Technical Note

Femoroacetabular Contact Force Measurement in Hip Arthroscopy: Surgical Technique

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Abstract: The femoroacetabular contact force and pressure are increased in the anterosuperior segment of the acetabulum in femoroacetabular impingement syndrome. We developed a special device for femoroacetabular contact force measurement in hip arthroscopy and present the surgical technique for measuring femoroacetabular contact force in the intact joint with a cam morphology and after cam resection, with the hip in different positions in a cadaver specimen. The device is introduced into the joint peripheral compartment. After joint distraction, the sensor is deployed through the cannula and advanced into the central compartment under direct arthroscopic control. We show a decrease in the contact force measured with this device after cam resection. This force analysis is limited to the anterosuperior femoroacetabular junction, which is the most frequent location for labral and chondral pathology in cam-type femoroacetabular impingement syndrome. We believe that this device also can be used in the evaluation of the contact forces in other joint conditions and in the assessment of diverse techniques of labral repair or reconstruction.

Femoroacetabular contact pressure and forces are increased in several joint conditions and particularly in femoroacetabular impingement syndrome (FAIS).[1,2] Hip contact pressures and forces have been evaluated in cadaver studies with different monitoring devices, in vivo with an instrumented prosthesis, and in finite element analysis used as a surrogate.[2,3] In FAIS, there is an increase in contact pressures and forces in the anterosuperior region of the acetabular cartilage, where most of the chondrolabral pathology occurs in the cam impingement.[1,2,4,5]

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Cadaver research and in silico studies showed that complete cam resection decreased the contact pressure, with the most significant change reported in the 11- to 2-o'clock region of the acetabulum.[1,3,6] These findings support the improvement of hip biomechanics after cam removal in cam-type FAIS.

In cadaveric open surgery, femoroacetabular contact pressure and force can be measured with thin-sheet multiplexed grid-array transducers,[1] and a specific sensor for the hip joint has been developed.[7] We describe a dedicated system to measure the femoroacetabular contact force in hip arthroscopy. Complementary, to monitor the axial load transmitted to the hip joint, we also characterize the axial force measuring unit that is placed at the knee. In this study, we detail the surgical technique for this dedicated device in cadaveric hip arthroscopy.

Hip Sensor

The device comprises 2 modules: a cannula, which guides and protects the sensor as it is introduced into the joint, and a handle body, which the surgeon uses to hold the device, housing the electronics module. The design was created using computer-aided engineering software (SolidWorks 2023 CAD software, Dassault Systèmes; Vélizy-Villacoublay, France) and manufactured using a 3-dimensional printer (Creator 3 Pro;

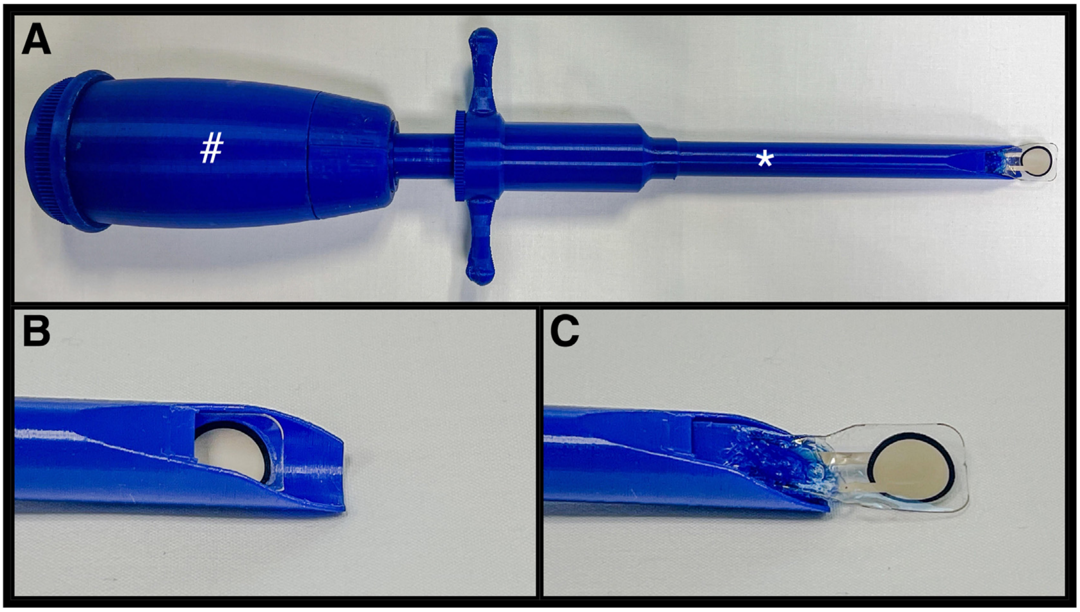

Fig 1. (A) Femoroacetabular contact force measuring device. Tip of the cannula with sensor retracted (B) and exposed (C). #, handle body that houses the electronics module; *, cannula, which guides and protects the sensor.

