG laser systems that utilize laser settings of high frequency and low pulse energy (HiFr-LoPE), varying pulse lengths, and Moses technology for reduction of retropulsion and improvement of fragmentation have expanded the surgeon's ability to ablate urinary tract stones and thereby opened a new era for the dusting technique. Reducing the need for fragment retrieval and the potential hazards of this technique (UAS usage and multiple scope passages) may be advantageous [73]. Recently, a new laser technology for stone management has emerged—the thulium fibre laser (TFL). The TFL emits light with a wavelength of 1940 nm, compared to 2100 nm with Ho:YAG [74–79]. Comparing laser setting options, TFL offers frequencies of 5–2200 Hz, pulse energies of 0.025–6 J, and pulse durations of 200–12,000 microsec [76, 80–83], whereas Ho:YAG offers 5–100 Hz, 0.2–6 J, and 50–1300 microsec [81, 84]. These qualities of the TFL laser give this technology the potential to produce 3–4 times more dust compared to high-power Ho-YAG lasers [78, 85, 86]. Furthermore, due to the novel laser beam generation by laser diodes in TFL, smaller fibres (50 µm) can be utilized, which may result in higher energy intensity at the tip of the fibre, better scope deflection, and better irrigation, all of which can potentially increase stone ablation volume at comparable settings [74, 80, 81]. Initial reports of TFL performance in the clinical setting are promising but still limited [87], and further evaluation, including consideration of safety aspects (temperature) and ability of the laser to embrace all lithotripsy strategies, will be necessary to define the role of TFL. To date, no clinical comparative studies of holmium and thulium fibre lasers have been conducted. Nevertheless, both the HiFr-LoPE Ho:YAG and the new TFL technology show promise in expanding the role of flexible ureteroscopic stone management by approaching larger stones and more complex stone scenarios.

Conclusions

Lasers have revolutionized the scenario of intracorporeal lithotripsy during fURS. Ho:YAG is still the predominant laser for stone management, and, with this technology, specific settings for dusting and fragmenting have evolved, which have expanded the role of fURS in endoscopic stone management. Recently, the TFL was introduced, and this new laser source may prove to further increase the efficiency of laser lithotripsy. There is still debate as to whether the fragmentation and basketing strategy are preferable to the dusting strategy for increasing SFR. However, one does not exclude the other, because different stone scenarios call for different lithotripsy approaches, and, for large stone burdens, all laser lithotripsy settings (dusting, fragmenting, and popcorning) may often be necessary for optimizing the final result. Technology for removing dust from the kidney should be a focus for future research and development. Safety aspects of fURS laser lithotripsy include high intrarenal pressures and temperatures. Inasmuch as measures to reduce both pressure and temperature are mandatory to avoid sepsis, bleeding, and nephron loss, technology to control these parameters should be targeted in further investigations.

Acknowledgements We are grateful to Boston Scientific, Olympus, Coloplast, Cook Medical, EMS, Lumenis, Richard Wolf, Karl Storz Endoscope, Apsu Medical, BL Medical, Opiva Nordic, and Rocamed for supporting the Copenhagen Consultation on Kidney Stones meeting 2019. We thank chief assistant Katrine Lindholtz for outstanding administrative management, Stockholm Data Design AB for managing the website, and Patricia Ödman for language revision.

Author contributions SKL: data analysis and manuscript writing. KA: data analysis and manuscript editing. JB: data analysis and manuscript editing. MBr: project co-ordination, presentation, manuscript editing. MBu: data collection and analysis, presentation, and manuscript editing. YE: data analysis and manuscript editing. KG: data collection and analysis, presentation, and manuscript editing. HJ: data collection and analysis, presentation, and manuscript editing. GK: data collection and analysis, presentation, and manuscript editing. PK: data collection and analysis, presentation, and manuscript editing. BT: data analysis and manuscript editing. OT: data collection and analysis, presentation, and manuscript editing. ØU: data analysis and manuscript editing. PO: project co-ordination, data analysis, presentation, manuscript writing, and editing.

Compliance with ethical standards

Conflict of interest Søren K. Lildal: no conflicts of interest. Kim Andreassen: consultant for AMBU. Joyce Baard: no conflicts of interest. Marianne Brehmer: no conflicts of interest. Matthew Bultitude: consultant for Boston Scientific. Ylva Eriksson: no conflicts of interest. Khurshid Ghani: consultant for Boston Scientific, Lumenis, and Olympus; Grant from Boston Scientific. Helene Jung: no conflicts of interest. Guido Kamphuis: consultant for Boston Scientific and Olympus. Peter Kronenberg: consultant for Olympus. Ben Turney: no conflicts of interest. Olivier Traxer: consultant for Boston Scientific, Olympus, Rocamed, and Coloplast. Øyvind Ulvik: consultant for Olympus. Palle J S Osther: consultant for Olympus, Boston Scientific, Bonvisi AB, and Coloplast.

Informed consent Informed consent is not relevant.

Human and animal rights This is a review article involving no studies of human participants and/or animals.

References

1. Kronenberg P, Traxer O (2015a) Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 33(4):463–469
2. Kronenberg P, Traxer O (2014a) The truth about laser fiber diameters. Urology 84(6):1301–1307
3. Pasqui F, Dubosq F, Tchala K, Tligui M, Gattegno B, Thibault P et al (2004) Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. Eur Urol 45(1):58–64
4. Kronenberg P, Traxer O (2014b) In vitro fragmentation efficiency of holmium: yttrium-aluminum-garnet (YAG) laser lithotripsy—a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 114(2):261–267

5. Kronenberg P, Traxer O (2013) V1718 laser fibers, pulse energy and retropulsion—what we can see and what we can't. J Urol 189(4s):e707
6. Kronenberg P, Somani B (2018) Advances in lasers for the treatment of stones-a systematic review. Curr Urol Rep 19(6):45
7. Baghdadi M, Emiliani E, Talso M, Serviân P, Barreiro A, Orosa A et al (2017) Comparison of laser fiber passage in ureteroscopic maximum deflection and their influence on deflection and irrigation: Do we really need the ball tip concept? World J Urol 35(2):313–318
8. Carlos EC, Li J, Young BJ, Radvak D, Wollin DA, Winship BB et al (2019) Let's get to the point: comparing insertion characteristics and scope damage of flat-tip and ball-tip holmium laser fibers. J Endourol 33(1):22–26
9. Kronenberg P, Traxer O (2016a) Lithotripsy performance of specially designed laser fiber tips. J Urol 195(5):1606–1612
10. Kronenberg P, Traxer O (2015b) Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol 193(3):1030–1035
11. Aldoukhi AH, Knudsen BE, Black KM, Hall TL, Roberts WW, Ghani KR (2019) Are we cutting ourselves short? Laser lithotripsy performance based on differences in fiber-tip preparation. Urology 134(1):79–83
12. Sea J, Jonat LM, Chew BH, Qiu J, Wang B, Hoopman J et al (2012) Optimal power settings for holmium:YAG lithotripsy. J Urol 187(3):914–919
13. Kronenberg P, Traxer O (2016b) Ultra-short, short, medium and long-pulse laser lithotripsy performance. Eur Urol Suppl 15(3):e1035
14. Sroka R, Pongratz T, Scheib G, Khoder W, Stief CG, Herrmann T et al (2015) Impact of pulse duration on Ho:YAG laser lithotripsy: treatment aspects on the single-pulse level. World J Urol 33(4):479–485
15. Bader MJ, Pongratz T, Khoder W, Stief CG, Herrmann T, Nagele U et al (2015) Impact of pulse duration on Ho:YAG laser lithotripsy: fragmentation and dusting performance. World J Urol 33(4):471–477
16. Elhilali MM, Badaan S, Ibrahim A, Andonian S (2017) Use of the Moses technology to improve holmium laser lithotripsy outcomes: a preclinical study. J Endourol 31(6):598–604
17. Winship B, Wollin D, Carlos E, Li J, Peters C, Simmons WN et al (2018) Dusting efficiency of the Moses holmium laser: an automated in vitro assessment. J Endourol 32(12):1131–1135
18. Aldoukhi AH, Roberts WW, Hall TL, Ghani KR (2019) Watch your distance: the role of laser fiber working distance on fragmentation when altering pulse width or modulation. J Endourol 33(2):120–126
19. Hecht SL, Wolf JSJ (2013) Techniques for holmium laser lithotripsy of intrarenal calculi. Urology 81(2):442–445
20. Chawla SN, Chang MF, Chang A, Lenoir J, Bagley DH (2008) Effectiveness of high-frequency holmium:YAG laser stone fragmentation: the "popcorn effect." J Endourol 22(4):645–650
21. Weiss B, Shah O (2016) Evaluation of dusting versus basketing—can new technologies improve stone-free rates? Nat Rev Urol 13(12):726–733
22. Doizi S, Keller EX, De Coninck V, Traxer O (2018) Dusting technique for lithotripsy: what does it mean? Nat Rev Urol 15(11):653–654
23. Aldoukhi AH, Roberts WW, Hall TL, Ghani KR (2017) Holmium laser lithotripsy in the new stone age: dust or bust? Front Surg 4:1–6
24. Emiliani E, Talso M, Cho S-Y, Baghdadi M, Mahmoud S, Pinheiro H et al (2017) Optimal settings for the noncontact holmium:YAG stone fragmentation popcorn technique. J Urol 198(3):702–706
25. Aldoukhi AH, Roberts WW, Hall TL, Teichman JMH, Ghani KR (2018) Understanding the popcorn effect during holmium laser lithotripsy for dusting. Urology 122:52–57
26. Humphreys MR, Shah OD, Monga M, Chang Y-H, Krambeck AE, Sur RL et al (2018) Dusting versus basketing during ureteroscopy-which technique is more efficacious? A prospective multicenter trial from the EDGE research consortium. J Urol 199(5):1272–1276
27. Elbahnasy AM, Shalhav AL, Hoenig DM, Elashry OM, Smith DS, McDougall EM et al (1998) Lower caliceal stone clearance after shock wave lithotripsy or ureteroscopy: the impact of lower pole radiographic anatomy. J Urol 159(3):676–682
28. Inoue T, Murota T, Okada S, Hamamoto S, Muguruma K, Kinoshita H et al (2015) Influence of pelvicaliceal anatomy on stone clearance after flexible ureteroscopy and holmium laser lithotripsy for large renal stones. J Endourol 29(9):998–1005
29. Jessen JP, Honeck P, Knoll T, Wendt-Nordahl G (2014) Flexible ureterorenoscopy for lower pole stones: influence of the collecting system's anatomy. J Endourol 28(2):146–151
30. Danilovic A, Rocha BA, Torricelli FCM, Marchini GS, Batagello C, Vicentini FC et al (2019) Size is not everything that matters: preoperative CT predictors of stone free after RIRS. Urology 132:63–68
31. Kourambas J, Delvecchio FC, Munver R, Preminger GM (2000) Nitinol stone retrieval-assisted ureteroscopic management of lower pole renal calculi. Urology 56(6):935–939
32. Auge BK, Dahm P, Wu NZ, Preminger GM (2001) Ureteroscopic management of lower-pole renal calculi: technique of calculus displacement. J Endourol 15(8):835–838
33. Schuster TG, Hollenbeck BK, Faerber GJ, Wolf JSJ (2002) Ureteroscopic treatment of lower pole calculi: comparison of lithotripsy in situ and after displacement. J Urol 168(1):43–45
34. Pan J, Xue W, Xia L, Zhong H, Zhu Y, Du Z et al (2014) Ureteroscopic lithotripsy in Trendelenburg position for proximal ureteral calculi: a prospective, randomized, comparative study. Int Urol Nephrol 46(10):1895–1901
35. Zhou R, Han C, Hao L, Chen B, Zang G, Fan T et al (2018) Ureteroscopic lithotripsy in the Trendelenburg position for extracting obstructive upper ureteral obstruction stones: a prospective, randomized, comparative trial. Scand J Urol 52(4):291–295
36. Patel N, Akhavein A, Hinck B, Jain R, Monga M (2017) Tipless nitinol stone baskets: comparison of penetration force, radial dilation force, opening dynamics, and deflection. Urology 103:256–260
37. Bach T, Geavlete B, Herrmann TRW, Gross AJ (2008) Working tools in flexible ureterorenoscopy—influence on flow and deflection: what does matter? J Endourol 22(8):1639–1643
38. Cloutier J, Cordeiro ER, Kamphuis GM, Villa L, Letendre J, de la Rosette JJ et al (2014) The glue-clot technique: a new technique description for small calyceal stone fragments removal. Urolithiasis 42(5):441–444
39. Lechevallier E, Luciani M, Nahon O, Lay F, Coulange C (2003) Transurethral ureterorenolithotripsy using new automated irrigation/suction system controlling pressure and flow compared with standard irrigation: a randomized pilot study. J Endourol 17(2):97–101
40. Ghani KR, Wolf JSJ (2015) What is the stone-free rate following flexible ureteroscopy for kidney stones? Nat Rev Urol 12(5):281–288
41. Ahn JS, Holt SK, May PC, Harper JD (2018) National imaging trends after ureteroscopic or shock wave lithotripsy for nephrolithiasis. J Urol 199(2):500–507
42. Chew BH, Brotherhood HL, Sur RL, Wang AQ, Knudsen BE, Yong C et al (2016) Natural history, complications and re-intervention rates of asymptomatic residual stone fragments after

ureteroscopy: a report from the EDGE research consortium. J Urol 195(4 Pt 1):982–986
43. Portis AJ, Laliberte MA, Heinisch A (2015) Repeat surgery after ureteroscopic laser lithotripsy with attempted complete extraction of fragments: long-term follow-up. Urology 85(6):1272–1278
44. Bhojani N, Paonessa JE, El Tayeb MM, Williams JCJ, Hameed TA, Lingeman JE (2018) Sensitivity of noncontrast computed tomography for small renal calculi with endoscopy as the gold standard. Urology 117:36–40
45. Fayad AS, Elsheikh MG, Ghoneima W (2017) Tubeless mini-percutaneous nephrolithotomy versus retrograde intrarenal surgery for lower calyceal stones of 2 cm: a prospective randomised controlled study. Arab J Urol 15(1):36–41
46. Lee YJ, Bak DJ, Chung J-W, Lee JN, Kim HT, Yoo ES et al (2016) Is it necessary to actively remove stone fragments during retrograde intrarenal surgery? Investig Clin Urol 57(4):274–279
47. El-Nahas AR, Almousawi S, Alqattan Y, Alqadri IM, Al-Shaiji TF, Al-Terki A (2019) Dusting versus fragmentation for renal stones during flexible ureteroscopy. Arab J Urol 17(2):138–142
48. Ibrahim A, Elhilali MM, Fahmy N, Carrier S, Andonian S (2020) Double-blinded prospective randomized clinical trial comparing regular and moses modes of holmium laser lithotripsy. J Endourol 34(5):624–628
49. Villa L, Ventimiglia E, Proietti S, Giusti G, Briganti A, Salonia A et al (2020) Does working channel position influence the effectiveness of flexible ureteroscopy? Results from an in vitro study. BJU Int 125(3):449–456
50. Dragos LB, Somani BK, Keller EX, de Coninck VMJ, Herrero MR-M, Kamphuis GM et al (2019) Characteristics of current digital single-use flexible ureteroscopes versus their reusable counterparts: an in-vitro comparative analysis. Transl Androl Urol 8(Suppl 4):S359–S370
51. Talso M, Emiliani E, Haddad M, Berthe L, Baghdadi M, Montanari E et al (2016) Laser fiber and flexible ureterorenoscopy: the safety distance concept. J Endourol 30(12):1269–1274
52. De Cruz JE, Morcillo E, Folkersma LR, Alvarez S, Margallo FMS, Soria F (2017) Complications of endourologic procedures: a review on iatrogenic ureteral perforation. ARC J Urol 2(2):17–24
53. Cornu JN, Herrmann T, Traxer O, Matlaga B (2016) Prevention and management following complications from endourology procedures. Eur Urol Focus 2(1):49–59
54. Paiva MM, da Silva RD, Jaworski P, Kim FJ, Molina WR (2016) Subcapsular hematoma after ureteroscopy and laser lithotripsy. Can J Urol 23(4):8385–8387
55. Srougi V, Padovani GP, Marchini GS, Vicentini FC, Mazzucchi E, Srougi M (2015) Outcomes of surgical treatment of ureteral strictures after laser ureterolithotripsy for impacted stones. Can J Urol 22(6):8079–8084
56. Schoenthaler M, Buchholz N, Farin E, Ather H, Bach C, Bach T et al (2014) The Post-Ureteroscopic Lesion Scale (PULS): a multicenter video-based evaluation of inter-rater reliability. World J Urol 32(4):1033–1040
57. Jung H, Osther PJS (2015) Intraluminal pressure profiles during flexible ureterorenoscopy. Springerplus 4:373
58. Wilson W, Preminger G (1990) Intrarenal pressures generated during flexible deflectable ureterorenoscopy. J Endourol 4(2):135–141
59. Guo H-Q, Shi H-L, Li X-G, Gan W-D, Zeng L-Q, Liu G-X et al (2008) Relationship between the intrapelvic perfusion pressure in minimally invasive percutaneous nephrolithotomy and postoperative recovery. Zhonghua Wai Ke Za Zhi 46(1):52–54
60. Alsyouf M, Abourbih S, West B, Hodgson H, Baldwin DD (2018) Elevated renal pelvic pressures during percutaneous nephrolithotomy risk higher postoperative pain and longer hospital stay. J Urol 199(1):193–199
61. Whitehurst LA, Somani BK (2017) Perirenal hematoma after ureteroscopy: a systematic review. J Endourol 31(5):438–445
62. Uchida Y, Takazawa R, Kitayama S, Tsujii T (2018) Predictive risk factors for systemic inflammatory response syndrome following ureteroscopic laser lithotripsy. Urolithiasis 46(4):375–381
63. Fan S, Gong B, Hao Z, Zhang L, Zhou J, Zhang Y et al (2015) Risk factors of infectious complications following flexible ureteroscope with a holmium laser: a retrospective study. Int J Clin Exp Med 8(7):11252–11259
64. Ng YH, Somani BK, Dennison A, Kata SG, Nabi G, Brown S (2010) Irrigant flow and intrarenal pressure during flexible ureteroscopy: the effect of different access sheaths, working channel instruments, and hydrostatic pressure. J Endourol 24(12):1915–1920
65. Osther PJS (2018) Risks of flexible ureterorenoscopy: pathophysiology and prevention. Urolithiasis 46(1):59–67
66. Al-Qahtani SM, Letendre J, Thomas A, Natalin R, Saussez T, Traxer O (2014) Which ureteral access sheath is compatible with your flexible ureteroscope? J Endourol 28(3):286–290
67. Hein S, Petzold R, Suarez-Ibarrola R, Müller P-F, Schoenthaler M, Miernik A (2020) Thermal effects of Ho:YAG laser lithotripsy during retrograde intrarenal surgery and percutaneous nephrolithotomy in an ex vivo porcine kidney model. World J Urol 38(3):753–760
68. Brehmer M, Svensson I (2000) Heat-induced apoptosis in human prostatic stromal cells. BJU Int 85(4):535–541
69. Wollin DA, Carlos EC, Tom WR, Simmons WN, Preminger GM, Lipkin ME (2018) Effect of laser settings and irrigation rates on ureteral temperature during holmium laser lithotripsy, an in vitro model. J Endourol 32(1):59–63
70. Aldoukhi AH, Ghani KR, Hall TL, Roberts WW (2017) Thermal response to high-power holmium laser lithotripsy. J Endourol 31(12):1308–1312
71. Sapareto SA, Dewey WC (1984) Thermal dose determination in cancer therapy. Int J Radiat Oncol Biol Phys 10(6):787–800
72. Aldoukhi AH, Hall TL, Ghani KR, Maxwell AD, MacConaghy B, Roberts WW (2018) Caliceal fluid temperature during high-power holmium laser lithotripsy in an in vivo porcine model. J Endourol 32(8):724–729
73. Tracey J, Gagin G, Morhardt D, Hollingsworth J, Ghani KR (2018) Ureteroscopic high-frequency dusting utilizing a 120-W holmium laser. J Endourol 32(4):290–295
74. Blackmon RL, Irby PB, Fried NM (2010) Thulium fiber laser lithotripsy using tapered fibers. Lasers Surg Med 42(1):45–50
75. Blackmon RL, Irby PB, Fried NM (2011) Comparison of holmium:YAG and thulium fiber laser lithotripsy: ablation thresholds, ablation rates, and retropulsion effects. J Biomed Opt 16(7):071403
76. Hardy LA, Gonzalez DA, Irby PB, Fried NM (2018) Fragmentation and dusting of large kidney stones using compact, air-cooled, high peak power, 1940-nm, thulium fiber laser. In: Kang HW, Chan KF (eds) Therapeutics and diagnostics in urology 2018. SPIE; 2018, pp 57–61
77. Ventimiglia E, Doizi S, Kovalenko A, Andreeva V, Traxer O (2020) Effect of temporal pulse shape on urinary stone phantom retropulsion rate and ablation efficiency using holmium:YAG and super-pulse thulium fibre lasers. BJU Int 126(1):159–167. https://doi.org/10.1111/bju.15079
78. Andreeva V, Vinarov A, Yaroslavsky I, Kovalenko A, Vybornov A, Rapoport L et al (2020) Preclinical comparison of superpulse thulium fiber laser and a holmium:YAG laser for lithotripsy. World J Urol 38(2):497–503

79. White MD, Moran ME, Calvano CJ, Borhan-Manesh A, Mehlhaff BA (1998) Evaluation of retropulsion caused by holmium:YAG laser with various power settings and fibers. J Endourol 12(2):183–186
80. Fried NM (2018) Recent advances in infrared laser lithotripsy [Invited]. Biomed Opt Express 9(9):4552–4568
81. Traxer O, Keller EX (2019) Thulium fiber laser: the new player for kidney stone treatment? A comparison with holmium:YAG laser. World J Urol. https://doi.org/10.1007/s00345-019-02654-5
82. Ergakov D, Martov AG, Guseynov M (2018) The comparative clinical study of Ho: YAG and SuperPulse Tm fiber laser lithotripters. Eur Urol Suppl 17(2):e1391
83. Yaroslavsky I, Vinnichenko V, McNeill T, Novoseltseva A, Perchuk I, Vybornov A et al (2018) Optimization of a novel Tm fiber laser lithotripter in terms of stone ablation efficiency and retropulsion reduction. In: procspie. 2018, p 104680H (Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series; vol. 10468)
84. Fried NM, Irby PB (2018) Advances in laser technology and fibre-optic delivery systems in lithotripsy. Nat Rev Urol 15(9):563–573
85. Traxer O, Rapoport L, Tsarichenko D, Dymov A, Enikeev D, Sorokin N et al (2018) V03-02 first clinical study on superpulse thulium fiber laser for lithotripsy. J Urol 199(4S):e321–e322
86. De Coninck VMJ, Keller EX, Kovalenko A, Vinnichenko V, Traxer O (2019) Dusting efficiency comparison between Moses technology of Ho:YAG laser and superpulse thulium fiber laser. Eur Urol Suppl 18(1):e1757–e1758
87. Enikeev D, Taratkin M, Klimov R, Alyaev Y, Rapoport L, Gazimiev M et al (2020) Thulium-fiber laser for lithotripsy: first clinical experience in percutaneous nephrolithotomy. World J Urol. https://doi.org/10.1007/s00345-020-03134-x

Article 9: Laser accessories: surgical fibers, strippers, cleavers, and protective glasses.

