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Multi-activity 3D printed assistive technology in children: a case study

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ABSTRACT

Congenital limb defects occur when a limb does not develop normally during pregnancy. The quality of each person's everyday life is significantly impacted by any of these defects and there is no concrete treatment. 3D modeling and printing, enables the creation and customization of precise virtual and/or physical models, including models of the human anatomy. These technologies provide a novel method of producing new devices with optimized design and production time, improving adaptability, and incorporating functionality. To this end, we propose a method of designing and producing 3D printed assistive devices and we also present an example of an assistive device, done in the 3D Printing Center for Health, as well as its impact on the patient's daily life. With this device, the patient became able to play the guitar and hold a knife, thus helping on these two activities.

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KEYWORDS
3D printing; assistive technology; biomedical research; congenital defects; design

Introduction

According to the World Health Organization (WHO), birth defects can result in long-term disability, which takes a significant toll on individuals, families, health care systems and societies (World Health Organization 2023). Congenital limb defects occur when a limb does not develop normally during pregnancy. The most common defects are: No limb at all; Part of the limb doesn't separate, often seen in fingers or toes; Duplication, often seen as extra fingers or toes; Abnormal limb size (Stanford Medicine 2023).

> The quality of each person's everyday life is significantly impacted by any of these defects and there is no concrete treatment. However, there are some assistive options like prosthetics, orthotics, surgery and rehabilitation, that can improve daily routines as well as the quality of life (Stanford Medicine 2023)

> A combination of technologies known as additive manufacturing, commonly known as threedimensional (3D) printing, enables the creation and customization of precise virtual and/or physical models, including models of the human anatomy. These technologies provide a novel methodof producing new devices with optimized design and production time, improving adaptability and incorporating functionality. They are also extremely flexible production methods with a high degree of geometric freedom (Chua & Leong, 2014; Chua et al., 2017; Santos et al., 2017)

> 3D printing has become a viable, safe and efficient method of producing assistive devices for individuals that are born with congenital defects. However, there is not much scientific guidance on how to use these devices. Additionally, most of the designers who work with 3D printing have little to no expertise with assistive technologies and lack the requisite background in health care (Degerli et al., 2022).

Objectives

It is the aim of this of this case study is to propose a method of designing and producing a 3D printed assistive device which is affordable, personalized, and simple to manufacture. This is a case study that specifically focuses on children with congenital defects. This paper also presents an example of the investigation work done in the 3D Printing Center for Health (2023), from the co-creative collaboration between the Center, Hospitals, clinicians, caregivers, and patients and culminating on the creative design and production of the personalized 3D printing assistive devices. This paper also describes the clinical needs and impact that this 3D printed assistive device has on the patient's daily life. This case report describes a client-centered approach of the whole process.

Methods

The device was designed and developed by a multidisciplinary team, composed of physicians, physical therapists, engineers, patients, caregivers, occupational therapists and doctors.

> The input of so many different areas was only possible due to a partnership between the 3D printing center for health and Hospital D. Estefânea, with the hospital forwarding their patients to the 3D Printing Center for Health with information about their current status (type of disability tasks for the assistive device to perform). Stakeholders, particularly occupational therapists (OTs), played a vital role throughout the process. Physical therapists (PTs) provided essential input on functional requirements, ensuring that the design not only prioritized patient safety but also facilitated optimal performance and mobility for individuals using the prosthesis.

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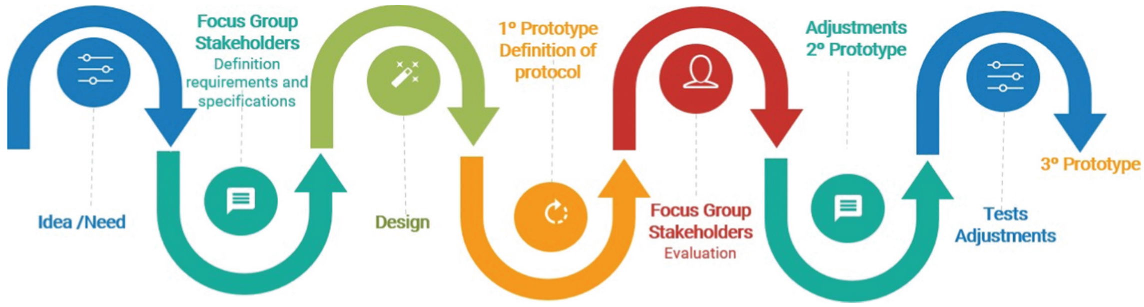

Figure 1. 3D printing center for health methodology roadmap.