Flashforge, Zhejiang, China) with a polylactic acid polymer[8] (Fig 1).

It incorporates a force-sensitive resistor (FlexiForce A201, 100 lbs; Tekscan Inc., Norwood, MA) characterised by a small size, ultra-thin profile (0.203 mm), which can measure up to 445N. The thin profile and flexibility enable its introduction into the hip central compartment, reducing the risk of cartilage damage and conforming to the joint curvature. Each sensor is calibrated using the universal testing machine Instron 5544 (Instron; Norwood, MA), resulting in an individual calibration curve for each sensor.[8]

An axial force measuring unit was developed to house a compression load cell (FX29, TE Connectivity, Schaffhausen, Switzerland). The knee load cell, attached to the patient's proximal leg, monitors the applied axial force (50 N) by the assistant, ensuring uniform loading criteria in all measurements and across different conditions. The hip sensor and the knee load cell data are transmitted via the Bluetooth low-energy protocol to a mobile device or a personal computer through a dedicated application.

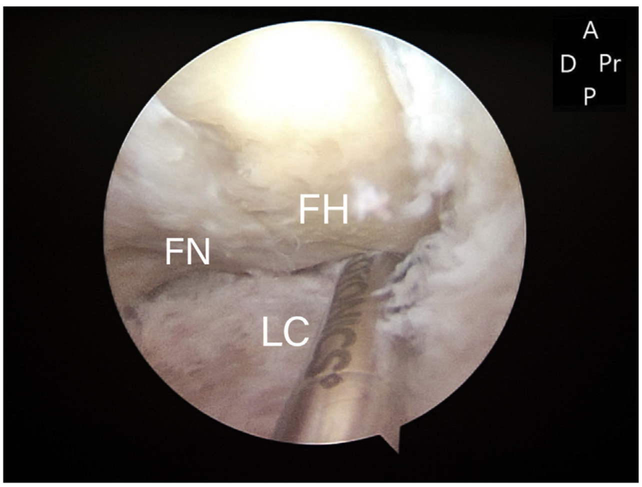

Fig 2. Image of the peripheral compartment of a left hip, viewed proximally from the proximal anterolateral portal. A capsular thinning is performed with a shaver in the midanterior portal to increase the exposure of the femoral head and neck. (A, anterior; D, distal; FH, femoral head; FN, femoral neck; LC, lateral capsule; P, posterior; Pr, proximal)

Surgical Technique

This device is demonstrated in hip arthroscopy in cadavers, as approved by Nova Medical School's ethics committee, with the technique of peripheral compartment initial access, although alternative techniques can be used.[4,9] The proximal anterolateral portal is used as a viewing portal in the peripheral compartment, the midanterior portal is established under direct arthroscopic vision (proximal to the zona orbicularis), and a periportal capsulotomy is performed to ease the introduction of the device. A partial synovectomy and capsular thinning are recommended to increase the exposure of the cam and the anterosuperior acetabulum (Fig 2, Video 1).

The transition zone at the 1- to 2-o'clock position in the acetabulum is identified (just below and lateral to the anterior inferior iliac spine) and marked with a radiofrequency device. An image intensifier also can be employed to confirm the location (Fig 3). This marking is crucial, since the femoroacetabular contact forces

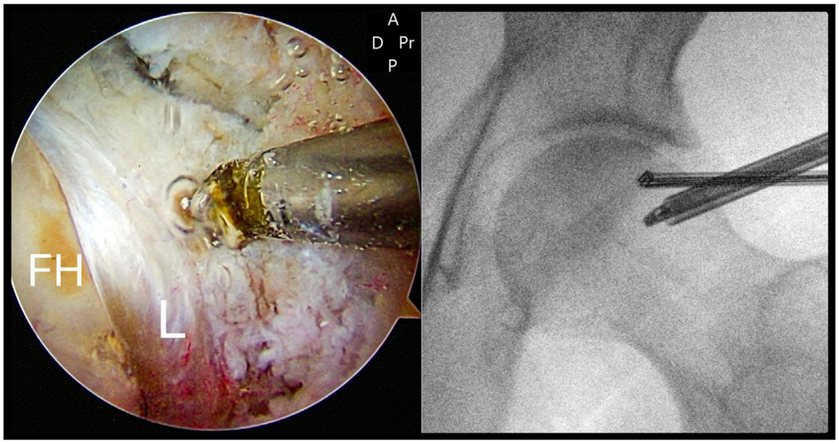

Fig 3. Image of the peripheral compartment of a left hip, viewed proximally from the proximal anterolateral portal. Identification and marking the transition zone at the 1- to 2-o'clock position in the anterosuperior acetabulum using a radiofrequency wand in the midanterior portal. In the right image, the position of the radiofrequency wand is confirmed through fluoroscopic imaging. (A, anterior; D, distal; FH, femoral head; L, labrum; P, posterior; Pr, proximal)

need to be measured at precisely the same location before and after cam resection.