REVIEW

CURRENT OPINION

Laser accessories: surgical fibers, strippers, cleavers, and protective glasses

Etienne Xavier Keller[a,b,c], Peter Kronenberg[d,e], Thomas Tailly[c,f], Mariela Corrales[b,g], Patrick Juliebø-Jones[c,h], Amelia Pietropaolo[c,h], Bhaskar Somani[e,h], and Vincent De Coninck[b,c,i]

Purpose of review

This review provides most recent findings and developments relating to surgical laser fibers, strippers, cleavers, and protective glasses.

Recent findings

The smallest core diameter that can be used with Holmium:YAG lasers is 200 μm. Smaller core diameter fibers can be used with the Thulium fiber laser and offer better flexibility and lower risk of fracture, at the risk of greater burnback effect. Misleading discrepancies between the true diameter of laser fibers and their packaging labels must be considered. Fiber tip degradation from the burnback occurs within few minutes, thus questioning the need for time-consuming fiber tip reprocessing with fiber strippers and special cleaving tools. This shortcoming also applies to instrument-protecting ball-tip fibers. Cleavage of fiber tips through their protective jackets ('coated tips') is a cheaper alternative for instrument protection, additionally offering better visual control of the fiber tip. Third-generation side-firing greenlight laser fibers are still prone to rapid deterioration. Laser eyewear does not seem necessary for Holmium:YAG applications, whereas laser-specific protective glasses should be worn for greenlight laser applications.

Summary

With better understanding of laser accessories, practicing urologists may tailor their practice to reach optimal efficacy and safety for Holmium:YAG, Thulium fiber laser and Greenlight laser applications.

Keywords

Holmium:YAG, laser fiber, lithotripsy, safety eyewear, Thulium fiber laser

INTRODUCTION

Lasers have been used over decades for multiple applications in urology. Several types of laser generators with various wavelengths and operating modes are currently available to the urologists [1,2,3▪]. All these laser platforms have one common property: delivery of energy to the surgical site via surgical laser fibers.

Laser lithotripsy is the most common laser application in the field of urology. It is mainly used in conjunction with flexible ureteroscopy, which has become the therapy of choice for interventional treatment of urinary stone disease [4▪,5]. For ureteroscopy, Holmium:YAG laser has been used as the energy source of choice since 1990 [6]. It offers many advantages, the most important being energy delivery over flexible laser fibers. Recently, the Thulium fiber laser (TFL) has been added to the armamentarium for lithotripsy and seems to overcome many limitations of the Holmium:YAG [7▪,8▪,9,10].

Surgical treatment of benign prostatic enlargement is another frequent urological intervention, for which the Holmium:YAG, Thulium:YAG, TFL and greenlight lasers are the major sources of energy

[a]Department of Urology, University Hospital Zurich, University of Zurich, Zurich, Switzerland, [b]Progressive Endourological Association for Research and Leading Solutions (PEARLS), Paris, France, [c]Young Academic Urologists (YAU), Urolithiasis & Endourology Working Party, Arnhem, The Netherlands, [d]Department of Urology, Hospital CUF Descobertas, Lisbon, Portugal, [e]Progress in Endourology, Technology and Research Association (PETRA), Paris, France, [f]Department of Urology, University Hospital Ghent, Ghent, Belgium, [g]Sorbonne Université, Service d'Urologie, AP-HP, Hôpital Tenon, Paris, France, [h]Department of Urology, University Hospital Southampton, Southampton, UK and [i]Department of Urology, AZ Klina, Brasschaat, Belgium

Correspondence to Etienne Xavier Keller, MD, Department of Urology, University Hospital Zurich, Frauenklinikstrasse 10, CH-8091 Zurich, Switzerland. Tel: +41 44 255 54 09; fax: +41 44 255 45 55; e-mail: etiennexavier.keller@usz.ch

Curr Opin Urol 2022, 32:000–000

DOI:10.1097/MOU.0000000000000977

KEY POINTS

- The actual diameter of laser fibers often differs considerably from packaging labels.
- Fiber tip degradation occurs shortly after beginning laser lithotripsy due to burnback and double-firing effects.
- Cleavage of laser fibers through their protective plastic jacket with regular metallic scissors is an advantageous technique to reprocess fiber tips.
- Laser safety glasses may be omitted for Holmium:YAG applications, but must be worn during Greenlight laser use.

used [11,12]. Other less frequent urological laser interventions include ureteral or urethral stricture incision, ablation or en-bloc resection of urothelial tumor as well as ablation of skin diseases.

In contrast to rapid technological improvement of laser generators, laser fibers have basically maintained the same architectural concept over decades. Nevertheless, constant improvements of surgical techniques have led to a better understanding of laser fiber properties that may impact on surgical routine.

A review is warranted to provide the most recent findings on properties, efficacy, and safety of laser fibers and their related accessories in the field of urology.

ANATOMY OF A SURGICAL LASER FIBER

Core, cladding, and jacket

Laser fibers are made of a low-hydroxyl (OH^-)silicate core (amorphous silicon dioxide, SiO_2), a fluorine-doped silicate cladding and an outer protective plastic jacket (typically ethylene tetrafluoroethylene) (Fig. 1a). The cladding has a lower refraction index

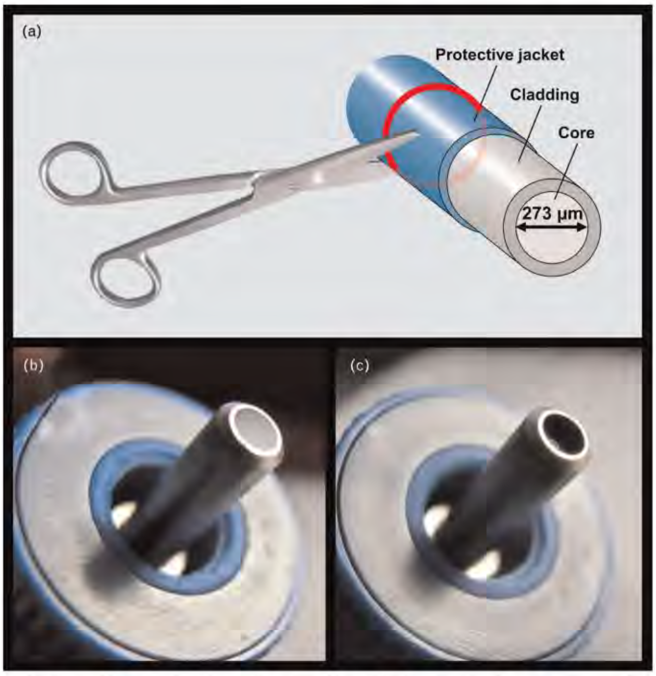


FIGURE 1. Anatomy of a laser fiber. (a) Distal tip of a laser fiber: The low-hydroxyl core is surrounded by a fluorine-doped cladding, which is surrounded by a plastic protective jacket. The metallic scissors and the red circle illustrate an advantageous cleaving technique through the protective jacket, allowing for a coated fiber tip design. (b) Proximal end of a laser fiber: intact SMA connector with a flat silicate surface. (c) Proximal end of a laser fiber: damaged SMA connector with a burned-down silicate surface from heat generation during laser application.

than the core, allowing for total internal reflection and almost loss-less traveling of laser energy (photons) within the fiber core.

True fiber diameter

Interestingly, the packaging labels of laser fibers can lead to two misconceptions concerning the actual fiber diameter. Where the labeling usually indicates the inner core diameter of the fiber, the actual measurement of this inner core may be distinguishably different from the labeled diameter. Additionally, the actual outer diameter (OD) of the fiber, including cladding and plastic jacket, is considerably larger than the labeled diameter, which needs to be taken into consideration when anticipating the space it will take up in the working channel of a ureteroscope. The literature evaluating these misconceptions in laser fibers labeled as '200 μm' is summarized in Table 1 [13–17].

Connector

A complex arrangement of optical lenses within laser generators is necessary to bundle laser energy to the connector, where the surgical laser fiber can be attached. To ensure proper coupling of the laser fiber, most manufacturers use the so-called 'SubMiniature version A' (SMA) 905 or 906 connector (Fig. 1b).

The quality of the spatial beam profile of the emitted photons defines the minimal core diameter of the laser fiber that can be connected to the laser generator. The Holmium:YAG exemplifies the importance of that property, since its heterogeneous spatial beam profile makes it impossible to use fibers with a core diameter smaller than 200 μm, at the risk causing thermal damages to the laser generator [16]. Even larger laser fibers with a 270 μm core diameter have been found to show substantial surface alterations at the proximal fiber end after Holmium:YAG lithotripsy, further illustrating the limitations and hazards of fiber coupling at the connector [18] (Fig. 1c).

Table 1. True fiber diameter of laser fibers labelled as '200'

First author and year of publication	Brand labels (as reported in original manuscripts)	Laboratory measurements	
		Outer diameter (μm)	Core diameter (μm)
Knudsen 2005 [13]	Sharplan 200	238	x
	Dornier LG Super 200	390	x
	Lumenis SL 200	408	x
Mues 2009 [14]	Dornier LG Super 200	393	x
	Boston Scientific Accuflex 200	406	x
	Lumenis SlimLine 200	408	x
	Lumenis SlimLine EZ 200	423	x
	Trimedyne FlexMAX 200	445	x
Kronenberg 2014 [15]	EMS SmartFiber 200	379	200
	Bard EndoBeam 200	384	199
	AMS SureFlex 200	407	203
	Boston Scientific AccuMax 200	433	239
	Lumenis SlimLine 200	433	278
Akar 2015 [16]	Cook-HLF-S200	374	x
	Storz ScopeSafe 200	374	x
	Bard EndoBeam 200	377	x
	Lumenis SlimLine 200	421	x
	Boston Scientific Flexiva 200	443	x
	Boston Scientific Flexiva TracTip 200	460	x
Lusch 2016 [17]	Cook OptiLite 200	357	x
	Storz ScopeSafe 200	360	x
	Cook SmartSync 200	366	x
	Boston Scientific AccuMax 200	418	x
	Boston Scientific AccuTrac 200	437	x

LASER FIBER FLEXIBILITY

The flexibility of laser fibers is of utmost importance to flexible ureteroscopy, since any resistance to the deflection mechanism at the distal tip of the ureteroscope may cause failure to access all renal cavities [4▪]. Increasing OD of laser fibers is the most important parameter directly correlating with increasing impairment of ureteroscopes' deflection. Potential loss of deflection ranges from 0 to 99° and has been summarized in Table 2 [13,14,16,17,19–22].

Additionally, the architectural construct and type of materials seem to influence flexibility of laser fibers. This is exemplified by a study from Knudsen *et al.* where the 'IQinc SureFlex 273T' fiber (true OD 422 μm) caused less deflection impairment than the 'Dornier LG Super 200' (true OD 390 μm) and 'Lumenis SL 200' (true OD 408 μm) [13]. The results were corroborated by Mues *et al.* and Akar *et al.* with the 'Boston Scientific Accuflex 273' (true OD 413 μm) and 'Storz ScopeSafe 272' (true OD 420 μm) causing less deflection impairment than the 'Lumenis SlimLine 200' (true OD 408 μm) [14,16].

Fiber fracture

Increasing deflection angle and decreasing bend radius of a laser fiber will cause increasing loss of energy transmission, as it has been demonstrated by Lusch *et al.* [17] and Heckscher *et al.* [23▪]. From a clinical point of view, this loss of power output may not appear clinically significant, since it hardly ever exceeds 2% of the nominal pulsed energy. On the other hand, this energy loss may cause fiber fracture. Fiber fracture can occur when the bent laser fiber exceeds the critical angle of total internal reflection, thus causing laser energy to involuntary penetrate through the cladding by evanescence. Fiber fracture is an important medical hazard, since the uncontrolled loss of laser energy puts ureteroscopes, patients, and surgeons at risk of damage and injury. Established determinants of fiber fracture are decreasing bend radius, decreasing pulse duration ('short pulse'), increasing core diameter, and increasing pulsed energy [13,14,16,17,20,24].

LASER FIBER BURNBACK

Degradation of the laser fiber tip occurs almost invariably during laser lithotripsy as a consequence of a phenomenon described as the 'burn-back effect'. The latter is easily observable and well known by urologists and prompts possible additional manipulations to the laser fiber to compensate for the loss of fiber tip length [25]. These changes can be measured either by microscopic analysis of the laser fiber tip, by power output measurement, or by changes in the laser aiming beam quality [26▪]. The extent of energy transmission loss as well as fiber degradation length is highly variable and has been reported as difficult to predict in multiple studies [25,27,28]. Also, the exact causes of fiber degradation from burn-back are yet to be fully understood. The proposed mechanisms include thermal, optical and mechanical causes.

Although the fiber tip degradation from burn-back does not occur when firing in water *in vitro* [25], this phenomenon has also been described during tissue applications such as Holmium laser enucleation of the prostate [29▪]. Established determinants of the burn-back effect are stones (particularly hard ones) or tissues as targets, decreasing core diameter, increasing pulse energy, increasing number of pulses, decreasing pulse duration ('short pulse'), and increasing axial force between the tip of the laser and the target [25,28,29▪,30▪].

Double-firing effect

In 2020, Ryan *et al.* evaluated a phenomenon described as 'double-firing effect', where not only

Table 2. Loss of ureteroscope's deflection caused by laser fibers

First author and year of publication	Loss of deflection (compared to empty working channel)			
	'100' fibers	'200' fibers	'270' to '273' fibers	'365' to '400' fibers
Knudsen 2005 [13]	x	−10° to −12°	−12°	−18° to −20°
Mues 2009 [14]	x	−9° to −38°	−22° to −53°	−40° to −99°
Lusch 2013 [19]	x	−7° to −8°	−40° to −42°	x
Akar 2015 [16]	x	−21° to −57°	−39° to −45°	−73° to −77°
Shin 2016 [20]	x	−10° to −39°	x	x
Lusch 2016 [17]	x	0° to −18°	−21° to −25°	−64° to −67°
Wilson 2016 [21]	−1°	x	x	x
Baghdadi 2017 [22]	x	0° to −33°	0° to −74°	x

the tip of the laser fiber would get damaged, but where the fiber would also get damaged within 4–8 mm further proximal from the tip [31]. Of note, the authors explored rather high pulse energy levels with a Holmium:YAG laser (pulse energy of 1.0 J and 2.0 J, together with either 200 μm or 365 μm core diameter fibers, respectively). Consequently, it remains to be clarified whether the double-firing effect may be prevented by low pulse energy levels (e.g. 0.2 J) or different laser technologies for laser lithotripsy (e.g. the TFL). Established determinants of the double-firing effect are stones as targets, increasing pulse energy, and increasing number of pulses [31].

LASER FIBER CLEAVAGE

User instruction manuals from laser generators and laser fiber providers recommend to reprocess the laser fiber tip whenever damaged to ensure optimal performance. Special fiber strippers and cleaving tools are provided to the operators to reprocess the fiber tips (Fig. 2). A major impairment to these recommendations is that there is no precise protocol on how to quantify damages to the fiber tip and when to choose to reprocess the laser fiber tip. Consequently, some authors have questioned the true clinical impact of fiber tip reprocessing [32].

Fiber strippers

Of interest, Kronenberg *et al.* found that stone ablation was significantly worse for stripped fibers (Fig. 2d–f) compared to unstripped 'coated' fibers (Fig. 2g) in an *ex vivo* study with various parameters using the Holmium:YAG laser and fiber labeled as '272 μm' [33]. A possible explanation was damages to the fiber cladding caused by the stripper tool found on microscopic analysis (Fig. 2f). Ritchie *et al.* found more controversial results with a higher ablated stone volume in favor of stripped fibers at equivalent power output, although these results were based on fibers labeled as '365 μm' from a brand known to have the largest discrepancies with their real fiber core diameters, rendering translation of their results to clinical routine questionable [34].

Fiber cleavage

Haddad *et al.* showed that fiber tip cleavage with ceramic scissors achieved better baseline power output (before lithotripsy) compared to metallic scissors for fragmentation settings (Holmium:YAG, 2.0 J, 5 Hz, '272 μm' fiber). The study group of Baldwin *et al.* then confirmed differences in laser fiber performance depending on fiber cleaving tools, but soon realized that these differences only last during a short time after laser activation, possibly due to fiber tip deterioration from burn-back and double-firing effects which occur anyway, irrespective of fiber cleavage technique [35,36].

Rapid fiber tip deterioration

The rapid fiber tip deterioration and associated loss of power output occurring during lithotripsy were confirmed by Haddad *et al.*, Ritchie *et al.*, and Aldoukhi *et al.*, who found that no differences in power

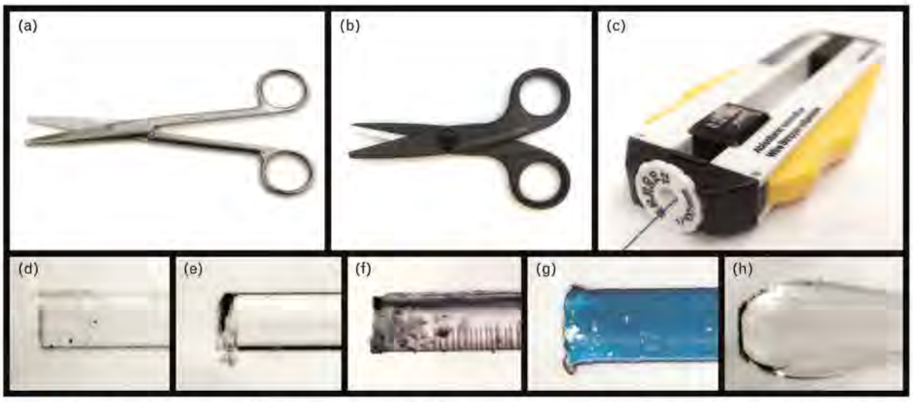


FIGURE 2. Fiber tip reprocessing. (a) Metallic scissors. (b) Ceramic scissors. (c) Fiber stripper. (d) New and polished tip. (e) Stripped and cleaved tip. (f) Damages to the fiber cladding caused by the stripper tool. (g) Unstripped, coated tip. (h) Ball-tip design.

output can be found after 1–3.6 min of laser lithotripsy with various Holmium:YAG settings [34,37, 38▪]. One may therefore question the real benefit of reprocessing fiber tips when deteriorations become evident, since it would translate into countless interruptions of the operation to reprocess fiber tips with no tangible clinical benefit.

WORKING CHANNEL PROTECTION

The silicate tip of a laser fiber presents as a serious hazard to the soft and fragile working channel of flexible ureteroscopes, which is usually made out of polytetrafluoroethylene. Forced insertion of a laser fiber in a deflected ureteroscope may cause abrasion and perforation of the working channel, therefore permanently damaging the scope. In an attempt to prevent this hazard, protective laser sheaths have been evaluated in the early years of flexible ureteroscopy (FlexGuard and ScopeGuardian) [19,39,40]. Unfortunately, these protective sheaths suffered from too many limitations (loss of irrigation flow and scope deflection) and have therefore been discontinued.

Ball-tip design

The ball-tip design has been introduced in 2015 as a viable solution for reducing friction forces and preventing working channel damages from fiber insertion (Fig. 2h) [20]. Studies using deflection angles of up to 270° and a bend radius as low as 1.0 cm did not reveal any damages when inserting ball-tip laser fibers, whereas 'regular' flat-tip designs as well as stripped-and-cut fibers caused working channel perforation rendered further fiber advancement impossible in many scenarios [20,41]. Regarding stone ablation efficiency, no differences have been found between ball-tip fibers and 'regular' flat-tip fibers [20,21,42].

A limitation to the ball-tip design is the inevitable fiber tip deterioration occurring after laser activation (see burnback and double-firing effects above). Although the extent of ball-tip deterioration was marginal at low pulse energy settings (<1.0 J) in multiple studies, it may be just sufficient to become as serious threat to the working channel [20,21,42]. At high pulse energy settings, complete deterioration of the ball-tip may occur within less than 300 pulses [42]. Established determinants of ball-tip design deterioration are increasing pulse energy and increasing number of pulses [20,21,42]. The ball-tip design shall therefore be understood as a 'single-use' benefit only applying to new fibers. After laser activation, safety principles of 'regular' flat-tip fibers apply, namely straightening the ureteroscope during fiber insertion.

Coated laser fiber tips

In response to the above observations, Traxer *et al.* explored the possibility of using the protective jacket of unstripped fiber tips ('coated tips', Fig. 2g) as a means of protecting the working channel when inserting fibers in deflected scopes [22]. As a matter of fact, coated fibers performed almost as good as ball-tip design fibers. The authors concluded that this technique may outperform the ball-tip design, since it can be reproduced for any fiber at no extra-costs by simply cleaving fibers through the protective jacket with regular metallic scissors (Fig. 1a).

Additionally, coated fibers allow for an optimal visual control of the fiber tip, which is particularly relevant to ureteroscopy because of frequent visibility impairments from bleeding sources or stone dust. Comparatively, visual control of transparent stripped or ball-tip fibers is rapidly lost under such circumstances and may cause frequent procedural interruptions and decreased operative efficacy.

Reusable vs. single-use fibers

Although Knudsen *et al.* advocated the use of reusable laser fibers as more cost-efficient, Chapman *et al.* highlighted that scope damage may occur more frequently with reusable fibers in comparison to single-use fibers, rendering the reusable version more costly [43,44]. Small cracks or fractures from fiber reprocessing may cause energy leaks at a distance from the fiber tip, possibly damaging the scope or injuring the patient or operating theater personnel. Consequently, the integrity of reusable fibers must be checked prior to their use.

The safety distance concept

One additional measure to prevent damages to the working channel and ureteroscope is the safety distance concept, which was presented in 2016 by Talso *et al.* [45]. In order to prevent contact of the scope with the cavitation bubble caused by Holmium:YAG laser activation, the authors concluded that maintaining the fiber tip at 1/4 of the view field ensures the necessary minimal safety distance of 3 mm between the tip of the fiber and the scope.

GREENLIGHT LASER FIBERS

Greenlight laser generators are mainly used in conjunction with side-firing laser fibers for laser vaporization of the prostate. These particular fibers underwent several modifications over time, due to their initially limited efficiency caused by fiber tip degradation. First-generation fibers (80 W GreenLight PV system) were shown to suffer a median

10%, 24%, and 80% output power decrease from baseline after application of 100, 200, and 275 kJ, respectively, with only 10% of all fibers free of significant output changes [46]. Second-generation fibers (120 W GreenLight HPS system) with improved laser beam still suffered a significant output losses with 43% decrease from baseline already occurring after application of 25 kJ [47]. Third-generation fibers (180 W GreenLight XPS system) with improved laser beam, active fiber cooling (MoXy fibers) and an integrated fiber tip heat-sensor (FiberLife) still suffered a median 23%, 43% and 49% power output decrease after application of 25, 150 and 250 kJ, respectively [48].

It, therefore, seems that side-firing laser fibers for greenlight laser vaporization of the prostate still need some improvements to withstand the overall power output increase (from 80 to 180 W) that was necessary to improve the initial limited efficacy of this procedure.

PROTECTIVE GLASSES

Medical lasers used in the field of urology belong to the highest hazard class ('Class IV') according to The American National Standards Institute [49,50]. This class of lasers may rapidly cause harm to the skin and eyes. Consequently, laser manufacturers recommend wearing protective glasses adapted to the emitted laser wavelength for all personnel and patients present in the operative room. These recommendations are mostly based on theoretical calculations.