The individual is interviewed about the activities with which he struggles and to understand the perceived importance and performance of the activities. Then, the case is evaluated in the Center and the creation process takes place, according to the 3D Printing Center for Health roadmap, shown in Figure 1. From the idea to the final prototype, the 3D Printing Center for Health follows every step of the roadmap in Figure 1 for every product created. In this case study, the 3D Printing Center for Health intends to make an assistive device that could help a 7year old child, with a congenital arm defect, not only during meals but also playing the guitar. According to the 2.1, the stakeholders, in this case study, are the patient's doctor, occupational therapists, caregivers and, evidently, the patient himself.

The schematic in Figure 2 resumes the technical method followed by the Center, from the design to the production of the 3D assistive devices.

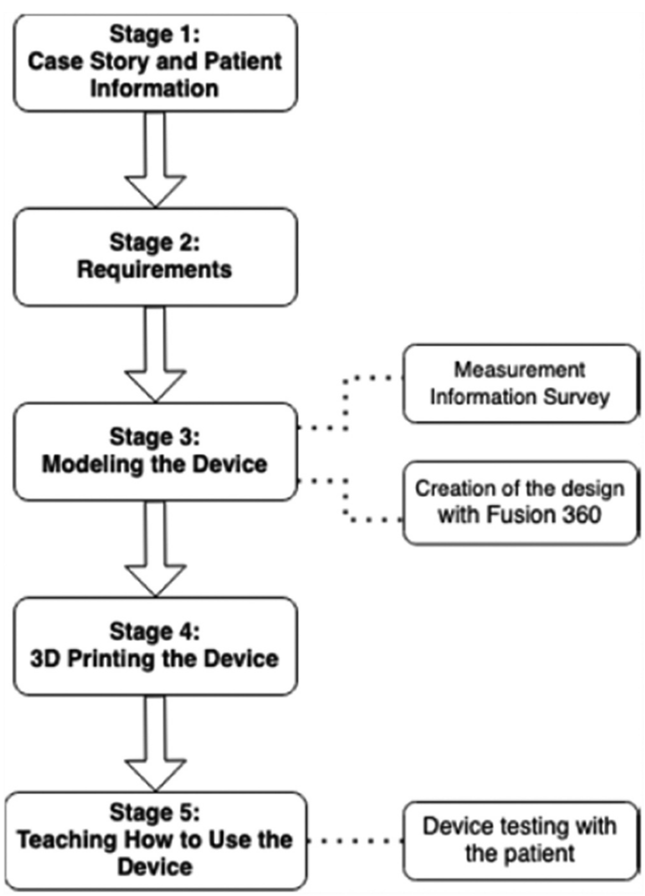

Figure 2. Methodology schematic.

Case story and patient information

This study reports to a 7 year old child. The child was born with an amputation on the right hand, associated with malformation of the forearm bones, which are hypo- plastic when compared to the contra-lateral bones, as shown in Figure 3. Clinically, it looks like an amputation of the forearm, but the X-ray shows otherwise. The patient is followed by the Physical Medicine and Rehabilitation department of the Hospital Dona Estefânea.

The 3D Printing Center for Health was contacted by his doctor in order to make an assistive device that would fit on his forearm, enabling the child to do two different activities: play the guitar and be able to hold cutlery. **There was no assistive device being used by the patient prior to the development of this 3D device.**

Requirements

Once the need is identified, requirements are the next step. The key characteristic of this assistive device is **multifunction**, which enables it to function as both a knife holder and a guitar pick holder. **While it is not necessary for the patient to use the same device for both holding knives and playing the guitar, considering the patient's perspective, who requires assistive devices to perform specific tasks, their preference would likely be to minimize the number of specialized devices for each individual task. The goal is to combine as much solutions as possible on one device without putting in question the functionality of each, in order to make the patient carry**

Figure 3. Patient malformation.

the least assistive technologies possible. This design feature eliminates the need for users to switch to another assistive technology when transitioning between these activities. It should also be light weight, resistant, and well fitted to the right amputated arm, with the aim of being as comfortable as possible.

Safety concerns were effectively addressed by incorporating measures, particularly in relation to patient skin protection, namely a protection foam. Based on the Clinicians feedback it was ensured that the foam used provided adequate pressure distribution and cushioning, reducing the risk of pressure sores or discomfort for patients using the prosthesis. Additionally, Clinicians played a crucial role in the process and were actively involved on the initial phases. Their expertise and insights were invaluable in understanding the specific needs and challenges faced by patients. By collaborating closely with occupational therapists (OTs), physical therapists (PTs) and physician, we were able to gain a comprehensive understanding of safety requirements and incorporate them into the final product.

Modelling the device

Considering the anatomical characteristics of the patient, the Center created a 3- dimensional (3D) sketch drawings of the device in order to design the knife and guitar pick holder apparatus. It was important to have a good contact area for the patient's forearm, so, according to his measurements, a support for the limb was modeled, as shown in the Figure 4.