Potential eye injuries include corneal burns and cataracts from infrared lasers such as the Holmium:YAG (2120 nm) and the TFL (1940 nm), as well as severe retinal injuries from the lasers within the visible light wavelength, such as the Greenlight-laser (532 nm).

The Canadian Urological Association is the only panel of experts to have made recommendations specific to the field of urology to date [51••]. Based on a systematic review of literature, the authors concluded that there is insufficient practical evidence highlighting the benefit of routine safety eyewear when using Holmium:YAG lasers. In a database analysis of adverse events reported to the United States Food and Drug Administration over 10 years, Althunayan *et al.* found only 11 minor skin burns caused by broken laser fibers and no reports of eye injuries from Holmium:YAG lasers [52]. In an experimental study on porcine eyes, Villa *et al.* found no Holmium:YAG laser-associated injuries as long as the tip of the laser fiber was maintained 5 cm or more away from the cornea [53]. Interestingly, the authors also found that regular corrective eyewear was as protective as laser safety glasses. In a survey of 264 urologists, Paterson *et al.* reported that only 40% of the respondents routinely wore laser safety glasses, whereas 97% of the respondents reported using the Holmium:YAG laser on a regular basis [54].

A recent review on ocular hazards of endourologists concluded that other underestimated threats to the eye such as irrigation, urine or blood splashes, as well as associated-ray-associated cataract are much more clinically relevant compared to laser-induced eye injuries [55]. The authors, therefore, propose the routine use of X-ray glasses for Holmium:YAG applications, since these may prevent all 3 hazards at once. Contrarily, the authors recommend laser-specific protective eyewear for greenlight laser applications, considering the much greater risk of retinal injuries.

FUTURE DEVELOPMENTS

Several experimental concepts relating to laser fibers have been explored in recent years, particularly aiming at improving laser lithotripsy.

Sung *et al.* evaluated an artificial intelligence (AI) device based on the visualization of the colored protective jacket of laser fibers [56]. A digital ureteroscope was employed for live-image processing. Whenever the blue protective jacket of the fiber was not recognized in the field of view, a control unit would deactivate the laser generator in order to prevent damages to the scope from inadvertent fiber retrieval within the working channel. The system proved to be very efficient. This study underlines the advantages of a cleavage technique through the protective jacket, since coated fiber tips allow a better visual control during the whole surgery. Special labeling and coloring of protective jackets shall be explored for AI-driven safety concepts in the future.

Hutchens et a. presented the concept of a hollow steel placed at the tip of laser fibers in order to artificially increase the working distance between the fiber tip and stone surface and herewith prevent fiber burnback [57]. Preventing fiber burnback during lithotripsy appeared particularly important to the authors, since they explored super-slim 100 μm core diameter laser fibers in conjunction with the TFL. The authors confirmed that no measurable burnback was found thanks to the hollow steel tip design. Increasing the working distance within the hollow steel tip design resulted in decreasing stone ablation rates, although this difference only became with working distances greater than 250 μm. The later observation is worth exploring, since it has recently been shown that noncontact lithotripsy may improve ablation efficiency [58]. Of note, a slight increase in stone retro-pulsion caused by the hollow steel tip design lead the authors to evaluate a 'fiber muzzle brake' tip design allowing the laser-induced vapor bubble to exit through lateral holes of a hollow steel placed at the fiber tip, in reminiscence of the propellant gas exiting a weapon's barrel. This novel tip design proved very efficient at preventing stone retropulsion, even performing better than regular bare fibers [59].

Most recently, vibrating super-slim 50, 100, and 150 μm core diameter fibers were evaluated as a means to improve stone dusting efficiency of the TFL [60]. Although the stone surface area revealed was significantly higher compared to nonvibrating fibers, the stone ablation volume did not differ between the two groups. The clinical impact of this vibrating fiber concept shall be further evaluated.

CONCLUSION

It is clear from this review that there is more than meets the eye with laser accessories and their attributes. Concerning surgical laser fibers, their actual fiber diameter is considerably larger than the size mentioned on packaging labels. Smaller fibers may allow for better irrigation flow, higher flexibility, and lower risk of fracture, conversely at greater risk of fiber tip deterioration from burnback effects. The latter effect occurs already after a few laser pulses during laser lithotripsy, thus questioning the necessity of fiber tip reprocessing, and limiting the benefit of the ball-tip design. In this context, cleavage of laser fibers through their protective plastic jacket with regular metallic scissors presents an advantageous technique to reprocess fibers tips. Regular metallic scissors are sufficient for cleaving the fiber. Concerning protective glasses, laser-specific eyewear may be omitted for Holmium:YAG applications, but must be worn during Greenlight laser use to prevent eyes injuries. Several aspects must be taken into account to take advantage of laser accessories and future developments may allow for smaller, safer and more wear-resistant laser fibers.

Acknowledgements

None.

ORCIDs: Etienne Xavier Keller: https://orcid.org/0000-0003-1667-7609.

Financial support and sponsorship

None.

Conflicts of interest

E.X.K. is a speaker and/or consultant for Coloplast, Olympus, Boston Scientific, Recordati, Debiopharm, and Alnylam and has no specific conflicts of interest relevant to this work.

P.K. has been a speaker and/or consultant for Boston Scientific, EDAP, Lumenis, Olympus and Rocamed and has no specific conflicts of interest relevant to this work. V.D.C. is a consultant for Axess Vision Technology, BD Bard and Coloplast and has no specific conflicts relevant to this work.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
- ■ of special interest
- ■■ of outstanding interest

1. Dołowy Ł, Krajewski W, Dembowski J, *et al.* The role of lasers in modern urology. Cent Eur J Urol 2015; 68:175–182.
2. Korn SM, Hübner NA, Seitz C, *et al.* Role of lasers in urology. Photochem Photobiol Sci 2019; 18:295–303.
3. ■ Netsch C, Becker B, Herrmann TRW, *et al.* Laser in der Urologie. Der Urologe 2021; 60:1211–1219.

Concise and up-to-date summary on lasers used in the field of urology (written in German language).

4. ■ Keller EX, De Coninck V, Traxer O. Next-generation fiberoptic and digital ureteroscopes. Urol Clin N Am 2019; 46:147–163.

Exhaustive and visonary review on current limitations and future developments to flexible ureteroscopy.

5. Geraghty RM, Jones P, Somani BK. Worldwide trends of urinary stone disease treatment over the last two decades: a systematic review. J Endourol 2017; 31:547–556.
6. Kronenberg P, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 2015; 33:463–469.
7. ■ Traxer O, Keller EX. Thulium fiber laser: the new player for kidney stone treatment? A comparison with Holmium:YAG laser. World J Urol 2019; 38:1883–1894.

First review available in litterature summarizing current evidence on the Thulium fiber laser based on laboratory studies. Fundamental principles on the operating mode of lasers are succintly reviewed.

8. ■ Keller EX, De Coninck V, Doizi S, *et al.* Thulium fiber laser: ready to dust all urinary stone composition types? World J Urol 2020; 39:1693–1698.

First orginal study verifying the application of the Thulium fiber laser for lithotripsy of all most frequent stone composition types.

9. Kronenberg P, Traxer O. The laser of the future: reality and expectations about the new thulium fiber laser—a systematic review. Transl Androl Urol 2019; 8(S4):S398–S417.
10. Keller EX, Traxer O. SuperPulsed Thulium fiber laser: the ultimate laser for lithotripsy? Arch Esp Urol 2020; 8:767–776.
11. Gilling PJ, Cass CB, Cresswell MD, Fraundorfer MR. Holmium laser resection of the prostate: preliminary results of a new method for the treatment of benign prostatic hyperplasia. Urology 1996; 47:48–51.
12. Bach T, Muschter R, Sroka R, *et al.* Laser treatment of benign prostatic obstruction: basics and physical differences. Eur Urol 2012; 61:317–325.
13. Knudsen BE, Glickman RD, Stallman KJ, *et al.* Performance and safety of holmium: YAG laser optical fibers. J Endourol 2005; 19:1092–1097.
14. Mues AC, Teichman JMH, Knudsen BE. Evaluation of 24 holmium:YAG laser optical fibers for flexible ureteroscopy. J Urol 2009; 182:348–354.
15. Kronenberg P, Traxer O. The truth about laser fiber diameters. Urology 2014; 84:1301–1307.
16. Akar EC, Knudsen BE. Evaluation of 16 new holmium:yttrium-aluminum-garnet laser optical fibers for ureteroscopy. Urology 2015; 86:230–235.
17. Lusch A, Heidari E, Okhunov Z, *et al.* Evaluation of contemporary holmium laser fibers for performance characteristics. J Endourol 2016; 30:567–573.
18. Wilson CR, Hardy LA, Irby PB, Fried NM. Microscopic analysis of laser-induced proximal fiber tip damage during holmium:YAG and thulium fiber laser lithotripsy. Opt Eng 2016; 55:046102.
19. Lusch A, Abdelshehid C, Liss MA, *et al.* In vitro evaluation of scopesafe fibers and the scope guardian sheath in prevention of ureteroscope endolumenal working damage. J Endourol 2013; 27:768–773.
20. Shin RH, Lautz JM, Cabrera FJ, *et al.* Evaluation of Novel Ball-Tip Holmium Laser Fiber: impact on ureteroscope performance and fragmentation efficiency. J Endourol 2016; 30:189–194.
21. Wilson CR, Hardy LA, Kennedy JD, *et al.* Miniature ball-tip optical fibers for use in thulium fiber laser ablation of kidney stones. J Biomed Opt 2016; 21;18003.
22. Baghdadi M, Emiliani E, Talso M, *et al.* Comparison of laser fiber passage in ureteroscopic maximum deflection and their influence on deflection and irrigation: Do we really need the ball tip concept? World J Urol 2017; 35:313–318.

23. Heckscher D, Zeng J, Samolis P, *et al.* The effect of holmium laser fiber ■ bending radius on power delivery during flexible ureteroscopy. J Endourol 2020; 34:682–686.

This recent study evaluates the effects of bending a laser fiber on its energy transmission. In analogy to previous studies, the authors found almost no loss of power output, even for very low bend radius.

24. Haddad M, Emiliani E, Rouchausse Y, *et al.* Impact of the curve diameter and laser settings on laser fiber fracture. J Endourol 2017; 31:918–921.
25. Mues AC, Teichman JMH, Knudsen BE. Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol 2009; 23:1425–1428.
26. Jongjitaree K, Subpayakorn C, Taweemonkongsap T, *et al.* The effect of laser ■ fiber on the damage of the working channel of a flexible ureteroscope. Heliyon 2020; 6:e05605.

Several fiber cleaving tools were evaluated in this study, concluding that ceramic scissors perform best compared to regular metallic scissors. Unfortunately, the authors did not evaluate if these baseline differences are maintained after several laser pulses on stones.

27. Khemees TA, Shore DM, Antiporda M, *et al.* Evaluation of a new 240-μm single-use Holmium:YAG optical fiber for flexible ureteroscopy. J Endourol 2013; 27:475–479.
28. Chan KF, Kang HW, Pang S, *et al.* The effect of force on laser fiber burnback during lithotripsy. Ther Diagn Urol 2018; 10468:104680I.
29. Nottingham CU, Large T, Heiman J, *et al.* Comparison of laser fiber degrada- ■ tion and perioperative outcomes following holmium laser enucleation of the prostate using 550 and 1000 μm fiber diameters. Int Urol Nephrol 2019; 52:639–644.

This study highlights that the burnback effect is not only found in laser lithtripsy, but also during soft tissue applications such as the Holmium:YAG laser enucleation of the prostate.

30. Levin BA, Aldoukhi AH, Black KM, *et al.* Burnback: the role of pulse duration ■ and energy on fiber-tip degradation during high-power laser lithotripsy. Lasers Med Sci 2021; 36:1817–1822.

In this throughout ex-vivo evaluation of the burnback effect, the authors confirm many findings from previous studies: determinants of burnback are increasing pulse energy, increasing number of pulses, decreasing pulse duration ('short pulse').

31. Riveiro Rodriguez A, Ryang SH, Ly TH, *et al.* How to reduce 'double-firing'-induced scope damage by investigating the relationship between laser fiber core degradation and fiber jacket burn? Plos One 2020; 15:e0233135.
32. Pauchard F, Ventimiglia E, Traxer O. Laser fibers and transparent tips? No Thanks! Urology 2020; 144:272–273.
33. Kronenberg P, Traxer O. Are we all doing it wrong? Influence of stripping and cleaving methods of laser fibers on laser lithotripsy performance. J Urol 2015; 193:1030–1035.
34. Ritchie C, Yang P, Peplinski B, *et al.* Jackets off: the impact of laser fiber stripping on power output and stone degradation. J Endourol 2017; 31:780–785.
35. Vassantachart JM, Lightfoot M, Yeo A, *et al.* Laser fiber cleaving techniques: effects on tip morphology and power output. J Endourol 2015; 29:84–89.
36. Peplinski B, Faaborg D, Miao E, *et al.* The effect of laser fiber cleave technique and lithotripsy time on power output. J Endourol 2016; 30:678–684.
37. Haddad M, Emiliani E, Rouchausse Y, *et al.* Impact of laser fiber tip cleavage on power output for ureteroscopy and stone treatment. World J Urol 2017; 35:1765–1770.
38. Aldoukhi AH, Knudsen BE, Black KM, *et al.* Are we cutting ourselves short? ■ Laser lithotripsy performance based on differences in fiber-tip preparation. Urology 2019; 134:79–83.

This study confirms that any differences from different fiber tip reprocessing techniques and tools become almost vanishing within few minutes of laser lithotriopsy.

39. Dursk E, Hruby G, Mitchell R, *et al.* Evaluation of a protective laser sheath for application in flexible ureteroscopy. J Endourol 2008; 22:57–59.
40. Herrmann TRW, Bach T, Imkamp F, *et al.* Insertion sheaths prevent breakage of flexible ureteroscopes due to laser fiber passage: a video-endoluminal study of the working channel. J Endourol 2010; 24:1747–1751.
41. Carlos EC, Li J, Young BJ, *et al.* Let's get to the point: comparing insertion characteristics and scope damage of flat-tip and Ball-Tip Holmium Laser Fibers. J Endourol 2019; 33:22–26.
42. Kronenberg P, Traxer O. Lithotripsy performance of specially designed laser fiber tips. J Urol 2016; 195:1606–1612.
43. Knudsen BE, Pedro R, Hinck B, Monga M. Durability of reusable holmium:YAG laser fibers: a multicenter study. J Urol 2011; 185:160–163.
44. Chapman RA, Somani BK, Robertson A, *et al.* Decreasing cost of flexible ureterorenoscopy: single-use laser fiber cost analysis. Urology 2014; 83:1003–1005.
45. Talso M, Emiliani E, Haddad M, *et al.* Laser fiber and flexible ureterorenoscopy: the safety distance concept. J Endourol 2016; 30:1269–1274.
46. Hermanns T, Sulser T, Fatzer M, *et al.* Laser fibre deterioration and loss of power output during photo-selective 80-W potassium-titanyl-phosphate laser vaporisation of the prostate. Eur Urol 2009; 55:679–686.
47. Hermanns T, Strebel DD, Hefermehl LJ, *et al.* Lithium triborate laser vaporization of the prostate using the 120 W, high performance system laser: high performance all the way? J Urol 2011; 185:2241–2247.
48. Hermanns T, Grossmann NC, Wettstein MS, *et al.* Is loss of power output due to laser fiber degradation still an issue during prostate vaporization using the 180 W GreenLight XPS laser? World J Urol 2018; 37:181–187.
49. Thomas R, Zimmerman S, Edwards B. ANSI Z136.1 – 2014. American National Standard for Safe Use of Lasers [press release]. Orlando, FL: Laser Institute of America; 2014.
50. Thomas R, Zimmerman S, Edwards B. American National Standard for Safe Use of Lasers in Healthcare [press release]. Orlando, FL: Laser Institute of America; 2011.
51. Bhojani N, Andonian S, Watterson JD, *et al.* Canadian Urological Association ■■ best practice report: Holmium:YAG laser eye safety. Can Urol Assoc J 2020; 14:380–382.

This is the first and sole publication to date with recommandations and evaluation on laser protective glasses for Holmium:YAG applications in urology.

52. Althunayan AM, Elkoushy MA, Elhilali MM, Andonian S. Adverse events resulting from lasers used in urology. J Endourol 2014; 28:256–260.
53. Villa L, Cloutier J, Compérat E, *et al.* Do we really need to wear proper eye protection when using holmium:YAG laser during endourologic procedures? Results from an ex vivo animal model on pig eyes. J Endourol 2016; 30:332–337.
54. Paterson NR, Fitzpatrick R, Blew B, *et al.* Perceptions and practice patterns of holmium laser goggles in endourological procedures: an unnecessary evil? J Endourol 2019; 33:146–150.
55. Doizi S, Audouin M, Villa L, *et al.* The eye of the endourologist: what are the risks? A review of the literature. World J Urol 2019; 37:2639–2647.
56. Sung C, Singh H, Schwartz M, *et al.* Evaluation of efficacy of novel optically activated digital endoscope protection system against laser energy damage. Urology 2008; 72:57–60.
57. Hutchens TC, Blackmon RL, Irby PB, Fried NM. Hollow steel tips for reducing distal fiber burn-back during thulium fiber laser lithotripsy. J Biomed Opt 2013; 18:078001.
58. De Coninck V, Keller EX, Chiron P, *et al.* Ho:YAG laser lithotripsy in non-contact mode: optimization of fiber to stone working distance to improve ablation efficiency. World J Urol 2019; 37:1933–1939.
59. Hutchens TC, Gonzalez DA, Irby PB, Fried NM. Fiber optic muzzle brake tip for reducing fiber burnback and stone retropulsion during thulium fiber laser lithotripsy. J Biomed Opt 2017; 22:18001.
60. Hall LA, Gonzalez DA, Fried NM. Thulium fiber laser ablation of kidney stones using an automated, vibrating fiber. J Biomed Opt 2019; 24:038001.

Article 10: Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology.

EUROPEAN UROLOGY FOCUS 10 (2024) 599–611

available at www.sciencedirect.com
journal homepage: www.europeanurology.com/eufocus

Review – Stone Disease

Laser Ablation Efficiency, Laser Ablation Speed, and Laser Energy Consumption During Lithotripsy: What Are They and How Are They Defined? A Systematic Review and Proposal for a Standardized Terminology

Jia-Lun Kwok[a,b], *Vincent De Coninck*[c,d,e], *Eugenio Ventimiglia*[c,d,f], *Frédéric Panthier*[c,g], *Mariela Corrales*[c,g], *Alba Sierra*[c,d,h], *Esteban Emiliani*[d,i,j], *Michele Talso*[d,j,k], *Arkadiusz Miernik*[l], *Peter Kronenberg*[j,m], *Dmitry Enikeev*[n,o], *Bhaskar Somani*[j,p], *Khurshid R. Ghani*[q], *Olivier Traxer*[c,g,j], *Etienne Xavier Keller*[a,c,d,*]

[a] Department of Urology, University Hospital Zurich, University of Zurich, Zurich, Switzerland; [b] Department of Urology, Tan Tock Seng Hospital, Singapore, Singapore; [c] Progressive Endourological Association for Research and Leading Solutions (PEARLS), Paris, France; [d] Young Academic Urologists (YAU) Endourology and Urolithiasis Working Group, Arnhem, The Netherlands; [e] Department of Urology, AZ Klina, Brasschaat, Belgium; [f] Division of Experimental Oncology/Unit of Urology, Urological Research Institute, IRCCS Ospedale San Raffaele, Milan, Italy; [g] Sorbonne Université, GRC n°20, Groupe de Recherche Clinique sur la Lithiase Urinaire, Hôpital Tenon, F-75020 Paris, France; [h] Urology Department, Hospital Clinic de Barcelona, Barcelona, Spain; [i] Department of Urology, Fundación Puigvert. Autonomous University of Barcelona, Barcelona, Spain; [j] Progress in Endourology, Technology and Research Association (PETRA), Paris, France; [k] Department of Urology, ASST Fatebenefratelli-Sacco, Luigi Sacco University Hospital, Milan, Italy; [l] Department of Urology, Faculty of Medicine, Medical Center, University of Freiburg, Freiburg, Germany; [m] Department of Urology, Hospital CUF Descobertas, Lisbon, Portugal; [n] Department of Urology, Comprehensive Cancer Center, Medical University of Vienna, Vienna, Austria; [o] Institute for Urology and Reproductive Health, Sechenov University, Moscow, Russia; [p] Department of Urology, University Hospital Southampton, Southampton, UK; [q] Department of Urology, University of Michigan, Ann Arbor, MI, USA

Article info

Article history:
Accepted October 4, 2023
Available online 7 November 2023
Associate Editor: Malte Rieken

Keywords:
Ureteroscopy
Percutaneous nephrolithotomy
Laser
Stone disease
Lithotripsy
Performance
Urolithiasis

Abstract

Context: Laser performance for lithotripsy is currently reported using units of measurement such as J/mm^3, mm^3/J, mm^3/s, s/mm^3, and mm^3/min. However, there are no current standardized definitions or terminology for these metrics. This may lead to confusion when assessing and comparing different laser systems.
Objective: The primary objective was to summarize outcome values and corresponding terminology from studies on laser lithotripsy performance using stone volume in relation to time or energy. The secondary objective was to propose a standardized terminology for reporting laser performance metrics.
Evidence acquisition: A systematic review of the literature was conducted using the search string ("j*/mm3" OR "mm3/j*" OR "mm3/s*" OR "s*/mm3" OR "mm3/min*" OR "min*/mm3" AND "lithotripsy") on Scopus, Web of Science, Embase, and PubMed databases. Study selection, data extraction, and quality assessment were performed independently by two authors.
Evidence synthesis: A total of 28 studies were included, covering holmium:yttrium-aluminum-garnet (Ho:YAG), MOSES, and thulium fiber laser (TFL) technologies. Laser energy consumption values reported for the studies ranged from 2.0 – 43.5 J/mm^3

* Corresponding author. Department of Urology, University Hospital Zurich, Frauenklinikstrasse 10, CH-8091 Zurich, Switzerland. Tel. +41 44 2555409; Fax: +41 44 2554555.
E-mail address: etiennexavier.keller@usz.ch (E.X. Keller).

https://doi.org/10.1016/j.euf.2023.10.004

in vitro and from 2.7 – 47.8 J/mm^3 *in vivo*, translating to laser ablation efficiency of 0.023 – 0.500 mm^3/J and 0.021 – 0.370 mm^3/J, respectively. Laser ablation speeds ranged from 0.3 – 8.5 mm^3/s *in vivo*, translating to lasing time consumption of 0.12 – 3.33 s/mm^3. Laser efficacy ranged from 4.35 – 51.7 mm^3/min *in vivo*. There was high heterogeneity for the terminology used to describe laser performance for the same metrics.

Conclusions: The range of laser performance metric values relating stone volume to energy or time is wide, with corresponding differing terminology. We propose a standardized terminology for future studies on laser lithotripsy, including laser ablation efficiency (mm^3/J), laser ablation speed (mm^3/s), and laser energy consumption (J/mm^3). Laser efficacy (mm^3/min) is proposed as a broader term that is based on the total operative time, encompassing the whole technique using the laser.