In Figure 5, it is shown a cover that was also modeled (1) and the holes needed to insert the velcro (2), thus preventing the forearm from leaving the device. The lateral holes (3) were placed in order to screw the knife through them, so it stayed steady. The number (4) and (5), represent, respectively, the guitar pick holder and the hole to insert the knife. This assistive device model was designed using Autodesk Fusion 360 © and modelled according to the taken measures. It is licensed under a Creative Commons Attribution Non-Commercial 4.0 International license.

After all of the stakeholders agreed on the prototype design, a preliminary meeting with the patient was scheduled and the measurements were taken according to the Figure 6. These measures are based on the E-Nabling the Future (E-Nabling the Future 2023) measurements for prosthetic scaling. For this device, only the B, C, F and I measurements were taken.

3D printing the device

After scaling, the 3D printed assistive device was printed with a 3D printer from FCT- NOVA FabLab, Original Prusa i3 MK3S. Polylactic Acid (PLA) filament was used as printing material, with printing completed in 4 hours and 43 minutes. The assistive device weighted 63 g. After printing, defects such as sharpness were observed. These defects were corrected with a heat gun and sandpaper. Velcro © has been added to prevent the device from slipping during use.

Teaching how to use the device

A second meeting with the patient and his parents was taken, in order to understand if there was the need to perform changes on the design. In this meeting, the patient tested the device for the first time. The feeding component was introduced to the individual and his parents and training was given regarding its use (e.g., knife-insertion, eating, apparatus removal 2.7) (Degerli et al., 2022). The guitar pick holder function was also tested and worked effectively, as seen in Figure 8. The effectiveness was analyzed by comparing hand function before and after wearing the device and no changes

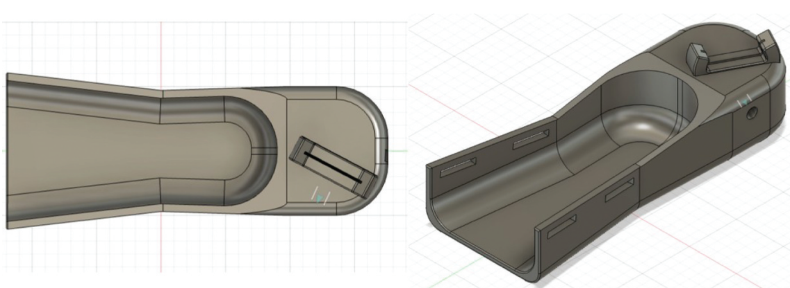

Figure 4. Assistive device 3D modeling using fusion 360 ©.

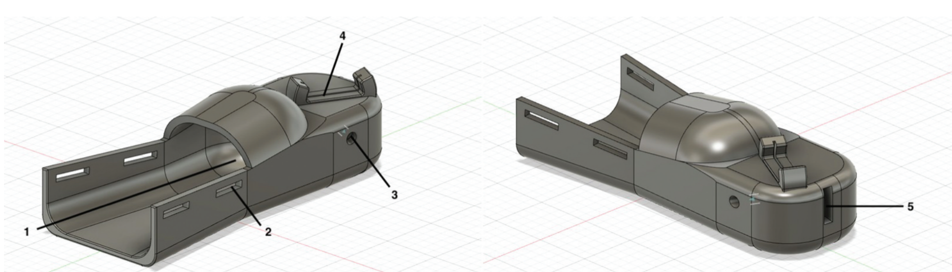

Figure 5. Assistive device 3D final sketch using fusion 360 ©.

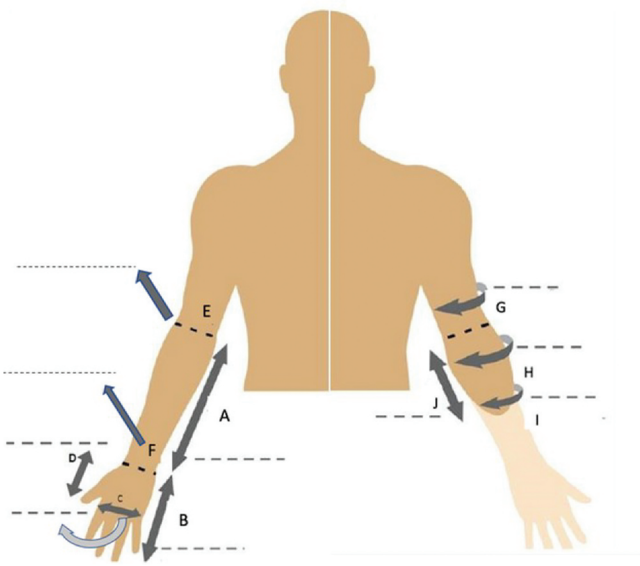

Figure 6. Patient measurements.

Figure 8. Assistive device as a guitar pick holder.

Figure 7. Assistive device as a knife holder.

were required. With this tool, the patient can use a knife and a guitar pick, as shown on Figures 7 and 8. The child started to practice the use of the assistive device by himself at home and at Hospital Dona Estefânea, where he is followed.