Patient summary: We reviewed studies to identify the units and terms used for laser performance when treating urinary stones. The review revealed a wide range of differing units, outcomes, and terms. Therefore, we propose a standardized terminology for future studies on laser stone treatment.

1. Introduction

Treatment of urinary stone disease has been increasing worldwide [1]. Among the tools used to treat urinary stone disease, the laser has become the mainstay for lithotripsy in endourology [2]. There has been an evolution in laser technology, from the established holmium:yttrium-aluminum-garnet (Ho:YAG) laser and pulse modulation to thulium fiber laser (TFL), and the more recent novel pulsed thulium:YAG (p-Tm:YAG) laser [3–5].

Assessment of clinical stone burden has shifted to include volume measurements [6], mainly because of limitations in measuring the diameter for stones of differing shapes [7]. Assessment of laser ablation performance has also incorporated stone volume in terms of Joules/mm^3 in addition to mm^3/s as proxies for laser performance [8]. However, to the best of our knowledge, there is no standardized terminology for reporting laser ablation performance metrics in relation to volume, energy, and time.

The aim of our study was to review laser ablation performance outcomes in lithotripsy studies and the terminology in relating stone volume to laser energy and time. We also propose a standardized terminology for reporting laser performance parameters.

2. Evidence acquisition

This study was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) checklist [9].

2.1. Search strategy

A systematic review of the literature was carried out on June 26, 2023 using the Scopus, Web of Science, Embase, and PubMed databases, with no time-period restriction. The search string ("j*/mm3" OR "mm3/j*" OR "mm3/s*" OR "s*/mm3" OR "mm3/min*" OR "min*/mm3" AND "lithotripsy") was used for articles in English. Reference lists for the manuscripts selected were checked manually for additional eligible articles.

2.2. Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) reports on laser ablation performance in J/mm^3, mm^3/J, mm^3/s, s/mm^3, mm^3/min, or min/mm^3; and (2) evaluations of current laser technologies (Ho:YAG, TFL or p-Tm:YAG). Original studies and conference abstracts on both *in vitro* and *in vivo* studies were considered. Systematic reviews, case reports, editorials, and letters were not considered. The exclusion criteria were as follows: (1) studies not related to human laser lithotripsy or models; (2) comparative studies using non-laser-related comparators; and (3) ambiguous reporting of results, typically studies reporting results in mm^3/s but not specifying which time period the denominator referred to. If either total operative time or lasing time was reported, it was assumed that the denominator in mm^3/s referred to the time value reported, and these studies were not excluded.

2.3. Outcomes

The primary outcome of interest was laser performance reported in units of J/mm^3, mm^3/J, mm^3/s, s/mm^3, mm^3/min, or min/mm^3. The values reported were interpreted according to the following definitions: laser energy consumption = energy consumed per unit of ablated stone volume (J/mm^3); laser ablation efficiency = ablated stone volume per unit of energy (mm^3/J); laser ablation speed = ablated stone volume per unit of lasing time (mm^3/s); lasing time consumption = lasing time per unit of ablated stone volume (s/mm^3); and laser efficacy = ablated stone volume per unit of operative time (mm^3/min). Lasing time was defined as the cumulative time of laser pedal activation.

2.4. Data extraction

Two authors (J.-L.K. and E.X.K.) extracted data independently using a standardized form. Conflicts were resolved via selective analysis and consensus. The studies included were assessed for characteristics and relevant outcomes and are listed in Tables 1–3. When only results expressed

Table 1 – Summary of in vitro studies: main characteristics and results

Study	Laser type	Fiber size (µm)	Study setup	Stone volume and/or density	Ablation volume measurement method	Target	Comparator groups	Laser energy consumption (J/mm^3) [b]	Laser ablation efficiency (mm^3/J) [b]	Laser ablation speed (mm^3/s)
Panthier 2020 [12]	Ho:YAG 30 W	272	Single pulse	Not specified	Micro-CT with 3D segmentation software	COM	0.6 J	34.0 (3.3)	0.029 (0.003) [c]	–
							0.8 J	23.2 (5.2)	0.043 (0.008) [c]	
							1.0 J	14.7 (3.9)	0.068 (0.014) [c]	
						CYS	0.6 J	8.5 (1.8)	0.118 (0.021) [c]	
							0.8 J	7.8 (5.8)	0.128 (0.055) [c]	
							1.0 J	6.4 (2.2)	0.156 (0.040) [c]	
						UA	0.6 J	3.2 (0.6)	0.313 (0.049) [c]	
							0.8 J	2.4 (0.7)	0.417 (0.094) [c]	
							1.0 J	2.0 (0.5)	0.500 (0.094) [c]	
King 2022 [13]	Ho: YAG [a]	200	10 pulses at 10 different surface points	Not specified	Optical coherence tomography	BegoStone	Annular beam, 1.0 J	15.4 (2.6) [c]	0.065 (0.013)	–
							Circular beam, 1.0 J	43.5 (5.0) [c]	0.023 (0.003)	

CT = computed tomography; 3D = three-dimensional; COM = calcium oxalate monohydrate; CYS= cystine; UA = uric acid.
[a] Power not reported.
[b] Reported as mean (standard deviation).
[c] Calculated for this review.

as either J/mm^3 or mm^3/J were reported, we calculated the value for the corresponding unreported term (1/[mm^3/J] = [J/mm^3]). This was also done for mm^3/s and s/mm^3 results in the same manner. When the laser ablation speed was reported in minutes, this was converted to seconds to maintain consistency.

2.5. *Quality assessment: risk of bias*

For applicable studies, two authors (J.-L.K. and E.X.K.) assessed the risk of bias independently using two Cochrane tools: RoB 2 [10] for randomized control trials, and ROBINS-I [11] for comparative studies. Conflicts were resolved via consensus. A comprehensive description of the risk-of-bias assessment can be found in the Supplementary material.

Considering the heterogeneity of the study outcomes, a narrative review was performed rather than a quantitative analysis. The structure of the manuscript was decided via consensus among the authors.

3. Evidence synthesis

3.1. *Literature search*

We identified 96 studies via the database searches and two additional studies from reference lists, of which 28 studies were selected for final review [8,12–38]. The selection process is detailed in Figure 1. There were two *in vitro* [12,13] and 26 *in vivo* studies [8,14–38]. Nine were peer-reviewed conference abstracts [13,16,19,22,29–31,36,37] and the rest were full-text peer-reviewed original studies.

3.2. *Quality assessment: risk of bias*

Risk-of-bias assessment was not applicable to the two *in vitro* studies or to ten self-controlled observational series. Of the sixteen remaining studies, only one had high risk of bias [36], with all other studies having moderate risk of bias (Supplementary Fig. 1).

3.3. *Study characteristics and results*

Both of the *in vitro* studies used methods relating to single pulse(s) on the stone surface and calculated the ablated stone crater volume (Table 1). One reported laser energy consumption (J/mm^3) [12] and the other laser ablation efficiency (mm^3/J) [13]. Neither reported time-related outcomes.

Characteristics of the 26 *in vivo* studies are summarized in Table 2. Three (12%) were randomized controlled trials [14,17,36], five (19%) were prospective comparative studies [18,20,24,27,38], ten (38%) were prospective observational studies [8,15,16,25,26,28,29,32,34,35], and eight (31%) were retrospective studies [19,21–23,28,30,31,37]. The number of patients included in the studies ranged from 26 to 631. Surgery types included mostly ureteroscopy (ureter and kidney), with six studies (23%) evaluating mini percutaneous neprolithotomy (mPCNL) [22,27,28,30,35,38]. Methods for measuring stone volume included preoperative computed tomography (CT) software calculations in six studies (23%) [8,15,16,34,35,38] and the CT ellipsoid formula in twelve studies (46%) [14,17,18,20,23–28,32,33]. One study included the use of either CT or X-ray imaging

Table 2 – Summary of in vivo studies: characteristics

Study	Design	Pts	Laser type	Comparator groups	Surgery	Stone location	Laser fiber (μm)	Method for measuring ablated stone volume	Definition of SF status	Method for measuring SFR	SFR assessment	Basketing/ Sheath evacuation allowed
Regular Ho:YAG												
Alghamdi 2020 [14]	RCT	145	Ho:YAG 30 W	Pulse shape	URS	K & U	275, 600	Preop CT, EF	No fragments ≥1 mm	Intraoperative	Intraoperatively	NS
Panthier 2021 [15]	PO	26	Ho:YAG 30 W & 100 W	–	URS	K	230, 272	Preop CT, imaging software[b]	No fragments >3 mm on CT or endoscopic absence of fragments	CT, endoscopic inspection at end of procedure	NS	NS
Ventimiglia 2021 [8]	PO	30	Ho:YAG 35 W	–	URS	K	272	Preop CT, 3D-RV	NS	CT	4 wk	NS
Panthier 2022 [16]	PO	45	Ho:YAG [a]	–	URS	K	Not specified	Preop CT, imaging software[b]	NS	NS	NS	Yes
Shrestha 2022 [17]	RCT	120	Ho:YAG 120 W	Settings	URS	K	200	Preop CT, EF	No fragments	X-Ray KUB and US	4 wk	NS
Ho:YAG MOSES technology												
Majdalany 2021 [18]	PC	29	MOSES 120 W 1.0 vs 2.0	Laser	URS	K	230	Preop CT, EF	No fragments	X-Ray KUB, US, or CT	NS	Yes (stone analysis)
Antoine 2022 [19]	R	82	MOSES 120 W 1.0 vs 2.0	Laser	URS	K & U	200	NS	NS	Intraoperative	Intraoperatively	NS
Ho:YAG MOSES technology vs regular Ho:YAG												
Mullerad 2017 [20]	PC	34	MOSES 120 W	Laser mode	URS	K & U	200, 365, 550	Preop CT, EF	NR	NA	NA	NS
Mekayten 2019 [21]	R	631	MOSES 120 W vs Ho:YAG 20 W	Laser	URS	K & U	200, 365, 550	NS	<2–3 mm and asymptomatic	CT or US + X-ray KUB	4–6 wk	NS
Dunne 2021 [22]	R	140	MOSES 120 W vs Ho:YAG	Laser	mPCNL	K & U	Not specified	Preop CT, exact method NS	NS	NS	NS	Yes
Wang 2021 [23]	R	216	MOSES 120 W	Laser mode	URS	K	200	Preop CT, EF	No fragments ≥2 mm	X-Ray KUB or US	4 wk	No
TFL												
Enikeev 2020 [24]	PC	40	TFL	Settings	URS	K	Not specified	Preop CT, EF	No stones >2mm	CT	3 mo	NS
Corrales 2021 [25]	PO	50	TFL	Stone location	URS	K & U	150, 200	Preop CT, EF	NR	NA	NA	No (implied)
Enikeev 2021 [26]	PO	149	TFL	–	URS	U	200, 400	Preop CT, EF	No fragments >2 mm	CT	3 mo	NS
Korolev 2021 [27]	PC	125	TFL	Settings	mPCNL	K	400	Preop CT, EF	No fragments ≥2 mm	CT	3 mo	Yes
Taratkin 2021 [28]	R	318	TFL	Surgery	URS & mPCNL	K	200 (URS) 400 (mPCNL)	Preop CT, EF	No fragments	Low-dose CT, US	3 mo	NS
Vaddi 2021 [29]	PO	109	TFL	–	URS	K	NS	Preop CT, exact method NS	NS	CT	3 mo	NS
Batra 2022 [30]	R	88	TFL	Surgery	URS & mPCNL	K	NS	NS	NS	CT, X-ray KUB	POD1, 1 mo	NS
Corrales 2022 [31]	R	81	TFL	Laser	URS	K	150	NS	NR	NA	NA	NS
Sierra 2022 [32]	PO	50	TFL	–	URS	K & U	150, 200	Preop CT and X-ray, EF	No fragments >150 μm core diameter laser fiber	End of procedure[c]	Intraoperatively	No
Taratkin 2022 [33]	PO	153	TFL	HU	URS	K	200, 400	Preop CT, EF	No fragments >2 mm	CT	3 mo	NS
Vaddi 2022 [34]	PO	126	TFL	–	URS	K & U	200	Preop CT, imaging software	No stones >2 mm	CT	3 mo	No
Shah 2020 [35]	PO	54	TFL	–	mPCNL + suction	K	400	Preop CT, imaging software	NS	CT, X-ray KUB	48 h, 1 mo	Yes
TFL vs regular Ho:YAG or Ho:YAG MOSES technology												
Ghazi 2021 [36]	RCT	62	TFL vs Ho:YAG 100 W	Settings	URS	K	NS	NS	NS	CT	1 mo	NS
Edison 2022 [37]	R	355	TFL vs Ho:YAG[a]	Laser	URS	K & U	NS	Imaging modality NS, EF	NR	NA	NA	Yes

Table 2 (*continued*)

Study	Design	Pts	Laser type	Comparator groups	Surgery	Stone location	Laser fiber (µm)	Method for measuring ablated stone volume	Definition of SF status	Method for measuring SFR	SFR assessment	Basketing/ Sheath evacuation allowed
Patil 2022 [38]	PC	102	TFL vs MOSES 120 W	Laser	mPCNL + suction	K	365 (MOSES) 400 (TFL)	Preop CT, imaging software	No fragments	CT	48 h, 1 mo	Yes

Pts = patients; SF = stone-free; SFR = stone-free rate; RCT = randomized controlled trial; PO = prospective observational study; PC = prospective comparative study; R = retrospective comparative study; URS = ureteroscopy (covering both ureteral and kidney stones); mPCNL = mini-percutaneous nephrolithotomy; K = kidney; U = ureter; Preop = preoperative; CT = computed tomography; EF = ellipsoid formula; 3D-RV = three-dimensional reconstructed volume; NS = not specified; NR = not reported; NA = not applicable; KUB = kidney-ureter-bladder; US = ultrasound; TFL = thulium fiber laser; POD1 = postoperative day 1.

[a] Power not reported.
[b] "Kidney Stone Calculator" software.
[c] Fluoroscopically and endoscopically.

for preoperative measurement of stone volume [32]. Definitions, diagnostic methods, and time points for assessment of the stone-free rate were very heterogeneous, as summarized in Table 2.

Results from the 26 *in vivo* studies are summarized in Table 3. Four studies (15%) [14,22,30,37] did not specify mean Hounsfield units. Two (8%) specified the distribution of stone composition types [14,18]. The stone-free rate was not available in five studies (19%) [8,20,25,31,37]. One study reported total laser energy results with a thousand-fold factor higher than what could be expected [36]. We assume that the authors mistakenly labeled energy in kilojoules instead of joules, and thus we interpreted the values as being in joules. The operative time was missing in 12 studies (46%) [19,20,24–26,28–33,36] and the lasing time was not reported in four studies (15%) [8,16,22,37]. Laser energy consumption (J/mm^3) was not available in seven studies (27%) [14,20,22,23,30,35,37]. Of note, none of the *in vivo* studies reported laser ablation efficiency (mm^3/J). Laser ablation speed (mm^3/s) was not available in four studies (15%) [14,16,21,37], of which one had ambiguity regarding the definition of the time unit [16] and one presented results as lasing time consumption (s/mm^3) instead [21]. Two studies (8%) reported laser efficacy (mm^3/min) [14,37].

3.4. *Outcomes*

Laser energy consumption ranged from 2.0 – 43.5 J/mm^3 in the *in vitro* Ho:YAG studies. For the *in vivo* studies, laser energy consumption ranged from 9.7 – 27.9 J/mm^3 for regular Ho:YAG laser, from 9.0 – 47.8 J/mm^3 for Ho:YAG MOSES technology, and from 2.7 – 21.2 J/mm^3 for TFL.

Laser ablation efficiency ranged from 0.023 – 0.500 mm^3/J in the *in vitro* Ho:YAG studies. For *in vivo* studies, laser ablation efficiency ranged from 0.036 – 0.103 mm^3/J for regular Ho:YAG laser, from 0.021 – 0.111 mm^3/J for Ho:YAG MOSES technology, and from 0.047 – 0.370 mm^3/J for TFL.

Among the *in vivo* studies, the laser ablation speed ranged from 0.4 – 4.1 mm^3/s for regular Ho:YAG laser, from 0.66 – 4.76 mm^3/s for Ho:YAG MOSES technology, and from 0.30 – 8.50 mm^3/s for TFL.

Among the *in vivo* studies, lasing time consumption ranged from 0.24 – 2.50 s/mm^3 regular Ho:YAG laser, from 0.21 – 1.52 s/mm^3 for Ho:YAG MOSES technology, and from 0.12 – 3.33 s/mm^3 for TFL.

Laser efficacy in the *in vivo* studies ranged from 4.35 – 51.7 mm^3/min for regular Ho:YAG laser, and one study reported 7.1 mm^3/min for TFL.

3.5. *Discussion*

Our review reveals a wide range of laser lithotripsy performance outcomes reported for the ablated volume in relation to energy and time metrics. There was high heterogeneity for the study methodologies applied both *in vitro* and *in vivo*. The studies cover multiple comparators and lithotripsy parameters: various laser technologies (high- and low-power Ho:YAG, MOSES technology, and TFL), a very broad range of laser settings, different stone locations (kidney and ureteric stones), and different surgical approaches (ureteroscopy and PCNL).

Table 3 – Summary of in vivo studies: results

Study	Comparator (if any) and settings	Stone density (HU)	SFR (%)	Total energy (kJ)	Stone volume (mm³)	Operative time (min)	Lasing time (s)	Laser energy consumption (J/mm³)	Laser ablation efficiency (mm³/J)	Laser ablation speed (mm³/s)	Lasing time consumption (s/mm³)	Laser efficacy (mm³/min)
Regular Ho:YAG												
Alghamdi 2020 [14]	Standard PS (K) : 1.5 J x10 Hz	–	82	–	348 (298)	21.7 (17.2)	114.6 (126.3)	–	–	–	–	22.4 (24.2)
	New PS (K) : 1.5 J x10 Hz	–	84	–	525 (429)	17.9 (18.7)	91.6 (130.5)	–	–	–	–	51.7 (61.3)
	Standard PS (U): 1.5 J x 10 Hz	–	83	–	133 (95)	10.6 (12.0)	41.7 (63.7)	–	–	–	–	28.8 (30.2)
	New PS (U): 1.5 J x 10 Hz	–	87	–	197 (139)	9.3 (9.9)	40.0 (39.4)	–	–	–	–	39.9 (44.9)
Panthier 2021 [15]	0.5–0.8 J x 15–30 Hz; 1–1.5 J x 10–15 Hz	15% <1000; 85% >1000	81	7.9	479 (268–4517)	70 (60–82)	1110 (582–1783)	17.6 (13.6–24.7)	0.057 (0.040–0.074)	0.4 (0.32–0.56)	2.5 (1.79–3.09)	–
Ventimiglia 2021 [8]	0.6 J (0.4–0.8)x 15 Hz (12–18)	1040 (753–1275)	–	37.1 (13.3–57.7)	1599 (630–3502)	68 (36–88) (LT)	–	19.0 (14.0–24.0)	0.053 (0.042–0.071)	0.7 (0.4–0.9)	1.43 (1.11–2.50)	–
Panthier 2022 [16]	Settings NS	69% <1000; 31% >1000	79	NR	508 (225–947)	68 (54–80.5)	–	16.8	0.060	–	–	–
Shrestha 2022 [17]	Low power setting: 0.5–0.8 J x 15–20 Hz; 1 J x 10 Hz; 1.2–1.5 J x 15–20 Hz	1000 (700–1112)	91	4.5 (2.0–8.3)	372 (252–688)	38 (19–60)	555 (321–780)	9.7 (5.3–17.7)	0.103 (0.056–0.189)	0.8 (0.5–1.3)	1.25 (0.77–2.00)	–
	High power setting: 0.2–0.3 J x 60–80 Hz; 1 J x 10 Hz; 0.5 J x 50–80 Hz	1012 (795–1317)	88	9.1 (5.9–18.7)	368 (213–584)	40 (25–60)	661 (348–1059)	27.9 (16.4–46.2)	0.036 (0.022–0.061)	0.6 (0.4–1))	1.67 (1.00–2.50)	–
Ho:YAG MOSES technology												
Majdalany 2021 [18]	MOSES 1.0: 0.2–0.3 J x 50–120 Hz; 0.5 J x 50–80 Hz	784 (369)	71	6.4 (3.1)	242 (215)	10.4 (4.5) (LT)	318 (186)	32.4 (18.0)	0.031 (0.011)	0.88 (0.71)	1.14 (0.51)	–
	MOSES 2.0: 0.2–0.3 J x 50–120 Hz; 0.5 J x 50–80 Hz	865 (433)	90	12.4 (13.0)	368 (468)	14.3 (8.4) (LT)	420 (408)	47.8 (60.0)	0.021 (0.012)	0.97 (0.51)	1.03 (0.36)	–
Antoine 2022 [19]	MOSES 1.0: settings NS	910	81	4.4	315	–	275 (11–1495)	11.0	0.091	4.76	0.21	–
	MOSES 2.0: settings NS	845	88	4.2	331	–	394 (9–2009)	21.0	0.048	1.35	0.74	–
Ho:YAG MOSES technology vs regular Ho:YAG												
Mullerad 2017 [20]	Lumenis 120H MOSES mode: settings NS	902 (554–1085)	–	4.5 (1.6–16.0)	782 (181–1691)	–	360 (168–780)	–	–	1.60 (0.86–2.96)	0.63 (0.34–1.17)	–
	Lumenis 120H regular mode: settings NS	867 (502–1268)	–	6.4 (2.6–11.9)	423 (182–875)	–	600 (150–900)	–	–	0.97 (0.51–1.71)	1.03 (0.59–1.95)	–
Mekayten 2019 [21]	MOSES: 0.7 J (0.16) x 14 Hz (4)	1085	87	4.7 (5.0)	428	31.8	397.1	17.2 (20.1)	0.058 (0.031)	0.66	1.51	–
	Ho:YAG: 0.5 J (0.12) x 63 Hz (24)	1021	85	3.6 (4.1)	367	21.1	195.0	13.0 (11.9)	0.077 (0.037)	1.25	0.80	–
Dunne 2021 [22]	MOSES: settings NS	–	95	–	–	85.9	–	–	–	2.4	0.42	–
	Ho:YAG: settings NS	–		–	–	98.1	–	–	–	1.8	0.56	–
Wang 2021 [23]	Lumenis 120H MOSES: contact mode: 0.3 J x 60 Hz	990 (150)	87	–	674 (41)	18.4 (5.1)	299 (64)	–	–	2.30 (2.73–1.91)	0.44 (0.52–0.37)	–
	Lumenis 120H regular DM: 0.3 J x 60 Hz	994 (150)	85	–	683 (39)	21.2 (6.8)	356 (58)	–	–	1.92 (2.20–1.69)	0.52 (0.59–0.45)	–
TFL												
Enikeev 2020 [24]	Laser settings: 0.5 J x 30 Hz	857 (348)	93	5.6 (1.4–6.4)	883 (606–1664)	–	219 (90–330)	2.7 (1.8–9.8)	0.370 (0.102–0.556)	5.5 (1.5–8.7)	0.18 (0.11–0.67)	–
	Laser settings: 0.15 Jx 200 Hz	894 (407)		6.6 (2.8–10.0)		–	372 (96–414)	4.8 (2.6–11.3)	0.208 (0.088–0.385)	8.5 (3.6–19.0)	0.12 (0.05–0.28)	–
Corrales 2021 [25]	U: 0.3 J (0.2–0.6) x 100 Hz (50–80)	1200 (750–1300)	–	NR	1800 (683–2760)	–	558 (438–1020)	18.6 (9.5–26.1)	0.061 (0.038–0.105)	0.7 (0.3–1.6)	1.43 (0.63–3.33)	–
	K: 0.4 J (0.2–0.4) x 40 Hz (20–55)	998 (776–1300)	–	NR	486 (332–1250)	–	1380 (852–2322)	16.3 (8.6–35.5)	0.054 (0.028–0.116)	1.16 (0.8–2.1)	0.86 (0.48–1.25)	–
Enikeev 2021 [26]	0.1–1 J x 7.5–200 Hz	985 (360)	90	1.0 (0.4–2.0)	179 (94–357)	–	70 (30–162)	5.6 (3.0–9.9)	0.179 (0.101–0.333)	2.3 (1.3–4.65)	0.43 (0.22–0.77)	–
Korolev 2021 [27]	Low frequency: 0.5–6 J x 4–19 Hz	900 (625–1275)	85	7.0 (4.7–16.6)	2386 (1083–4202)	10.15 (3.9–13.25)	319 (198–576)	3.4 (1.7–5.4)	0.296 (0.185–0.588)	6.8 (4.6–12.5)	0.15 (0.08–0.22)	–
	High frequency: 0.5–2 J x 20–49 Hz	1100 (750–1350)		5.4 (2.7–9.0)	1186 (905–2317)	17 (5.8–27.5)	312 (177–528)	4.9 (2.8–7.4)	0.204 (0.135–0.357)	5.1 (3–8.7)	0.20 (0.11–0.33)	–
	Higher frequency: 0.1–0.5 J x 50–200 Hz	1170 (636–1300)		7.2 (5.0–13.7)	1337 (878–3665)	22 (8.25–29)	354 (213–632)	4.2 (3.3–6.1)	0.238 (0.164–0.303)	4.4 (3.4–7.6)	0.23 (0.13–0.29)	–
Taratkin 2021 [28]	URS: 0.15 J x 200 Hz/0.5 J x 30 Hz	834 (298)	86	13.8 (11.8–25.0)	2743 (1451–4213)	–	702 (600–930)	4.6 (2.9–5.5)	0.217 (0.182–0.345)	3.9 (3.9–5.7)	0.26 (0.18–0.26)	–
	mPCNL: 0.8 J x 31–38 Hz	882 (409)	89	12.0 (7.0–20.1)	3285 (2210–3775)	–	600 (360–726)	3.8 (2.1–5.8)	0.263 (0.172–0.476)	5.0 (4.6–11.3)	0.20 (0.09–0.22)	–
Vaddi 2021 [29]	FM: 1–2 J x 6–30 Hz	986 (303)	95	13.1 (8.9)	1061 (807)	–	1109 (714)	14.4 (5.7)	0.069 (0.020)	0.94 (0.32)	1.06 (0.27)	–
	DM: 0.1–0.2 J x 60–100 Hz						1275 (765)			0.77 (0.27)	1.30 (0.34)	–
Batra 2022 [30]	mPCNL: settings NS	–	POD1: 86; 1 mo: 93	18.8 (11.5)	–	–	607.8 (407.0)	–	–	3.89 (3.52)	0.26 (0.12)	–
	URS: settings NS	–	POD1: 73; 1 mo: 86	25.0 (14.0)	–	–	1451.4 (486)	–	–	1.09 (1.09)	0.92 (0.46)	–