Results

As mentioned previously, the patient was introduced to the assistive device and instructed on how to use it (e.g., eating and playing the guitar). By comparing hand function before and after wearing the gadget, the effectiveness was evaluated. For this evaluation two methods were used: a System Usability Scale (SUS) questionnaire was performed with the patients' parents, due to his early age, and a live interview with the patient, presenting him with three questions, giving us a qualitative form of evaluation.

> A SUS questionnaire consists of 5 negative statements and 5 of a positive nature. Each statement has response options that vary from 1 to 5, where 1 corresponds to "Strongly disagree" and 5 corresponds to "Strongly Agree."
>
> The questions of the SUS questionnaire are presented on the Annex and its answers on Table 1. According to these results it is acknowledged that the device brought improvements to the intended activities performed by the patient. Nonetheless, the functionalities could be even better integrated and advancements could be made.

Discussion

On the live interview, three additional questions were presented to the patient:

- Does the device allow you to carry out activities that you were previously unable to do on your own?
- Is there anything on the device that causes you discomfort or doesn't work?
- What would you change on the device?

Table 1. SUS questionnaire answers.

	Classification				
Questions	1	2	3	4	5
Q1					X
Q2	X				
Q3					X
Q4	X				
Q5				X	
Q6		X			
Q7					X
Q8	X				
Q9				X	
Q10		X			

The patient stated that he could now "play the guitar and use the knife at meals but would also appreciate if "it allowed to use knives with different handle widths." He also stated that in no way does the device cause discomfort or doesn't work. By analysing the two evaluation methods, we came to the conclusion that the quality of the patients' life was improved by using the 3D printed assistive device. **Furthermore, it is worth noting that the patient had consistently rejected the idea of using a standard prosthesis. However, when presented with the option of the customized assistive technology device developed specifically for their needs, they embraced it**. The weight, dimension, durability, simplicity of use and comfort of the device satisfied the patient. Overall, the person was extremely happy with the created device. The material cost of the device was approximately 8€ **and the whole process took around 1 month.**

Current limitations and future work

Despite its effectiveness and efficiency, the assistive device can be improved, with regard to the knife and guitar pick, since it is difficult for the patient to put them all by himself. Another limitation is due to the print material, PLA. When exposed to significant heat (e.g., leaving the device on the car in the summer), for instance the device suffers deformations. So, in terms of future work, to overcome some limitations of the physical properties of print materials, new filaments will be explored on the construction of the assistive devices. Improving the design of the product, meaning its appearance is also on the road-map of the 3D Printing Center for health for future assistive devices.

Conclusions

This case report presented a description of a client-centered process in the selection and 3D printing. Performance of the tool was evaluated with a case study. Regarding the usability of the tool, the patient considered it improved his life quality. This assistive device provides a simultaneous holder for a knife and a guitar pick, helping the subject in two areas: eating and music playing.

We acknowledge that the use of 3D printing for personalized assistive technology devices is not a novel concept. However, it is crucial to emphasize the disruptive nature of our co-creation and iterative methodology, particularly in the healthcare context, and more specifically, in the field of rehabilitation. Throughout the entire construction process, which encompasses the definition of requirements, design, and material selection, active involvement, and collaboration with all stakeholders, including patients, caregivers, engineers, medical professionals, and occupational therapists, were fundamental. This dynamic process enabled us to develop a tailored solution that genuinely addressed the unique needs and preferences of the end-users.

The product development methodology began with the design idea based on the patient's needs and it was followed by a first meeting for measuring purposes. This allowed developing the first 3D sketch of the device and its printing. This assistive technology was applied in a case study context, and it proved to be a reliable and suitable tool, fulfilling the objectives that were stabilised. 3D Printing Center for Health devices help patients in many daily activities on a personalised and **multi-function** way for each one.

The methodology on which the center is based, as well as the chosen approach to each device creation and modeling, can be reproduced in many contexts, such as World Health Organization initiatives and missions, especially to poorer countries, due to its ease of implementation and low cost.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Annex

System Usability Scale

	Strongly Disagree				Strongly Agree
1. I think I'd like to use this product frequently.	1	2	3	4	5
2. I found the product more complex than necessary.	1	2	3	4	5
3. I found the product easy to use.	1	2	3	4	5
4. I think I would need help from a technician to be able to use this product.	1	2	3	4	5
5. I found that the various features of this product were well integrated.	1	2	3	4	5
6. I thought this product had too many inconsistencies.	1	2	3	4	5
7. I assume that most people would quickly learn to use this product.	1	2	3	4	5
8. I found the product too complicated to use.	1	2	3	4	5
9. I felt very confident using this product.	1	2	3	4	5
10. I had to learn a lot before I could handle this product.	1	2	3	4	5