Table 3 (*continued*)

Study	Comparator (if any) and settings	Stone density (HU)	SFR (%)	Total energy (kJ)	Stone volume (mm³)	Operative time (min)	Lasing time (s)	Laser energy consumption (J/mm³)	Laser ablation efficiency (mm³/J)	Laser ablation speed (mm³/s)	Lasing time consumption (s/mm³)	Laser efficacy (mm³/min)
Corrales 2022 [37]	Olympus SOLTIVE: 0.3 J (0.2–0.6) x 100 Hz (50–180)	1200 (750–1300)	–	–	1800 (683–2760)	–	1380 (852–2322)	18.6 (9.3–26.1)	0.054 (0.038–0.105)	1.16 (0.8–2.1)	0.86 (0.48–1.25)	–
	Quanta Fiber dust: 0.6 J (0.5–0.9) x 15 Hz (10–20)	950 (725–1125)	–	–	1125 (294–4000)	–	1583 (1020–3426)	14.3 (7.8–24.7)	0.070 (0.040–0.128)	0.7 (0.4–1.2)	1.43 (0.83–2.50)	–
Sierra 2022 [32]	U: 0.6 J (0.5–1) x 10 Hz (10–20) short pulse	900 (400–1500)	100	–	346 (147–1800)	–	1044 (792–1464)	8.7 (4.8–65.2)	0.115 (0.015–0.208)	0.3 (0.2–1.3)	3.33 (0.77–5.00)	–
	K: 0.6 J (0.5–0.9) x 15 Hz (10–20) short pulse	950 (725–1125)		–	1125 (294–4000)	–	1583 (1020–3426)	14.3 (7.8–24.7)	0.070 (0.040–0.128)	0.7 (0.4–1.2)	1.43 (0.83–2.50)	–
Taratkin 2022 [33]	Stone density	657 (206)	89	4.0 (2.1–7.17)	351 (132–754)	–	162 (90–408)	11.5 (6.8–16.8)	0.087 (0.060–0.147)	2.1 (1.2–3.5)	0.48 (0.29–0.83)	–
		1306 (194)		3.9 (2.3–6.8)	264 (147–461)	–	174 (102–336)	16.2 (8.6–22.8)	0.062 (0.044–0.116)	1.3 (0.9–2.5)	0.77 (0.40–1.11)	–
Vaddi 2022 [34]	Laser settings: 1–0.2 J x 100–150 Hz + 0.1–0.2 J x 200 Hz	1018 (315)	94	12.6 (8.5)	1003 (684)	33.2 (16.1)	1263 (803)	14.1 (5.0)	0.071 (0.010)	0.76 (0.25)	1.32 (0.33)	–
	Laser settings: 1–2 J x 10–20 Hz + 0.1–0.2 J x 200 Hz	956 (299)		13.7 (8.8)	1122 (798)		1121 (655)	14.6 (3.9)	0.068 (0.020)	0.95 (0.28)	1.05 (0.24)	–
Shah 2020 [13]	0.1–1 J x 100–300 Hz	1300 (435)	46 h: 64.8; 1 mo: 100	18.4 (18.2)	2338 (1997)	39.9 (20.5)	605 (465)	–	–	5.02 (3.99)	0.20 (0.09)	–
TFL vs regular Ho:YAG/Ho:YAG MOSES technology												
Chari 2021 [18]	TFL:0.4 J x 60 Hz	846 (371)	68	11.7 (2.9–1.9)	1151 (2254)	–	534 (116–619)	21.2 (5.8–28.3)	0.047 (0.035–0.172)	1.19 (0.4–1.4)	0.84 (0.71–2.50)	–
	Ho:YAG:0.4 J x 60 Hz	803 (308)	35	8.2 (3.3–1.0)	1089 (1613)	–	381 (340–609)	12.5 (5.8–16.6)	0.080 (0.060–0.172)	4.1 (1.3–4.0)	0.24 (0.25–0.91)	–
Edison 2022 [37]	TFL: settings NS	–	–	–	488	55	–	–	–	–	–	7.1
	Ho:YAG: settings NS	–	–	–	373	63	–	–	–	–	–	4.35
Patil 2022 [39]	TFL: 0.1–1 J x 100–250 Hz	1232 (263)	69	16.3 (15.0)	2294 (1503)	23.7 (11.3)	552 (422)	7.9 (4.0)	0.143 (0.052)	5.2 (2.8)	0.19 (0.07)	–
	MOSES: 0.3–1.2 J x 20–80 Hz	1212 (260)	78	21.9 (23.3)	2770 (1977)	41.9 (13.2)	679 (494)	9.0 (5.0)	0.111 (0.040)	4.6 (2.1)	0.22 (0.07)	–

SFR = stone free rate; PS = pulse shape; K = kidney; U = ureter; LT = lithotripsy time; NS = not specified; NR = not reported; TFL = thulium fiber laser; URS = ureteroscopy (covering both ureteral and kidney stones); mPCNL = mini-percutaneous nephrolithotomy; FM = fragmentation mode; DM = dusting mode; POD = postoperative day; mo = month.
[a] Mean (standard deviation).
[b] Median (interquartile range).
[c] Not stated whether mean or median.
[d] Overall for all comparator groups.
[e] Calculated for this review.

3.5.1. In vitro studies

The two *in vitro* studies reflect highly standardized, idealized settings in attempts to assess laser ablation performance, which may impact the *in vivo* application of the laser technology. Therefore, data from *in vitro* studies cannot be extrapolated to the expected *in vivo* performance of a given laser, since environmental and surgical factors are likely to impact clinical findings. The two *in vitro* studies estimated ablated volume by measuring pulse craters on the stone surface, which is a limitation, as it omits qualitative assessment of the stone material broken off. Larger stone fragments broken off the "main stone" may falsely account for ablated stone volume [39]. Nevertheless, *in vitro* settings represent an adequate scenario for initial evaluation of any new technology or technique that may apply to lithotripsy.

Other *in vitro* studies on laser performance used weight as a metric for assessing ablation performance [39–43]; however, this approach entirely omits consideration of the volume. We believe that volume parameters are more clinically translatable. If the study setup requires weight as a primary outcome, volume parameters should be reported as well, if possible. A heavier weight may not mean a higher volume, as this depends on the stone density. Methods for determining the ablated volume should be evaluated in future studies, and may require additional tools and standardization. A recent study used known stone densities to estimate the ablated volume [44], which is a feasible way for estimating this parameter in settings that only allow weight measurements.

3.5.2. Stone volume measurements

Among the *in vivo* studies included in this review, stone volume was estimated on the basis of preoperative CT scans, with the exception of one study that also used X-ray of the kidney, ureter, and bladder [32]. Estimation methods varied from the use of three-dimensional software-reconstructed volumes to ellipsoid formulas for calculations using measured dimensions. There are several ways to estimate volume [7,15,45], but there is no current standardized methodology. However, we would like to propose that in the era of low-dose noncontrast CT, CT should be the standard modality for radiological assessment of stone burden in studies on laser performance. The calculation method subsequently used for estimating volume is still a matter of debate.

3.5.3. Ablated stone volume

For *in vivo* studies, the preoperative stone volume and the postoperative-stone free rate play a key role in estimating the true ablated stone volume. Assessment of the stone-free rate was interchangeably based on CT, X-rays, or ultrasound in some studies. Of note, no study accounted for non-ablated remnant stone volume in ablation performance

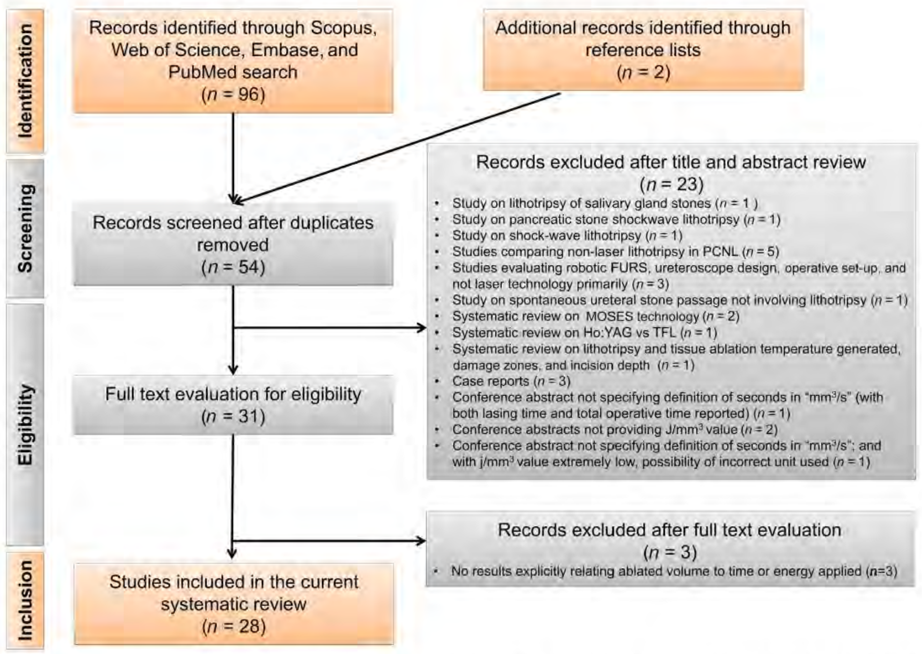


Fig. 1 – Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) flowchart. PCNL = percutaneous nephrolithotomy; FURS = flexible ureteroscopy; TFL = thulium fiber laser.

measurements, a parameter that is technically challenging to measure. Consequently, the laser energy consumption and efficiency values reported may have arguably been affected by the postoperative stone-free rate. In fact, stone-free rates in the studies included in the review varied widely from as low as 35% up to a 100%. The study with high risk of bias had starkly different stone-free rates in the comparator groups (35% vs 68%) [36]. In addition, when basketing and evacuation of fragments are included in the study methodology [16,18,22,27,35,37,38], this would arguably increase the outcome values for laser ablation efficiency and laser ablation speed, especially in PCNL studies [22,27,35,38]. The values reported arguably reflect concomitant non–laser-related procedural contributors to stone removal. Thus, the measurement methodology, the stone-free rate, and the inclusion of stone evacuation may contribute to the wide range of values for laser ablation efficiency and laser ablation speed in studies on laser performance.

3.5.4. Terminology

In referring to outcomes that relate stone volume to energy or time, eight studies used the term "efficiency" [13–16,22,28,35,36] and ten used "efficacy" [16,23,24,26,27,29,32–34,36] (Table 4). For energy outcome metrics, only one *in vitro* study reported values in mm^3/J (laser ablation efficiency) [13], while 20 studies reported values in J/mm^3 (laser energy consumption) [8,12,15–19,21,24–29,31–34,36,38]. The terminology used to describe results for mm^3/J and J/mm^3 also differed widely between different studies. Of note, three studies [24,27,36] termed laser energy consumption (J/mm^3) as "ablation efficacy" or "ablation efficiency", then astonishingly and mistakenly interpreted their data as "the higher, the better", when in fact the exact opposite is the case. It is conceivable that due to the terminology used in these studies, the authors unknowingly interpreted laser energy consumption (J/mm^3) falsely, when it is in fact inversely proportional to laser ablation efficiency (mm^3/J). Naturally, this can also be confusing to readers.

There was also variability in describing time-related outcomes. Most studies included lasing time, with other time periods reported including "total operative time" and "operative time", and two studies using "lithotripsy time" (first laser activation to the end of the last laser activation) [8,18]. Of the two studies reporting laser efficacy (mm^3/min), one defined "operative time" from the beginning of the laser procedure until removal of the last stone fragment [14], while the other used "total operative time" without further elaborating how this was defined [37]. All the studies that reported laser ablation speed (mm^3/s) specifically described that the time unit referred to lasing time, which is directly

Table 4 – Terms used for volume-related units in the studies on laser performance

Study	J/mm^3	mm^3/J	mm^3/s	s/mm^3	mm^3/min
Panthier 2020 [12]	Required energy to treat 1 mm^3	–	–	–	–
King 2022 [13]	–	Ablation efficiency	–	–	–
Alghamdi 2020 [14]	–	–	–	–	Laser efficiency
Panthier 2021 [15]	Efficiency ratio, volumetric energy	–	Ablation rate	–	–
Ventimiglia 2021 [8]	Energy required to ablate 1 mm^3 of stone volume	–	Ablation speed	–	–
Panthier 2022 [16]	Efficiency ratio, volumetric energy	–	Efficacy ratio, ablation rate	–	–
Shrestha 2022 [17]	Laser energy used to ablate 1 mm^3 of stone	–	Ablation speed	–	–
Majdalany 2021 [18]	Energy used per unit stone volume	–	Fragmentation speed	–	–
Antoine 2022 [19]	Energy use rate	–	Stone ablation rate	–	–
Mullerad 2017 [20]	–	–	–	–	Fragmentation rate
Mekayten 2019 [21]	Energy	–	–	Laser time per volume	–
Dunne 2021 [22]	–	–	Efficiency score	–	–
Wang 2021 [23]	–	–	–	–	Stone fragmentation efficacy
Enikeev 2020 [24]	Energy for ablation of 1 mm^3, ablation efficacy	–	Ablation speed	–	–
Corrales 2021 [25]	Amount of energy needed to ablate 1 mm^3 of stone volume	–	Ablation speed	–	–
Enikeev 2021 [26]	Energy for ablation of 1 mm^3, ablation efficacy	–	–	–	Ablation speed
Korolev 2021 [27]	Energy for ablation of 1 mm^3, ablation efficacy	–	Ablation speed	–	–
Taratkin 2021 [28]	Energy for ablation of 1 mm^3, ablation efficiency	–	Stone ablation speed	–	–
Vaddi 2021 [29]	Laser efficacy	–	Ablation speed	–	–
Batra 2022 [30]	–	–	Stone fragmentation rate	–	–
Corrales 2022 [31]	Not defined; referred to directly as J/mm^3	–	Ablation speed	–	–
Sierra 2022 [32]	Laser efficacy	–	Ablation speed, ablation rate	–	–
Taratkin 2022 [33]	Ablation efficacy	–	Ablation speed	–	–
Vaddi 2022 [34]	Laser efficacy, energy required for ablation of 1 mm^3 of stone volume	–	Ablation speed	–	–
Shah 2020 [35]	–	–	Stone fragmentation rate, stone fragmentation efficiency	–	–
Ghazi 2021 [36]	Ablation efficacy, ablation efficiency	–	Ablation speed	–	–
Edison 2022 [37]	–	–	–	–	Operating speed
Patil 2022 [38]	Energy per volume of stone, energy consumed per volume of stone	–	Stone fragmentation rate	–	–

Table 5 – Proposal of a standardized terminology for outcomes in laser lithotripsy studies

Term	Unit	Interpretation	Numerator	Denominator	Scientific relevance	Clinical relevance
Laser ablation efficiency	mm^3/J	The higher, the better	Ablated stone volume	Total laser energy	*In vitro* outcome comparisons	Highly efficient lasers can operate very efficiently with low-power settings, which is of relevance considering the risk of thermal damage associated with high-power settings.
Laser ablation speed	mm^3/s	The higher, the better	Ablated stone volume	Lasing time	Correlates directly with average power rather than laser ablation efficiency. The mean stone volume, total energy, and mean lasing time are therefore the minimal set of variables that must be detailed to correctly interpret this outcome.	Little clinical relevance since it is recommended that the maximum power is limited to prevent thermal damage due to heat generated during laser lithotripsy.
Laser efficacy	mm^3/min	The higher, the better	Clearance of stone volume (*in vivo*)	Total operative time, from insertion of first instrument to removal of last instrument	Accounts for the whole procedure time, including lithotripsy, stone basketing, stone dust suction, and any other relevant steps.	Best outcome for comparing the overall performance of a laser together with the specific technique used (including laser settings).
Consumption						
Laser energy consumption	J/mm^3	The lower, the better	Total laser energy	Ablated stone volume	*In vivo* outcome comparisons	Estimation of total laser energy needed to ablate a given stone volume. Such calculations could help with preoperative planning.
Lasing time consumption	s/mm^3	The lower, the better	Lasing time	Ablated stone volume	Correlates directly with average power rather than laser energy efficiency.	May help with preoperative planning, although this parameter is mainly dictated by average power, which should generally be kept within a limited and safe margin.
Total operative time laser consumption	min/mm^3	The lower, the better	Total operative time	Ablated stone volume	Accounts for the whole procedure (considering total operative time, or total experimental time), and therefore time required for subsequent steps such as stone basketing and dust suction, among others	Best outcome for estimating operative time for a given stone volume. May help with preoperative planning, although this outcome is mainly dictated by average power, which should be kept within a safe margin.

correlated with average power. Three studies in the screening process had ambiguity regarding whether the time component referred to total operative time or lasing time [16,46,47].

3.5.5. Proposal for a standardized terminology for reporting on laser performance

Considering the above, there is a need for a standardized terminology for describing laser performance. To this end, we propose a standardized terminology for outcomes in studies on laser lithotripsy (Table 5).

According to the *Cambridge English Dictionary*, efficiency is "the quality of achieving the largest amount of useful work using as little energy, fuel, effort, etc. as possible" [48]. We thus propose the use of "efficiency" in describing the volumetric ablation performance in relation to the energy resource used — "laser ablation efficiency" (mm^3/J): the higher the value, the more efficient is the laser. To differentiate units with inverse relationships, we propose use of "consumption" to describe the resources (energy or time) needed per unit volume (J/mm^3, s/mm^3, min/mm^3), as detailed in Table 5. Thus, the lower the value for these measures, the better. When referring to laser performance in terms of lasing time spent on ablation, we propose the term "laser ablation speed" (mm^3/s) to reflect the volume ablated per unit of lasing time.

Efficacy is defined as "the ability, especially of a medicine or a method of achieving something, to produce the intended result" [49]. To describe the overall efficacy of the procedure using a particular laser, we propose the term "laser efficacy" (mm^3/min) for clearance of stone volume per unit of total operative time. In a lithotripsy procedure, this accounts for non-lasing time, including stone basketing [50], percutaneous sheath evacuation [51], and stone dust suction [52]. These ancillary maneuvers are closely related to the ability of the laser to produce small fragments or fine dust. For example, a laser would be highly efficacious in the context of mini-PCNL if it can achieve adequately sized fragments in a short time, facilitating faster fragment evacuation. Another example would be laser efficacy in ureteroscopy using a dusting technique. A higher efficacy would be when dusting time is short, yet with the laser being able to produce fine dust and consequently a short suction and evacuation time for the dust. Of note, a high laser ablation speed may not translate to greater laser efficacy. An example would be a laser capable of ablating a large volume of stone per unit time, but producing numerous large fragments that would need a long total operative time to clear out. To account for the whole procedure, total operative time should be defined from insertion of the first instrument to removal of last instrument. Importantly, laser efficacy must be reported within the context of a particular procedure and specific technique.

Finally, we propose that future studies on laser performance should always present results in terms of ablated stone volume, total laser energy, lasing time, and total operative time (where applicable), in addition to values calculated for laser ablation efficiency (mm^3/J), laser energy consumption (J/mm^3), and laser ablation speed (mm^3/s). When possible, studies should strive to report volume outcomes owing to their clinical applicability to radiological stone volume measurements.

3.5.6. Limitations

There are limitations to our review that need acknowledgement. First, we limited our review to studies evaluating laser performance on the basis of ablated stone volume and did not include studies on ablated stone weight. Nevertheless, and as stated above, volume-related parameters are more clinically relevant, as stones are measured radiologically by dimension and volume, and not by weight. Second, our methodology is based on a search of current laser performance metrics using volume, energy, and time units, and a subsequent review of the corresponding terminology used. We chose this approach rather than a primary search for the terms currently used (eg, efficiency, efficacy, speed), as the metrics corresponding to these terms may not reflect laser performance in the specific volumetric units of interest (eg, weight), which is not the aim of the review. Third, information for some data fields was limited in some conference abstracts. Nonetheless, for completeness, we opted to include these conference abstracts. Finally, heterogeneity for the laser settings, study setup and study protocols meant that no direct conclusions could be drawn from comparison of results between studies. Therefore, no meta-analysis was performed.

3.5.7. Future research

There is a strong need for consensus on standardized terminology for laser performance in the era of volumetric measurement of stone burden. This will provide clarity in interpretation of performance results, forming a solid foundation for future research in assessment of laser performance.

4. Conclusions

In conclusion, a wide range of laser performance metrics relating stone volume to energy or time are used in the literature, with corresponding differing terminology. Urologists need to interpret laser performance studies with care, to consider the terms used, and the methodology of measuring the ablated volume and stone-free rates before applying results to their clinical practice. The standardized terminology proposed in this study may help in the interpretation and comparison of future studies on laser lithotripsy.

Author contributions: Etienne Xavier Keller had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Traxer, Keller.
Acquisition of data: Kwok, Keller.
Analysis and interpretation of data: Kwok, Keller.
Drafting of the manuscript: Kwok, Keller.
Critical revision of the manuscript for important intellectual content: Kwok, De Coninck, Ventimiglia, Panthier, Corrales, Sierra, Emiliani, Talso, Miernik, Kronenberg, Enikeev, Somani, Ghani, Traxer, Keller.
Statistical analysis: None.
Obtaining funding: None.
Administrative, technical, or material support: None.
Supervision: Keller.
Other: None.

Financial disclosures: Etienne Xavier Keller certifies that all authors have no specific conflicts of interest relevant to this study, including specific financial interests and relationships and affiliations relevant to the subject matter or materials discussed in the manuscript (eg, employment/affiliation, grants or funding, consultancies, honoraria, stock ownership or options, expert testimony, royalties, or patents filed, received, or pending). Non relevant disclosures are the following: Vincent De Coninck is a consultant for Axess Vision Technology, BD Bard, and Coloplast. Peter Kronenberg has been a consultant for Boston Scientific, EDAP, Endovision, Karl Storz, Lumenis, Olympus, and Rocamed. Bhaskar Somani is a consultant for Coloplast, Pusen, and Boston Scientific. Khurshid R. Ghani is a consultant for Coloplast, Karl Storz, Ambu, and Boston Scientific. Olivier Traxer is a consultant for Coloplast, Karl Storz, Rocamed, Quanta Systems, Ambu, Boston Scientific, and IPG Medical. Etienne Xavier Keller is a speaker and/or consultant for Coloplast, Olympus, Boston Scientific, Recordati, Debiopharm, and Alnylam. The remaining authors have nothing to disclose.

Funding/Support and role of the sponsor: None.

Data sharing statement: Data extracted from the studies included in the review and the review protocol can be provided on reasonable request to the corresponding author.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.euf.2023.10.004.

References

[1] Geraghty RM, Jones P, Somani BK. Worldwide trends of urinary stone disease treatment over the last two decades: a systematic review. J Endourol 2017;31:547–56. https://doi.org/10.1089/end.2016.0895.

[2] Kronenberg P, Traxer O. Update on lasers in urology 2014: current assessment on holmium:yttrium–aluminum–garnet (Ho:YAG) laser lithotripter settings and laser fibers. World J Urol 2015;33:463–9. https://doi.org/10.1007/s00345-014-1395-1.

[3] Kim HJ, Ghani KR. Which is the best laser for lithotripsy? Holmium laser. Eur Urol Open Sci 2022;44:27–9. https://doi.org/10.1016/j.euros.2022.05.017.

[4] Traxer O, Sierra A, Corrales M. Which is the best laser for lithotripsy? Thulium fiber laser. Eur Urol Open Sci 2022;44:15–7. https://doi.org/10.1016/j.euros.2022.05.020.

[5] Bergmann J, Rosenbaum CM, Netsch C, Gross AJ, Becker B. First clinical experience of a novel pulsed solid-state thulium:YAG laser during percutaneous nephrolithotomy. J Clin Med 2023;12:2588. https://doi.org/10.3390/jcm12072588.

[6] De Coninck V, Traxer O. The time has come to report stone burden in terms of volume instead of largest diameter. J Endourol 2018;32:265–6. https://doi.org/10.1089/end.2017.0886.

[7] Merigot De Treigny O, Bou Nasr E, et al. The cumulated stone diameter: a limited tool for stone burden estimation. Urology 2015;86:477–81. https://doi.org/10.1016/j.urology.2015.06.018.

[8] Ventimiglia E, Pauchard F, Gorgen ARH, Panthier F, Doizi S, Traxer O. How do we assess the efficacy of Ho:YAG low-power laser lithotripsy for the treatment of upper tract urinary stones? Introducing the Joules/mm3 and laser activity concepts. World J Urol 2021;39:891–6. https://doi.org/10.1007/s00345-020-03241-9.

[9] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev 2021;10:89. https://doi.org/10.1186/s13643-021-01626-4.

[10] Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928. https://doi.org/10.1136/bmj.d5928.

[11] Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919. https://doi.org/10.1136/bmj.i4919.

[12] Panthier F, Ventimiglia E, Berthe L, et al. How much energy do we need to ablate 1 mm^3 of stone during Ho:YAG laser lithotripsy? An *in vitro* study. World J Urol 2020;38:2945–53. https://doi.org/10.1007/s00345-020-03091-5.

[13] King JB, Katta N, Teichman JMH, Tunnell JW, Milner TE. Increased ablation efficiency in hard and soft tissues using an annular beam. Progress in Biomedical Optics and Imaging – Proceedings of SPIE2022.

[14] Alghamdi A, Kretschmer A, Stief CG, Strittmatter F. Influence of the laser pulse shape in the treatment of stones in the upper urinary tract. Invest Clin Urol 2020;61:594–9. https://doi.org/10.4111/icu.20200130.

[15] Panthier F, Traxer O, Yonneau L, et al. Evaluation of a free 3D software for kidney stones' surgical planning: "Kidney Stone Calculator" a pilot study. World J Urol 2021;39:3607–14. https://doi.org/10.1007/s00345-021-03671-z.

[16] Panthier F, Duquesne I, Doizi S, et al. MP15-07 "Kidney Stone Calculator": predicting the lithotripsy duration and its influencing factors. J Endourol 2022;36(1 Suppl):A209–10. https://doi.org/10.1089/end.2022.36001.abstracts.

[17] Shrestha A, Corrales M, Adhikari B, Chapagain A, Traxer O. Comparison of low power and high power holmium YAG laser settings in flexible ureteroscopy. World J Urol 2022;40:1839–44. https://doi.org/10.1007/s00345-022-04040-0.

[18] Majdalany SE, Levin BA, Ghani KR. The efficiency of Moses technology holmium laser for treating renal stones during flexible ureteroscopy: relationship between stone volume, time, and energy. J Endourol 2021;35(Suppl 3):S14–21. https://doi.org/10.1089/end.2021.0592.

[19] Antoine S, Thurmon K, Atwell M, et al. PD55-10 Moses 2.0 laser impact on intraoperative parameters. J Urol 2022;207:e951–2. https://doi.org/10.1097/JU.0000000000002635.10.

[20] Mullerad M, Aguinaga JRA, Aro T, et al. Initial clinical experience with a modulated holmium laser pulse-Moses technology: does it enhance laser lithotripsy efficacy? Rambam Maimonides Med J 2017;8:e0038.

[21] Mekayten M, Lorber A, Katafigiotis I, et al. Will stone density stop being a key factor in endourology? The impact of stone density on laser time using Lumenis Laser p120w and standard 20 W laser: a comparative study. J Endourol 2019;33:585–9. https://doi.org/10.1089/end.2019.0181.

[22] Dunne M, Drescher M, Abbott J, Davalos J. MP18-04 Lumenis Pulse™ MOSES™ technology improves efficiency of laser lithotripsy for patients undergoing mini-PCNL. J Urol 2021;206(Suppl 3):e318. https://doi.org/10.1097/JU.0000000000002003.04.

[23] Wang M, Shao Q, Zhu X, Wang Z, Zheng A. Efficiency and clinical outcomes of Moses technology with flexible ureteroscopic laser lithotripsy for treatment of renal calculus. Urol Int 2021;105:587–93. https://doi.org/10.1159/000512054.

[24] Enikeev D, Taratkin M, Klimov R, et al. Superpulsed thulium fiber laser for stone dusting: in search of a perfect ablation regimen—a prospective single-center study. J Endourol 2020;34:1175–9. https://doi.org/10.1089/end.2020.0519.

[25] Corrales M, Traxer O. Initial clinical experience with the new thulium fiber laser: first 50 cases. World J Urol 2021;39:3945–50. https://doi.org/10.1007/s00345-021-03616-6.

[26] Enikeev D, Grigoryan V, Fokin I, et al. Endoscopic lithotripsy with a superpulsed thulium-fiber laser for ureteral stones: a single-center experience. Int J Urol 2021;28:261–5. https://doi.org/10.1111/iju.14443.

[27] Korolev D, Akopyan G, Tsarichenko D, et al. Minimally invasive percutaneous nephrolithotomy with superpulsed thulium-fiber laser. Urolithiasis 2021;49:485–91. https://doi.org/10.1007/s00240-021-01258-2.

[28] Taratkin M, Azilgareeva C, Chinenov D, et al. Retrograde intrarenal surgery versus percutaneous nephrolithotomy in larger kidney stones. Could superpulsed thulium-fiber laser change the game? Cent Eur J Urol 2021;74:229–34. https://doi.org/10.5173/ceju.2021.0133.

[29] Vaddi D, Ramakrishna P, Siddalinga Swamy P, et al. MP15-03 60Watt superpulse thulium fiber laser in retrograde intrarenal surgery-aiming towards faster dust. J Endourol 2021;35(Suppl 1):A153–4. https://doi.org/10.1089/end.2021.35001.abstracts.

[30] Batra RS, Patel D, Singh A, Ganpule A, Sabnis R, Desai M. MP8-14 MiniPCNL vs RIRS in large burden stones from 1.5cm to 3cm using thulium fiber laser: a propensity matched analysis. J Endourol

2022;36(Suppl 1):A125. https://doi.org/10.1089/end.2022.36001.abstracts.
[31] Corrales M, Sierra A, Traxer O. MP9-10 Thulium fiber laser: Soltive vs Quanta – initial clinical experience. J Endourol 2022;36(Suppl 1): A135–6. https://doi.org/10.1089/end.2022.36001.abstracts.
[32] Sierra A, Corrales M, Kolvatzis M, Traxer O. Initial clinical experience with the thulium fiber laser from Quanta System: first 50 reported cases. World J Urol 2022;40:2549–53. https://doi.org/10.1007/s00345-022-04096-y.
[33] Taratkin M, Azilgareeva C, Korolev D, et al. Prospective single-center study of superpulsed thulium fiber laser in retrograde intrarenal surgery: initial clinical data. Urol Int 2022;106:404–10. https://doi.org/10.1159/000516933.
[34] Vaddi CM, Ramakrishna P, Ganeshan S, et al. The clinical efficiency and safety of 60W superpulse thulium fiber laser in retrograde intrarenal surgery. Indian J Urol 2022;38:191–6. https://doi.org/10.4103/iju.iju_60_22.
[35] Shah D, Patil A, Reddy N, et al. A clinical experience of thulium fibre laser in miniperc to dust with suction: a new horizon. World J Urol 2020;39:2727–32. https://doi.org/10.1007/s00345-020-03458-8.
[36] Ghazi A, Khalil M, Feng C, Quarrier S, Jain R. Holmium:YAG (Ho: YAG) versus thulium fiber laser (TFL) for treatment of upper urinary tract calculi in dusting mode: a clinical comparison of efficiency, efficacy and costs effectiveness. J Urol 2021;206(Suppl 3):e925–6. https://doi.org/10.1097/JU.0000000000002081.08.
[37] Edison E, De Luyk N, Arumuham V, Choong S, Allen S, Smith D. MP8-08 Early UK experience of thulium fibre laser for ureterorenoscopy: case series and comparative cost-analysis versus holmium-YAG. J Endourol 2022;36(Suppl 1):A122. https://doi.org/10.1089/end.2022.36001.abstracts.
[38] Patil A, Reddy N, Shah D, et al. High-power holmium with MOSES technology or thulium fiber laser in miniperc with suction: a new curiosity. J Endourol 2022;36:1348–54. https://doi.org/10.1089/end.2021.0915.
[39] Teichman JMH, Vassar GJ, Bishoff JT, Bellman GC. Holmium:YAG lithotripsy yields smaller fragments than lithoclast, pulsed dye laser or electrohydraulic lithotripsy. J Urol 1998;159:17–23. https://doi.org/10.1016/S0022-5347(01)63998-3.
[40] Wollin DA, Ackerman A, Yang C, et al. Variable pulse duration from a new holmium:YAG laser: the effect on stone comminution, fiber tip degradation, and retropulsion in a dusting model. Urology 2017;103:47–51. https://doi.org/10.1016/j.urology.2017.01.007.
[41] Wollin DA, Tom WR, Jiang R, Simmons WN, Preminger GM, Lipkin ME. An in vitro evaluation of laser settings and location in the efficiency of the popcorn effect. Urolithiasis 2019;47:377–82. https://doi.org/10.1007/s00240-018-1066-6.
[42] Emiliani E, Talso M, Cho SY, et al. Optimal settings for the noncontact holmium:YAG stone fragmentation popcorn technique. J Urol 2017;198:702–6. https://doi.org/10.1016/j.juro.2017.02.3371.
[43] Kraft L, Yilmaz M, Petzold R, Gratzke C, Suarez-Ibarrola R, Miernik A. Dusting efficiency of a novel pulsed thulium:yttrium aluminum garnet laser vs a thulium fiber laser. J Endourol 2022;36:259–65. https://doi.org/10.1089/end.2021.0441.
[44] Kwok JL, Ventimiglia E, De Coninck V, et al. Pulsed Thulium:YAG laser – What is the lithotripsy ablation efficiency for stone dust from human urinary stones? Results from an in vitro PEARLS study. World J Urol 2023; Online ahead of print. https://doi.org/10.1007/s00345-023-04640-4.
[45] Ackermann D, Griffith DP, Dunthorn M, Newman RC, Finlayson B. Calculation of stone volume and urinary stone staging with computer assistance. J Endourol 1989;3:355–60. https://doi.org/10.1089/end.1989.3.355.
[46] Reddy N, Desai M, Patil A. MP20-07 Optimal laser settings for maximal dusting in mini-PCNL with suction using high power holmium laser: a prospective study of 110 patients. J Endourol 2021;35(Suppl 1):A221. https://doi.org/10.1089/end.2021.35001.abstracts.
[47] Singh A, Shah D, Patil A, Ganpule A, Sabnis R, Desai M. MP8-01 Prospective comparative study of thulium fiber laser vs holmium laser with Moses technology for kidney stone in percutaneous nephrolithotomy: a randomised controlled single-center trial. J Endourol 2022;36(Suppl 1):A118–9. https://doi.org/10.1089/end.2022.36001.abstracts.
[48] Cambridge English dictionary. Efficiency. https://dictionary.cambridge.org/dictionary/english/efficiency.
[49] Cambridge English dictionary. Efficacy. https://dictionary.cambridge.org/dictionary/english/efficacy.
[50] Doizi S, Traxer O. Flexible ureteroscopy: technique, tips and tricks. Urolithiasis 2018;46:47–58. https://doi.org/10.1007/s00240-017-1030-x.
[51] Nicklas AP, Schilling D, Bader MJ, Herrmann TRW, Nagele U. The vacuum cleaner effect in minimally invasive percutaneous nephrolitholapaxy. World J Urol 2015;33:1847–53. https://doi.org/10.1007/s00345-015-1541-4.
[52] Solano C, Chicaud M, Kutchukian S, et al. Optimizing outcomes in flexible ureteroscopy: a narrative review of suction techniques. J Clin Med 2023;12:2815. https://doi.org/10.3390/jcm12082815.

Conclusion and Afterthoughts

When embarking on this journey into the world of laser lithotripsy several years ago, I had no idea it would evolve into an odyssey. What began as a simple conversation during a fellowship in Paris, ignited a spark of curiosity that has since fueled years of research, discoveries, and personal growth. My mentor's casual remark about the mysteries of lithotripter settings and the gaps in our understanding planted a seed that grew into an unwavering determination to uncover the truth.

As I dived deeper into the complexities of laser lithotripsy, they unfolded before me like an uncharted sea – each wave of discovery revealing new questions, challenges, but also opportunities. From defining the importance of the various laser lithotripter parameters to exposing inconsistencies in laser fiber diameters and challenging entrenched practices like fiber stripping, I have navigated through waters both turbulent and serene. Along the way, I've had the opportunity and privilege of collaborating with brilliant minds, challenging conventions, and contributing to create new knowledge that has reshaped parts of this fascinating field.

I'm still not aware of how vast and deep the ocean of laser lithotripsy is. The uncharted depths are full of mysteries to be uncovered, promises of innovation, and improved patient care. My odyssey continues, and I am eager to see where the next wave will take me.

Bibliography

[1] Chawla SN, Chang MF, Chang A, Lenoir J, Bagley DH. Effectiveness of high-frequency holmium:YAG laser stone fragmentation: the "popcorn effect". J. Endourol 2008; 22(4):645–50 (doi: 10.1089/end.2007.9843 PubMed ID: 18307379).

[2] Spore SS, Teichman JM, Corbin NS, Champion PC, Williamson EA, Glickman RD. Holmium: YAG lithotripsy: optimal power settings. J Endourol 1999; 13(8):559–66 (doi: PubMed ID: 10597125).

[3] Lee H, Ryan RT, Kim J, Choi B, Arakeri NV, Teichman JMH, Welch AJ. Dependence of calculus retropulsion dynamics on fiber size and radiant exposure during Ho:YAG lithotripsy. J Biomech Eng 2004; 126(4):506–15 (doi: PubMed ID: 15543869).

[4] Blackmon RL, Irby PB, Fried NM. Thulium fiber laser lithotripsy using tapered fibers. Lasers Surg Med 2010; 42(1):45–50 (doi: 10.1002/lsm.20883 PubMed ID: 20077487).

[5] Teichman JM, Vassar GJ, Glickman RD. Holmium:yttrium-aluminum-garnet lithotripsy efficiency varies with stone composition. Urology 1998; 52(3):392–7 (doi: PubMed ID: 9730449).

[6] Vassar GJ, Teichman JM, Glickman RD. Holmium:YAG lithotripsy efficiency varies with energy density. J. Urol 1998; 160(2):471–6 (doi: PubMed ID: 9679900).

[7] Teichman JM, Chan KF, Cecconi PP, Corbin NS, Kamerer AD, Glickman RD, Welch AJ. Erbium: YAG versus holmium:YAG lithotripsy. J. Urol 2001; 165(3):876–9 (doi: PubMed ID: 11176490).

[8] Blackmon RL, Irby PB, Fried NM. Comparison of holmium:YAG and thulium fiber laser lithotripsy: ablation thresholds, ablation rates, and retropulsion effects. J Biomed Opt 2011; 16(7):71403 (doi: 10.1117/1.3564884 PubMed ID: 21806249).

[9] Jelinkova H, Köhler O, Miyagi M, Koranda P, Nemec M, Sulc J, Fibrich M, Pokorny J, Iwai K, Matsuura Y, Kollias N, Choi B, Zeng H, Malek RS, Wong BJ, Ilgner JFR, Gregory KW, Tearney GJ, Marcu L, Hirschberg H, Madsen SJ. Comparison of Ho:YAG and Er:YAG lasers for lithotripsy [Proc. SPIE]. Photonic Therapeutics and Diagnostics V 2009; 7161(1):71611H-7 (doi: 10.1117/12.808667 PubMed ID:).

[10] Kang HW, Lee H, Teichman JMH, Oh J, Kim J, Welch AJ. Dependence of calculus retropulsion on pulse duration during Ho: YAG laser lithotripsy. Lasers Surg Med 2006; 38(8):762–72 (doi: 10.1002/lsm.20376 PubMed ID: 16868932).

[11] Delvecchio FC, Auge BK, Brizuela RM, Weizer AZ, Zhong P, Preminger GM. In vitro analysis of stone fragmentation ability of the FREDDY laser. J. Endourol 2003; 17(3):177–9 (doi: 10.1089/089277903321618752 PubMed ID: 12803991).

[12] Blackmon RL, Irby PB, Fried NM. Holmium:YAG (lambda = 2,120 nm) versus thulium fiber (lambda = 1,908 nm) laser lithotripsy. Lasers Surg Med 2010; 42(3):232–6 (doi: 10.1002/lsm.20893 PubMed ID: 20333745).

[13] Sroka R, Hecht V, Reich O, Seitz M, Stief CG, Bader MJ, Kollias N, Choi B, Zeng H, Malek RS, Wong BJ, Ilgner JFR, Gregory KW, Tearney GJ, Marcu L, Hirschberg H, Madsen SJ. In vitro comparison of laser induced lithotripsy on artificial stones by means of different laser systems

[Proc. SPIE]. Photonic Therapeutics and Diagnostics V 2009; 7161(1):71611T-6 (doi: 10.1117/12.812216 PubMed ID:).

[14] Sea J, Jonat LM, Chew BH, Qiu J, Wang B, Hoopman J, Milner T, Teichman JMH. Optimal power settings for Holmium:YAG lithotripsy. J. Urol. 2012; 187(3):914–9 (doi: 10.1016/j.juro.2011.10.147 PubMed ID: 22264464).

[15] Marguet CG, Sung JC, Springhart WP, L'Esperance JO, Zhou S, Zhong P, Albala DM, Preminger GM. In vitro comparison of stone retropulsion and fragmentation of the frequency doubled, double pulse nd:yag laser and the holmium:yag laser. J. Urol 2005; 173(5):1797–800 (doi: 10.1097/01.ju.0000154341.08206.69 PubMed ID: 15821590).

[16] Bach T, Geavlete B, Herrmann TRW, Gross AJ. Working tools in flexible ureterorenoscopy--influence on flow and deflection: what does matter? J. Endourol. 2008; 22(8):1639–43 (doi: 10.1089/end.2008.0184 PubMed ID: 18620506).

[17] Pasqui F, Dubosq F, Tchala K, Tligui M, Gattegno B, Thibault P, Traxer O. Impact on active scope deflection and irrigation flow of all endoscopic working tools during flexible ureteroscopy. Eur. Urol. 2004; 45(1):58–64 (doi: PubMed ID: 14667517).

[18] Kuo RL, Aslan P, Zhong P, Preminger GM. Impact of holmium laser settings and fiber diameter on stone fragmentation and endoscope deflection. J Endourol 1998; 12(6):523–7 (doi: PubMed ID: 9895256).

[19] Poiseuille J-L-M. Recherches expérimentales sur Ie mouvement des liquides dans les tubes de très petits diamètres: III. Influence du diamètre sur la quantité de liquide qui traverse les tubes de très petits diamètres. C. R. Acad. Sci. 1840; (11):1041–8 (doi: PubMed ID:).

[20] Knudsen BE, Pedro R, Hinck B, Monga M. Durability of reusable holmium:YAG laser fibers: a multicenter study. J. Urol 2011; 185(1):160–3 (doi: 10.1016/j.juro.2010.08.020 PubMed ID: 21074810).

[21] Mues AC, Teichman JMH, Knudsen BE. Quantification of holmium:yttrium aluminum garnet optical tip degradation. J Endourol 2009; 23(9):1425–8 (doi: 10.1089/end.2009.0384 PubMed ID: 19698052).

[22] Bagley DH, Das A. Endourologic use of the holmium laser. Jackson, WY: Teton NewMedia; 2001.

[23] Nazif OA, Teichman JMH, GLICKMAN RD, Welch AJ. Review of laser fibers: a practical guide for urologists. J Endourol 2004; 18(9):818–29 (doi: 10.1089/end.2004.18.818 PubMed ID: 15659912).

[24] Sung C, Singh H, Schwartz M, Mirabile G, Hruby GW, Ryan CD, Landman J. Evaluation of efficacy of novel optically activated digital endoscope protection system against laser energy damage. Urology 2008; 72(1):57–60 (doi: 10.1016/j.urology.2008.01.011 PubMed ID: 18329076).

[25] Boston Scientific. AccuMax Single-Use Holmium Laser Fiber; URO-93705-AA; 2012 [cited 2013 Mar 23].

[26] Boston Scientific. AccuTrac Flexiva TracTip Brochure; BVU2640; 2011 [cited 2014 Jul 16]. Available from: URL:https://www.bostonscientific.com/content/dam/bostonscientific/uro-wh/portfolio-group/lithotripsy/tractip/AccuTrac_Flexiva_TracTip_Brochure.pdf.

[27] American Medical Systems. SureFlex™ Laser Fiber Brochure: Instructions for Use; 0138-0410 Rev C (11/10); 2010 [cited 2014 Apr 11]. Available from: URL:http://www.amselabeling.com/assets/files/0138-0410-C_ReusableSureFlexIFU_1110.pdf.

[28] Reynders McVeigh Capital Management LLC. IPG Photonics: Recent News; 2013.

[29] Herrmann TRW, Liatsikos EN, Nagele U, Traxer O, Merseburger AS. EAU guidelines on laser technologies. European urology 2012; 61(4):783–95 (doi: 10.1016/j.eururo.2012.01.010 PubMed ID: 22285403).

[30] Rocamed. MH01 Laser Lithotripter Brochure; V.Uk.2; 2013 [cited 2014 Jun 19]. Available from: URL:http://www.rocamed-urology.com/images/stories/doc/br.uk.v2.laser.pdf.

[31] Electro Medical Systems. Swiss Laserclast Brochure; FA -398; 2012 [cited 2014 Jun 19]. Available from: URL:http://www.ems-company.com/media/PDF%20NEW/FA-398_EN_Ed_08-2012_LaserClast%20Brochure_single.pdf.

[32] Lumenis. VersaPulse PowerSuite Brochure; PB-1106750 Rev. B; 2013 [cited 2014 Jun 19]. Available from: URL:http://www.surgical.lumenis.com/pdf/PB-1106750_rB_VPPS_P20v_br_LowRes%20(1).pdf.

[33] Althunayan AM, Elkoushy MA, Elhilali MM, Andonian S. Adverse events resulting from lasers used in urology. J Endourol 2014; 28(2):256–60 (doi: 10.1089/end.2013.0451 PubMed ID: 24074324).

Appendix

APU2013

CONGRESSO DA ASSOCIAÇÃO PORTUGUESA DE UROLOGIA

10 a 13 • out • 2013

Centro de Congressos do Algarve
Tivoli Marina Hotel - Vilamoura

90 anos APU

CERTIFICADO

Certificamos que o trabalho Litotrícia a laser – Parâmetros do litotritor e eficácia da fragmentação

da autoria de Peter Kronenberg e Olivier Traxer

foi o vencedor do **1º Prémio** para **Melhor Comunicação Oral** apresentado no **Congresso da Associação Portuguesa de Urologia**, que decorreu de 10 a 13 de outubro de 2013 no Centro de Congressos do Algarve, Tivoli Marina Hotel - Vilamoura.

Vilamoura, 13 de outubro 2013

Dr. Tomé Lopes
Presidente do Congresso

Dr. Francisco Carrasquinho Gomes
Presidente da Comissão Organizadora

Patrocínio

Pierre Fabre Médicament


the American Urological Association
founded in 1902
Annual Audio-Visual Award
2013 Annual Meeting
in San Diego
First Prize
Laser Fibers, Pulse Energy and Retropulsion -
What we can see and what we can't
Peter Kronenberg, Olivier Traxer
Secretary
President
American
Urological
Association
Education and Research, Inc.

Ao longo dos três meses de estágio, ganhei competências importantes em cirurgia laparoscópica para o tratamento dos cancros da próstata, bexiga e rim. Tive ainda oportunidade de ganhar uma experiência inicial e algumas competências em cirurgia robótica. Destaco que o Serviço de Urologia do Hospital Val de Grâce tem um volume cirúrgico de cerca de 1 000 cirurgias por ano, sendo que, destas, 200 são cirurgias laparoscópicas ou robóticas.

Por outro lado, foi extremamente importante a oportunidade que tive de constatar *in loco* o modelo organizacional do Serviço de Urologia em particular e do Hospital Militar Val de Grâce no geral, que são vistos como modelos de referência pela sociedade francesa. Saliento a preocupação deste Hospital e, particularmente, do Serviço de Urologia, em divulgar a sua atividade clínica. Por exemplo, através do *site* www.urologie-valdegrace.fr, é possível aceder a um conjunto de informações sobre a patologia urológica e, inclusive, marcar uma consulta.

Destaco ainda o facto de ter sido criada uma sinergia e uma parceria importante com este Serviço congénere, que poderá ser útil num futuro próximo para a realização de projetos conjuntos noutras áreas. Por último, saliento a constatação do apreço que os franceses têm pelos médicos militares portugueses e pela Urologia nacional.»

terapêutico, entre outras. Na Unidade de Lesões Vertebrais do Northern General Hospital, colaborei nas consultas e nos estudos urodinâmicos realizados a diversos doentes do foro neurourológico.

No plano cirúrgico, este estágio concedeu-me também valiosos conhecimentos, já que, além de ter assistido a diversas cirurgias de Urologia reconstrutiva (como, por exemplo, uretroplastias da uretra anterior e posterior, correções de fístulas vesicovaginais, reconstruções da uretra feminina, construção de bolsas cateterizáveis, cirurgias de incontinência com *slings* autólogos, etc.), pude igualmente discutir as indicações cirúrgicas e as alternativas técnicas apropriadas para cada caso com o Prof. Chapple. Nesta área em particular, estes aspetos são cruciais e dificilmente se encontram explanados de forma inequívoca na literatura, já que derivam largamente da experiência individual de cada cirurgião.

Resta-me agradecer ao meu Serviço, por ter incentivado a realização deste estágio, e à Associação Portuguesa de Urologia, pelo apoio prestado.» ■

Melhor vídeo apresentado é de um português

Peter Kronenberg, interno de Urologia no Hospital Prof. Doutor Fernando Fonseca (Amadora-Sintra), brilhou na reunião deste ano da American Urological Associaton, com um trabalho de investigação na área da endourologia que arrecadou o prémio de Melhor Vídeo.

Vanessa Pais

O projeto de Peter Kronenberg, que venceu o prémio de Melhor Vídeo apresentado na reunião anual de 2013 da American Urological Associaton (de 4 a 8 de maio, em San Diego), começou em Paris, no âmbito de um estágio que o interno realizou no Hôpital Tenon, e terminou em Portugal. «Durante o estágio, quis testar a melhor forma de fragmentar cálculos urinários e apresentei a minha ideia ao orientador, o Prof. Olivier Traxer, uma referência mundial na área da endourologia, que me apoiou e pôs à minha disposição todo o material necessário», conta o premiado.

A ideia era aparentemente simples, mas Peter Kronenberg deixou-se entusiasmar e a investigação assumiu proporções mais complexas e ambiciosas, envolvendo, inclusive, «a análise do efeito de retropulsão que os lasers exercem sobre os cálculos». Rapidamente o tempo destinado ao estágio (um mês) se revelou curto e Peter Kronenberg foi convidado por Olivier Traxer a prolongar a sua estadia em Paris. Terminada a investigação, o interno voltou para Portugal e dedicou-se à preparação do vídeo de alta velocidade que viria a orgulhar a comunidade urológica nacional na última reunião anual da American Urological Associaton.

«Já me sentira muito contente por o trabalho ter sido aceite para apresentação, pelo que a notícia do primeiro prémio foi uma surpresa extremamente gratificante», confessa Peter Kronenberg. No entanto, apesar do entusiasmo causado pelo prémio recebido, o interno salienta que a importância da sua investigação assenta nas principais conclusões a que foi possível chegar: «O efeito de retropulsão aumenta com níveis de energia mais altos, fibras de laser com maior diâmetro e emissão de laser dentro de crateras de fragmentação. A posição dos cálculos pode ser afetada pelo laser, mesmo a distâncias consideráveis da sua superfície. Os vídeos de alta velocidade revelam pormenores sobre a litotrícia a laser de outra forma invisíveis ao olho humano.» ■

APU2013
CONGRESSO DA ASSOCIAÇÃO PORTUGUESA DE UROLOGIA
10 a 13 • out • 2013
Centro de Congressos do Algarve
Tivoli Marina Hotel - Vilamoura

90 anos APU

CERTIFICADO

Certificamos que o trabalho Fibras laser, energia e retropulsão – O que vemos e não vemos

da autoria de Peter Kronenberg; Olivier Traxer

foi o vencedor do **3º Prémio** para **Melhor Vídeo** apresentado no **Congresso da Associação Portuguesa de Urologia**, que decorreu de 10 a 13 de outubro de 2013 no Centro de Congressos do Algarve, Tivoli Marina Hotel - Vilamoura.

Vilamoura, 13 de outubro 2013

Dr. Tomé Lopes
Presidente do Congresso

Dr. Francisco Carrasquinho Gomes
Presidente da Comissão Organizadora

Patrocínio
Pfizer

31st WORLD CONGRESS OF ENDOUROLOGY & SWL
New Orleans, Louisiana

WCE TOP TEN VIDEO PRESENTATION

"Myths, Doubts and Facts about Laser Lithotripsy"

Peter Kronenberg, Olivier Traxer

Mahesh Desai, M.D.
President, Endourology Society

Endourological Society
NEWSLETTER

Endourological Society Report from the Secretary General **April 2016**

Report from the President:

Dear Society Members and Friends,

Since the first endourological treatment of renal stones in 1941 by Rupel and Brown, a variety of endoscopic and laparoscopic procedures have been developed in urology, promoting minimally invasive urology. Since its development in 1983 by our Founding President, Dr. Arthur Smith, our society has played a major role in the development and wide spread knowlege of minimally invasive urology worldwide. The WCE 2016 meeting in Cape Town will bring out society to the next stage, gathering a lot of urologists from developing countries. The World Endo Initiative will help such urologists to join us at Cape Town. I hope many of you visit our website and donate to achieve our goal (www.endourology.org).

[...]

Journal of Endourology: Editorial Box:

Ralph Clayman, M.D.
Arthur Smith, M.D.
John Denstedt, M.D.

We are pleased to highlight the "top read" and "top viewed" articles over the past few months in the *Journal of Endourology and VideoUrology*:

JOURNAL OF ENDOUROLOGY

The Clinical Research Office of the Endourological Society Ureteroscopy Global Study: Indications, Complications, and Outcomes in 11,885 Patients, Jean de la Rosette, John Denstedt, Petrisor Geavlete, Francis Keeley, Tadashi Matsuda, Margaret Pearle, Glenn Preminger, Olivier Traxer, on behalf of the CROES URS Study Group

According to Thompson Reuters/Web of Science, the above is a "highly cited paper" – meaning it is "in the top 1% of its academic field based on a highly cited threshold for the field and publication year"

[...]

VIDEOUROLOGY

Laser-Assisted Laparoscopic Partial Nephrectomy Without Ischemia: Procedure and Challenges, Wael Y. Khoder, Ronald Sroka, Nicole Kellhammer, Nikolas Haseke, Christian G. Stief, Armin J. Becker

[...]

Myths, Doubts, and Facts about Laser Lithotripsy, Kronenberg Peter and Traxer Olivier

Certificate

The European Association of Urology and EULIS are pleased to confer upon

Dr. P. Kronenberg

the honour of receiving the **best poster for clinical research 2013 EULIS**, entitled: **" The truth about laser fiber diameter"**

Copenhagen, September 2013

Prof. P.J. Osther
EULIS Chairman/
Local Organiser

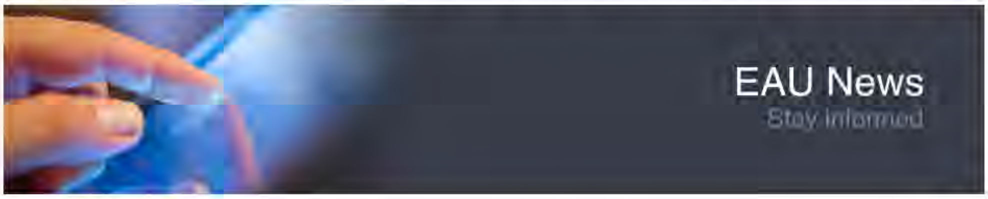
Ass. Prof. K.H. Andreassen
Co-Chairman

PO Box 30016
6803 AA Arnhem
The Netherlands

T +31 (0) 26 38 90 680
F +31 (0) 26 38 90 674

eau@uroweb.org
www.uroweb.org

European
Association
of Urology



Information conveyed to urologists regarding laser fiber diameter is incorrect, says new study

18-09-2013 1846 views

Dr. Kronenberg (left) received the Clinical Research Award at the 2nd EULIS Meeting in Copenhagen

Neither the total nor the core diameters of laser fibers correspond to the advertised laser fiber diameter, revealed a new study investigating lasers used for urological surgery. Furthermore, there are serious differences between manufacturers of fibers with a supposedly equal diameter.

The new study, conducted by Dr. Peter Kronenberg of Hospital Fernando Fonseca in Amadora, Portugal, and Prof. Olivier Traxer of the Hôpital Tenon in Paris, France, aimed to objectively confirm the diameter between laser fibers of supposed equal thickness by different brands.

According to Dr. P. Kronenberg, who recently presented the findings at the 2nd Meeting of the EAU Section of Urolithiasis (EULIS) in Copenhagen, Denmark, urologists need to know the exact technical specifications of the material they use.

"If the information conveyed to them, whether written on a product label or transmitted by an industry representative, is incorrect, their judgments and the decisions they make based on this knowledge may have surgical repercussions," he explained.

"And yet our measurements and survey suggest that most information conveyed to urologists regarding laser fiber diameter is incorrect and that the large majority of industry representatives are not aware of the real diameter of the laser fibers they represent."

The findings should warrant attention from the urological community, as larger than advertised laser fibers influence irrigation flow, visibility, scope deflection and stone retropulsion. The study won the Clinical Research Award at the 2nd EULIS.

In the course of the study 14 different brand-new laser fibers of 6 leading brands (with advertised diameters of 200, 270, 272, 273, 365, and 400 µm, including single use and re-usable fibers) were assessed through light microscopy. Multiple measurements of both the total diameter (including fiber coating) and the fiber core diameter were performed and compared to their respective advertised diameter. A 10% diameter deviation was considered as the maximum tolerance margin to be acceptable due to manufacture procedures. In addition to that, representatives of those brands at the top two major urology congresses were questioned on what the real diameter of their fibers were and if said diameter was the total diameter or only its core.

The total and the core diameters measured were both significantly different from the advertised diameter in all fibers ($p<0.00001$). If one considers the advertised diameter as the total diameter, none of the fibers had a measured diameter within the 10% tolerance range. The median increase between total diameter and advertised diameter was 85.3% (range 50.7-116.7%), with four of the fibers being more than double as thick as promoted.

If the advertised diameter corresponds to the fiber core diameter, only one fiber respected the 10% margin, the rest of the fibers having a median increase in core diameter of 30.9% (range 16.7-80.1%). The measurement of core diameters of fibers with a supposed equal diameter revealed differences of up to 100 µm in core diameter between manufacturers.

"Due to the ever increasing miniaturization of the instruments today, small differences in laser fiber diameter have repercussions on flexibility, irrigation flow and indirectly on visibility and operating time of ureterorenoscopy," commented Kronenberg on the findings. "And we detected differences in all fibers tested, sometimes well over 100%."

Additionally, in the enquiry, 4 out of 12 representatives said the advertised diameter to be the core diameter, acknowledging that the total fiber diameter was thicker than advertised. Only 1 of those 4 representatives admitted that the core diameter of his fibers was in fact bigger than advertised. The majority of representatives promoted the advertised diameter as the total diameter.

Referring to the implications of the study, Kronenberg explained that such large discrepancies found in the course of the study might warrant the researchers to look into other technical specifications of these and other materials used in endourology.

"It is highly necessary to see if the materials we use are in conformity with the provided information and if there are significant inter-manufacturer differences between materials with supposedly equal characteristics."

Information conveyed to urologists regarding laser fiber diameter is incorrect

Date: September 17, 2013
Source: European Association of Urology

Summary: Neither the total nor the core diameters of laser fibers correspond to the advertised laser fiber diameter, revealed a new study investigating lasers used for urological surgery. Furthermore, there are serious differences between manufacturers of fibers with a supposedly equal diameter.

Neither the total nor the core diameters of laser fibers correspond to the advertised laser fiber diameter, revealed a new study investigating lasers used for urological surgery. Furthermore, there are serious differences between manufacturers of fibers with a supposedly equal diameter.

The new study, conducted by Dr. Peter Kronenberg of Hospital Fernando Fonseca in Amadora, Portugal, and Prof. Olivier Traxer of the Hôpital Tenon in Paris, France, aimed to objectively confirm the diameter between laser fibers of supposed equal thickness by different brands.

According to Dr. P. Kronenberg, who recently presented the findings at the 2nd Meeting of the EAU Section of Urolithiasis (EULIS) in Copenhagen, Denmark, urologists need to know the exact technical specifications of the material they use.

"If the information conveyed to them, whether written on a product label or transmitted by an industry representative, is incorrect, their judgments and the decisions they make based on this knowledge may have surgical repercussions," he explained.

"And yet our measurements and survey suggest that most information conveyed to urologists regarding laser fiber diameter is incorrect and that the large majority of industry representatives are not aware of the real diameter of the laser fibers they represent."

The findings should warrant attention from the urological community, as larger than advertised laser fibers influence irrigation flow, visibility, scope deflection and stone retropulsion.

In the course of the study 14 different brand-new laser fibers of 6 leading brands (with advertised diameters of 200, 270, 272, 273, 365, and 400 μm, including single use and re-usable fibers) were assessed through light microscopy. Multiple measurements of both the total diameter (including fiber coating) and the fiber core diameter were performed and compared to their respective advertised diameter. A 10% diameter deviation was considered as the maximum tolerance margin to be acceptable due to manufacture procedures. In addition to that, representatives of those brands at the top two major urology congresses were questioned on what the real diameter of their fibers were and if said diameter was the total diameter or only its core.

The total and the core diameters measured were both significantly different from the advertised diameter in all fibers ($p<0.00001$). If one considers the advertised diameter as the total diameter, none of the fibers had a measured diameter within the 10% tolerance range. The median increase between total diameter and advertised diameter was 85.3% (range 50.7-116.7%), with four of the fibers being more than double as thick as promoted.

If the advertised diameter corresponds to the fiber core diameter, only one fiber respected the 10% margin, the rest of the fibers having a median increase in core diameter of 30.9% (range 16.7-80.1%). The measurement of core diameters of fibers with a supposed equal diameter revealed differences of up to 100 μm in core diameter between manufacturers.

"Due to the ever increasing miniaturization of the instruments today, small differences in laser fiber diameter have repercussions on flexibility, irrigation flow and indirectly on visibility and operating time of ureterorenoscopy," commented Kronenberg on the findings. "And we detected differences in all fibers tested, sometimes well over 100%."

Additionally, in the enquiry, 4 out of 12 representatives said the advertised diameter to be the core diameter, acknowledging that the total fiber diameter was thicker than advertised. Only 1 of those 4 representatives admitted that the core diameter of his fibers was in fact bigger than advertised. The majority of representatives promoted the advertised diameter as the total diameter.

Referring to the implications of the study, Kronenberg explained that such large discrepancies found in the course of the study might warrant the researchers to look into other technical specifications of these and other materials used in endourology.

"It is highly necessary to see if the materials we use are in conformity with the provided information and if there are significant inter-manufacturer differences between materials with supposedly equal characteristics."

The study won the Clinical Research Award at the 2nd EULIS.

< Previous: Avo helps design, produce Optofluidics' NanoTweezer
Next: Bruker Acquires Prairie Technologies >

Urologists need better information on laser fiber diameter

The advertised total and core diameters of laser fibers for urological surgery do not correspond with the actual diameters, according to a new study.

Furthermore, there are serious differences between manufacturers of fibers with supposedly equal diameters.

Urologists need to know the exact technical specifications of the material they use, said Dr. Peter Kronenberg of Hospital Fernando Fonseca in Amadora, Portugal, who conducted the study with professor Olivier Traxer of Hôpital Tenon in Paris. "If the information conveyed to them, whether written on a product label or transmitted by an industry representative, is incorrect, their judgments and the decisions they make based on this knowledge may have surgical repercussions," Kronenberg said.

They evaluated 14 different laser fibers from six brands with advertised diameters of 200, 270, 272, 273, 365 and 400 µm, taking multiple measurements of both the total diameter (including fiber coating) and the fiber core diameter and comparing them to their respective advertised diameters.

The total and the core diameters measured were both significantly different from the advertised diameter in all fibers ($p<0.00001$). The median increase between total diameter and advertised diameter was 85.3 percent, with a range of 50.7 to 116.7 percent; four of the fibers were more than twice as thick as promoted. The measurement of core diameters of fibers with supposedly equal diameters revealed differences of up to 100 µm between manufacturers.

The study won the Clinical Research Award at the second meeting of the EAU Section of Urolithiasis (EULIS) in Copenhagen, Denmark. The findings warrant attention from the urological community – larger-than-advertised laser fibers influence irrigation flow, visibility, scope deflection and stone retropulsion – and the manufacturers of these fibers should consider the implications as well.

BIOPHOTONICS >
2014 | 2013 | 2012 | 2011 | 2010
NOVEMBER

FEATURES
EDITORIAL
BIOSCAN
RAPIDSCAN
POST SCRIPTS
PRODUCTS

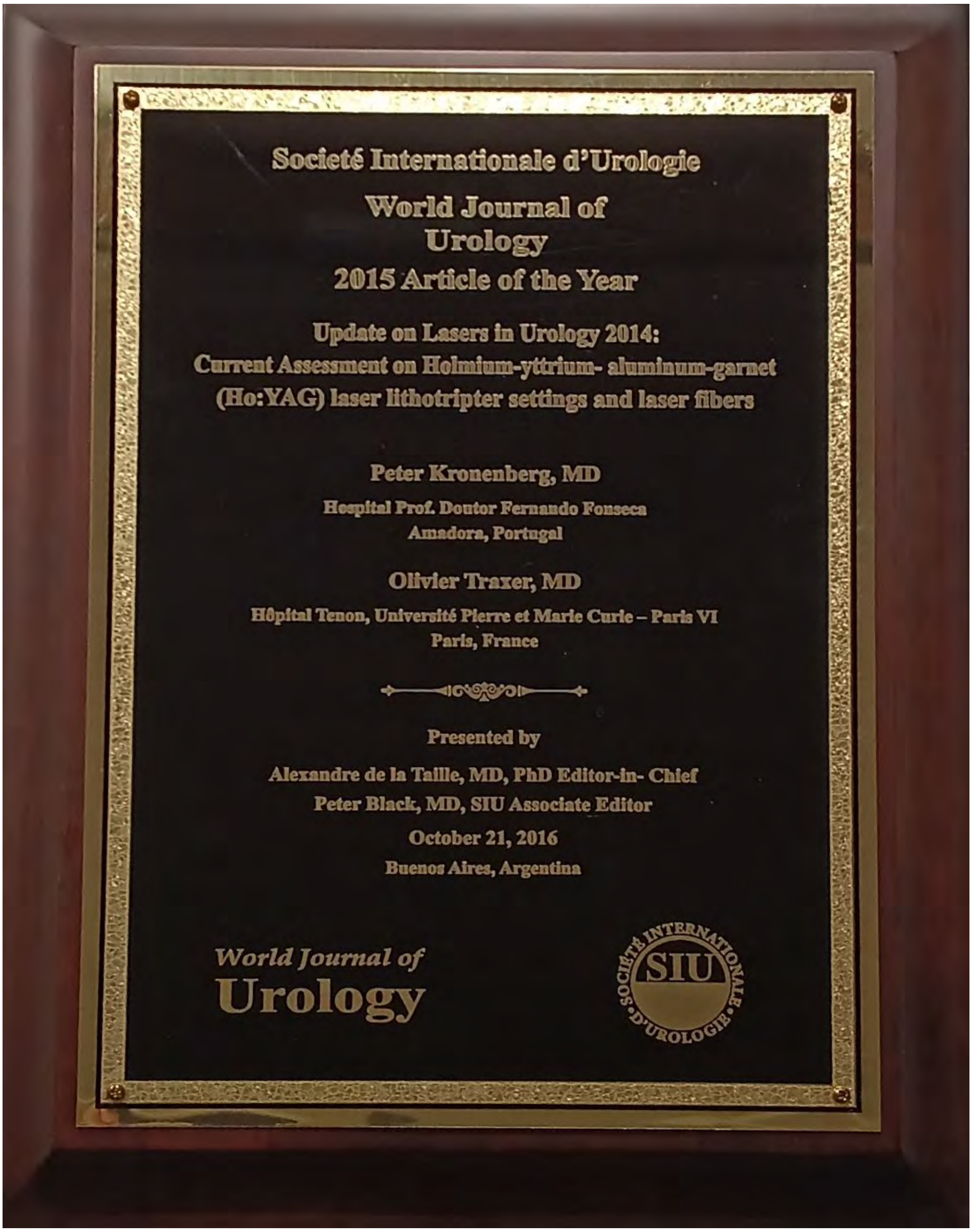
COMMENTS Post a comment >

The ability to post comments on **Photonics.com** is one benefit of a FREE Photonics.com membership.

Please login or register, for FREE, to post comments:

Register | Login

MORE FROM PHOTONICS MEDIA >
Zecotek Photonics raises $3.5M
Quantum Wave Fund (QWave)
Trojan Technologies wins Enabled by Optics contest
US Research Spending Decline Driven By Industry
OPMI Lumera 700/Rescan 700 – Carl Zeiss Meditec AG
Nanoscribe - 2014 Prism Award Winner - Photonic Professional GT
Filter Sets for Imaging DsRed (Red
The Future of Imaging: Three


Societé Internationale d'Urologie
World Journal of Urology
2015 Article of the Year
Update on Lasers in Urology 2014:
Current Assessment on Holmium-yttrium- aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers
Peter Kronenberg, MD
Hospital Prof. Doutor Fernando Fonseca
Amadora, Portugal
Olivier Traxer, MD
Hôpital Tenon, Université Pierre et Marie Curie – Paris VI
Paris, France
Presented by
Alexandre de la Taille, MD, PhD Editor-in- Chief
Peter Black, MD, SIU Associate Editor
October 21, 2016
Buenos Aires, Argentina
World Journal of Urology
SIU
SOCIÉTÉ INTERNATIONALE D'UROLOGIE

1073

Long-pulse versus short-pulse laser lithotripsy performance

Eur Urol Suppl 2015;14/2;e1073

Print!

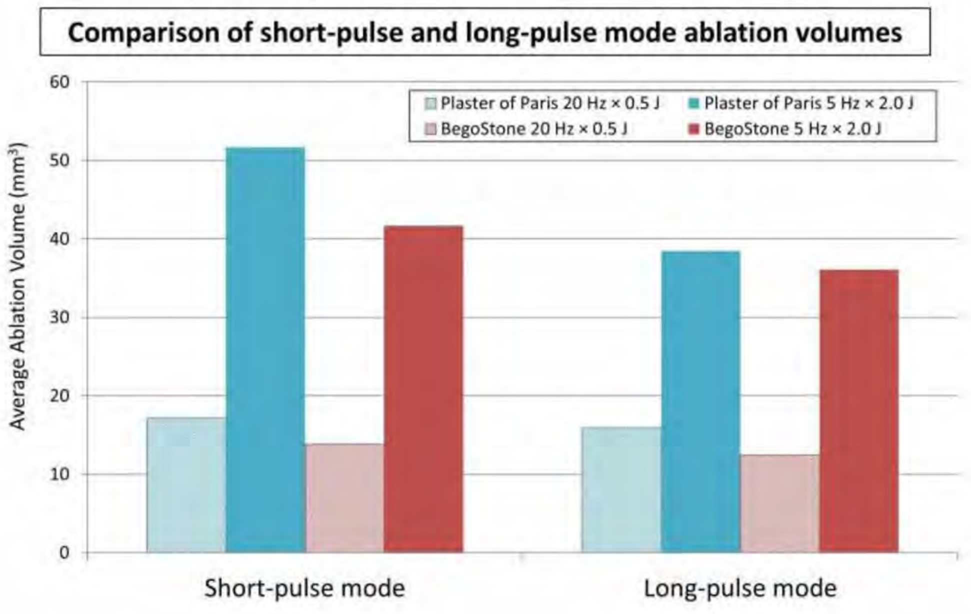
Kronenberg P.M.[1], Traxer O.[2]

[1]Hospital Prof. Doutor Fernando Fonseca, Dept. of Urology, Amadora, Portugal, [2]University Paris 6 Pierre Et Marie Curie – Hospital Tenon, Dept. of Urology, Paris, France

INTRODUCTION & OBJECTIVES: Long-pulse lithotripsy has recently become available and its efficiency is still unclear. The authors decided to evaluate long-pulse lithotripsy performance in comparison to traditional short-pulse lithotripsy.

MATERIAL & METHODS: An automated laser fragmentation testing system was used to perform laser-lithotripsy experiments creating ablation fissures on artificial stones made from soft and hard stone material (plaster of Paris and BegoStone). 272-µm core laser fibers (stripped and cleaved according to manufacturer recommendations), as well as high-frequency low-pulse energy (HiFr-LoPE; 20Hz x 0.5J) and low-frequency high-pulse energy (LoFr-HiPE; 5Hz x 2.0J) lithotripter settings were employed to cover most typical lithotripsy conditions. All combinations were tested using both the traditional short-pulse and the novel long-pulse mode, in multiple 30-second-long lithotripsy experiments. Ablation volumes were measured and compared. Laser-fiber tips were photographed before and after lithotripsy to complement the results.

RESULTS: Short-pulse mode is always more ablative than long-pulse mode ($p<0.00001$), regardless of stone material or lithotripter settings, with an average 17.4% higher ablation volume, 25.0% at LoFr-HiPE and 9.9% at HiFr-LoPE. Short-pulse mode makes 25.2% wider fissures, and although less ablative, long-pulse mode creates on average 13.0% deeper fissures. Ablation volume increased with softer stone material or with LoFr-HiPE settings, regardless of pulse type. More fiber tip degradation with harder stone material or with LoFr-HiPE settings is observed in both pulse modes, however, these damages are considerably less evident in long-pulse lithotripsy.



CONCLUSIONS: Traditional short-pulse lithotripter settings are more ablative than novel long-pulse settings. Long-pulse lithotripsy shows less fiber tip degradation.

Certificate

The European Association of Urology acknowledges the selection of the Best Poster of:

Peter Kronenberg

Co-authors: Traxer O. [2]
[1]Amadora, , [2]Paris,

in the session "Ureteroscopy: Devices, stents, and drugs"

with the abstract entitled: "Long-pulse versus short-pulse laser lithotripsy performance"

at the time of the 30th Annual Congress of the European Association of Urology, 20-24 March 2015, Madrid, Spain

Prof. C.R. Chapple	Prof. A. Stenzl
Secretary General	Chairman Scientific
EAU Office	Congress Office

PO Box 30016
6803 AA Arnhem
The Netherlands

T +31 (0) 26 389 0680
F +31 (0) 26 389 0674

eau@uroweb.org
www.uroweb.org

European Association of Urology

941 **Burst laser lithotripsy – a novel lithotripsy mode**

Eur Urol Suppl 2016;15(3);e941 Print!

Kronenberg P.[1], Traxer O.[2]

[1]Hospital Prof. Doutor Fernando Fonseca, Dept. of Urology, Amadora, Portugal, [2]Université Paris 6 Pierre Et Marie Curie – Hôpital Tenon, Dept. of Urology, Paris, France

INTRODUCTION & OBJECTIVES: A new laser lithotripter has been put on the market that allows a novel lithotripsy mode: burst lithotripsy. Each bursts consists of three individual laser pulses, the first one being the more energy intense while the last one the least energy intense, and having successive increasing pulse lengths. The authors decided to evaluate this new lithotriptsy mode and compare it to conventional lithotripsy.

MATERIAL & METHODS: An automated laser fragmentation testing system was used to perform laser-lithotripsy experiments creating ablation fissures on artificial stones made from different stone material (plaster of Paris and BegoStone™), using band-new 273-µm core laser fibers (SureFlex™ from AMS). The burst mode of the new laser lithotripter (StoneLight 30 from AMS), is predefined to emit 3 bursts per second, each containing 3 pulses, with the total burst energy being the only selectable parameter in this setting. A total burst energy of 3.5J was selected, equivalent to a power output of 10.5W (10.5W = 3.5J × 3 bursts per second; 3.5J per burst, each burst with 3 pulses ≈ 1.17J per pulse). Conventional short-pulse lithotripsy was performed using lithotripter settings set at nearby values (10Hz × 1.0J), as well as at lower energy (10Hz × 0.5J) and higher energy levels (10Hz × 1.5J), all of them using a standard pulse length of 300 µs. Ablation volumes were compared and statistically analyzed.

RESULTS: At approximate power and energy levels, the novel burst mode (at 10.5W) was significantly more ablative than conventional lithotripsy (at 10W = 10Hz × 1.0J), outperforming the latter by 60.5% higher ablation volumes ($p<0.00001$), regardless of stone material, as well as producing 28.5% wider and 18.6% deeper fissures on average (p0.05). Comparison to the lower energy lithotripsy setting (5W = 10Hz × 0.5J), revealed an obvious advantage favoring the burst mode, with 250.1% higher ablation volumes on average ($p<0.00001$).

CONCLUSIONS: The novel burst mode is significantly more ablative than the conventional lithotripsy at similar power and energy settings. The synchronized continuous variation of pulse energy and pulse length throughout the same lithotripter setting might improve and speed up laser lithotripsy procedures in the future.

Certificate

The European Association of Urology acknowledges the selection of the Best Poster of:

Peter Kronenberg

Co-authors: Traxer O. [2]
[1]Amadora, , [2]Paris,

in the session "New technologies in endo-urology"

with the abstract entitled: "Burst laser lithotripsy – a novel lithotripsy mode"

at the time of the 31st Annual Congress of the European Association of Urology, 11-15 March 2016, Munich, Germany

Prof. C.R. Chapple	**Prof. A. Stenzl**
Secretary General	**Chairman Scientific**
EAU Office	**Congress Office**

PO Box 30016
6803 AA Arnhem
The Netherlands

T +31 (0) 26 389 0680
F +31 (0) 26 389 0674

eau@uroweb.org
www.uroweb.org

European Association of Urology

continence is related to the individual surgeon technique rather than the sling procedure. Further follow up is ongoing to determine long term impact on continence.

Source of Funding: None

These authors (HN,ML,SP) contributed equally.

PI-04

SURGEON AND HOSPITAL VARIATION IN THE COSTS OF ROBOT-ASSISTED RADICAL PROSTATECTOMY IN THE UNITED STATES

Alexander Cole, Jeffrey Leow, Steven Chang, Christian Meyer, Nawar Hanna, Adam Kibel, Boston, MA; Mani Menon, Jesse Sammon, Firas Abdollah, Detroit, MI; Benjamin Chung, Palo Alto, CA; Maxine Sun, Quoc-Dien Trinh, Boston, MA*

INTRODUCTION AND OBJECTIVES: In a cost-conscious healthcare environment, eliminating unwarranted costs and understanding cost variation are paramount. Prostate cancer is the most common malignancy among men and surgical treatment with radical prostatectomy (RP) is associated with substantial costs, particularly with the recent rapid adoption of robot-assisted RP (RARP). We sought to assess individual surgeon-level variation in costs of RARP and identify independent predictors of high and low-cost surgery.

METHODS: We identified 291,015 men in the Premier all-payer discharge database who underwent RARP for prostate cancer by 667 unique surgeons at 197 different hospitals across the United States from 2003 to 2013. We evaluated 90-day direct hospital costs (2014 US$). High costs were defined as costs superior to the 90th percentile of all patient costs (≥$18,564/RARP), while low costs were defined as the costs inferior to the 10th percentile of all patient costs (≤$5,585/RARP). Multivariable logistic regression models identified independent predictors of high and low costs, while multilevel hierarchal models determined variability of various characteristics on costs

RESULTS: Mean costs for each RARP patient was $11,878 (95% CI 11,804-11,952), Mean costs per RARP in the low-cost group was $2837 (95% CI: $2805-$2869) compared to $25,906 (95% CI: $24702-$25490) in the high-cost group. Nearly a third of the variation in RARP cost was attributable to hospital characteristics, and over a fifth was attributable to surgeon characteristics (R-squared for each 30.43% and 21.25%, respectively). Factors associated with high-cost surgeries included Black race (vs. Whites; OR: 1.42, 95% CI: 1.12 to 1.33), Charlson comorbidity≥2 (vs. 0; OR 1.88 95% CI 1.55-2.29) and teaching hospitals (vs. non-teaching; OR 2.27, 95% CI 1.28-4.04). High-volume providers (≥90th percentile) was associated with significantly lower odds of high-cost surgery (surgeons: OR 0.24, 95% CI 0.11-0.54; hospitals: OR 0.105 95% CI 0.02-0.46). As for predictors for low-cost surgeries, high-volume surgeons were found to be less likely to have low-cost RARPs (OR: 0.41, 95% CI: 0.20-0.84). Conversely, high-volume hospitals were highly associated with low-cost RARPs (OR: 839, $p<0.0001$).

CONCLUSIONS: This study provides new insight into the key role played by individual surgeons performing RARP across a large nationally representative sample. Given the substantial variability in RARP costs contributed by hospital and surgeon characteristics, future steps to identify and remedy the root cause of outliers costs, and to reduce unwarranted variability in costs may yield great benefits for patients, physicians and the health system as a whole.

Source of Funding: none

PI-05

ULTRA-SHORT, SHORT, MEDIUM AND LONG-PULSE LASER LITHOTRIPSY PERFORMANCE

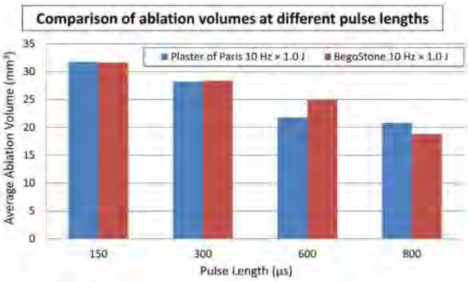
Peter Kronenberg, Amadora, Portugal; Olivier Traxer, Paris, France*

INTRODUCTION AND OBJECTIVES: Recent laser lithotripter models allow the user to choose between long-pulse and short-pulse mode. However, the latest lithotripter models offer additional pulse lengths, i.e. additional pulse widths or pulse durations, ranging from the traditional short-pulse mode, to long-, medium-, and ultra-short-pulse modes. The authors decided to evaluate how the variations of these new pulse-length modes affect lithotripsy performance in comparison to traditional short-pulse lithotripsy.

METHODS: An automated laser fragmentation testing system was used to perform laser-lithotripsy experiments creating ablation fissures on artificial stones made from different stone material (plaster of Paris and BegoStone®). Brand-new 273-µm core laser fibers (Sure-Flex® 273 from AMS), cleaved with metal scissors, were employed together with a novel lithotripter (StoneLight 30 from AMS) set at 10Hz × 1.0J, capable of ultra-short- (150 µs), short- (300 µs), medium- (600 µs) and long-pulse (800 µs) lithotripsy. All combinations were tested in multiple 30-second-long lithotripsy experiments. Ablation volumes were measured, compared, and statistically analyzed.

RESULTS: All pulse lengths differed from each other significantly ($p<0.00001$), with shorter pulse lengths always outperforming the longer ones regarding ablation volume. A negative linear relation was confirmed between pulse length and ablation volume, i.e. as pulse length rises, ablation volume decreases ($p<0.00001$). Extreme pulse lengths comparisons (150 µs vs 800 µs) showed an average 60.6% higher ablation volume difference favoring ultra-short-pulse mode ($p<0.00001$). Intermediary comparisons (150 µs vs 300 µs, 300 µs vs 600 µs, and 600 µs vs 800 µs) revealed also significant differences with 12.0%, 21.6%, and 18.8% higher ablation volumes, respectively ($p<0.001$ for all), regardless of stone material. Ultra-short pulse mode makes 64.7% wider fissures (up to 85.9%; $p<0.00001$) in comparison to long-pulse mode, and although the latter creates on average 9.8% deeper fissures it isn't statistically significant ($p=0.15$).

CONCLUSIONS: Pulse length is inversely correlated with ablation volume. Traditional short-pulse lithotripter settings remain one of the more ablative settings, being only slightly out-performed by ultra-short-pulse mode.



Source of Funding: none

PI-06

LONG-TERM PUDENDAL NERVE ELECTRICAL STIMULATION ACCELERATES RECOVERY FROM STRESS INCONTINENCE VIA INCREASED NEUROTROPHIN EXPRESSION AND NERVE REGENERATION IN AN ANIMAL MODEL

Hai-Hong Jiang, Qixiang Song, Cleveland, OH; Bradley Gill, Cleveland, OH; Yolanda Cruz, Cleveland, OH; Zhiliang Weng, Wenzhou, China, People's Republic of; Margot Damaser, Cleveland, OH*

INTRODUCTION AND OBJECTIVES: Postpartum stress urinary incontinence (SUI) is usually temporary but is strongly associated with later SUI development, in part due to insufficient regeneration of the pudendal nerve after injury. Electrical stimulation at certain frequencies improves neuroregeneration by upregulating neurotrophin expression. This study determined if whether long-term electrical

Urologia portuguesa em alta no congresso da AUA

Foram vários os portugueses que participaram no AUA (American Urological Association) Annual Meeting 2016, que decorreu em San Diego, entre 6 e 10 de maio. Com um programa dinâmico e muito variado, que abrangeu diferentes subespecialidades, este congresso contou com um momento alto da representação nacional, quando a classificação de melhor *abstract* foi atribuída a Peter Kronenberg.

Ana Luísa Pereira

O AUA 2016 atraiu cerca de 16 000 participantes oriundos de todo o mundo, entre os quais vários portugueses

O último congresso da AUA «teve um nível globalmente elevado e cobriu todas as vertentes da Urologia», nas palavras de Raul Rodrigues, diretor do Serviço de Urologia do Hospital de Santo Espírito da Ilha Terceira, nos Açores. Já Lorenzo Marconi, urologista no Centro Hospitalar e Universitário de Coimbra, destaca «as três novidades que vão transformar a cirurgia robótica num futuro próximo: o *feedback* tátil, os braços robóticos flexíveis e a entrada no mercado de novos fabricantes de robots». Estreante no congresso americano, Álvaro Nunes, urologista no Centro Hospitalar Barreiro Montijo, considera que este evento «estava muito bem organizado, oferecendo um vasto leque de temas e abordando as mais recentes novidades», mas sublinha que «a Europa não fica atrás do que se faz nos Estados Unidos».

O que mais se destacou no AUA 2016, na opinião de Lorenzo Marconi, foi «o enfoque na nefrectomia citorredutora, campo no qual a seleção dos doentes que irão ser submetidos a essa técnica cirúrgica assume cada vez maior importância» e «a caracterização das pequenas massas renais, com debates sobre as biópsias percutâneas e o potencial papel da imagiologia quantitativa (*radiomics*)». Para Raul Rodrigues, a principal novidade foram as sessões apelidadas de SOS (sigla resultante de *Setbacks and Operative Solutions*), que «colocaram os melhores urologistas a falar sobre as complicações que surgem na prática diária e as estratégias para as resolver».

Também Álvaro Nunes salienta este aspeto como o mais interessante a que assistiu neste encontro, uma vez que «foram apresentadas complicações que raramente são abordadas nos congressos, o que constituiu um ato de humildade por parte de cirurgiões reconhecidos mundialmente». Este congressista destaca também a abordagem de «algumas inovações tecnológicas no campo da endourologia e de novas terapêuticas para o carcinoma da próstata metastizado resistente à castração».

Maiores desafios e novidades

Porém, as maiores novidades no contexto urológico, segundo Álvaro Nunes, passam pela robótica e pela endourologia, com «a tendência de surgirem instrumentos cada vez mais pequenos e menos invasivos», e pela terapêutica do carcinoma da próstata, «que está em grande evolução com o aparecimento de novas informações e fármacos em ensaios clínicos de fases II e III». Esta área do carcinoma da próstata está «em grande mudança, surgem novidades praticamente todos os semestres e, de facto, o que se faz hoje não se fazia há uma década». «Provavelmente, daqui a cinco ou dez anos, teremos indicações e combinações de fármacos muito diferentes dos que temos atualmente», frisa Álvaro Nunes.

Por sua vez, Raul Rodrigues admite que o maior desafio, a nível nacional, é a «criação de verdadeiros centros de referência, por analogia com o que se faz no estrangeiro, parecendo que estão a ser dados passos sérios nesse sentido». Este urologista prevê que «apareçam muitas novidades tecnológicas, farmacológicas e até patológicas (com novas doenças e novos paradigmas terapêuticos), tendo em conta que a Urologia é, possivelmente, uma das especialidades mais tecnológicas e mais diversificadas da Medicina».

PETER KRONENBERG DISTINGUIDO ENTRE MILHARES

De uma seleção inicial dos seis melhores trabalhos, entre os milhares que foram apresentados no AUA 2016, o *abstract* intitulado «*Ultra-short, short, medium and long-pulse laser lithotripsy performance*», da autoria de Peter Kronenberg, do Hospital Prof. Doutor Fernando Fonseca, na Amadora, foi classificado como *Best Abstract*. Este urologista português desenvolve investigação há vários anos no âmbito dos lasers em endourologia, «algo muito prático e inovador», como classifica Álvaro Nunes, que considera ter sido «muito relevante assistir à distinção mundial do trabalho de um colega e amigo português, no âmbito de um congresso americano». Peter Kronenberg assume-se satisfeito por ver o seu trabalho científico reconhecido internacionalmente, sendo «recompensador pelo tempo dedicado à investigação e "roubado" à família» e antecipa que «existirão muitos avanços na Urologia nos anos que se avizinham, sobretudo em termos de robótica».