Fig 4. The hip sensor is inserted through the midanterior portal into the peripheral compartment using a slotted cannula. The arthroscopic camera is in the proximal anterolateral portal. *, slotted cânulan #, hip sensor. (D, distal; L, lateral; M, medial; Pr, proximal.)

The device is introduced in the midanterior portal into the peripheral compartment using either a slotted or a half-pipe cannula (Fig 4). During joint movements and positioning of the device in the peripheral compartment, the sensor should be in the retracted position to ensure its protection. Viewing from the proximal anterolateral portal, the device is positioned close to the marked position in the anterosuperior acetabulum (Fig 5), and slight distraction is applied to separate the labrum from the femoral head (Fig 6). The sensor is then deployed through the cannula and advanced between the anterosuperior acetabulum and femoral head under direct arthroscopic control (Fig 6). The traction is released to restore contact between the femoral head and the acetabulum. The joint is placed in

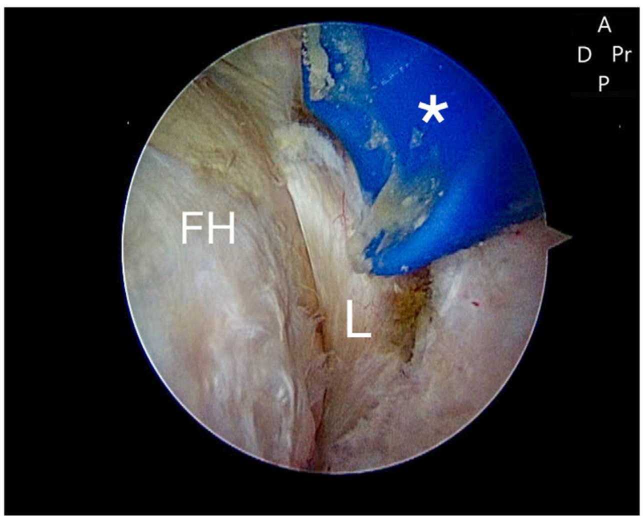

Fig 5. Image of the peripheral compartment of a left hip, viewed proximally from the proximal anterolateral portal, the cannula is moved within the peripheral compartment with the sensor retracted to avoid its damage. It's positioned near the markings on the anterosuperior labrum before applying traction. *, Hip sensor cannula. (A, anterior; D, distal; FH, femoral head; L, labrum; P, posterior; Pr, proximal.)

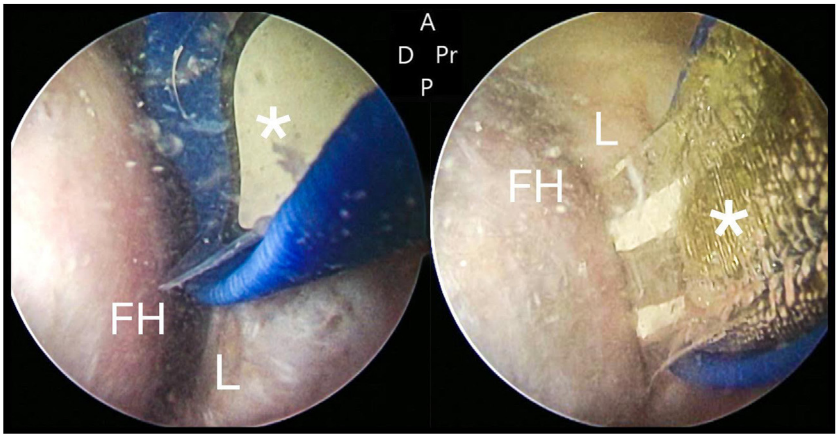

Fig 6. Peripheral compartment image of a left hip, viewed proximally from the proximal anterolateral portal. Slight traction is applied to allow the introduction of the sensor in the central compartment (left image). Traction is then released, and the sensor becomes compressed between the anterosuperior acetabulum and femoral head (right image). *, Hip sensor. (A, anterior; D, distal; FH, femoral head; L, labrum; P, posterior; Pr, proximal.)

the desired position, a constant axial load is applied to the knee load cell, and the measurements can then be taken (Fig 7). As the joint is mobilized and the load applied, it's important to ensure the sensor position is maintained and confirmed through arthroscopic imaging. During hip flexion and rotations, there's a risk of the sensor sliding, advancing further, or being pulled out, so the device should be firmly held.

Special care is necessary when advancing the sensor into the central compartment and during joint mobilization to prevent excessive bending and potential damage to the sensor. If this occurs, it's possible to replace the sensor and the cannula while retaining the device handle body.

The femoroacetabular contact force measurement is conducted in the same femoroacetabular location and

Fig 7. The hip sensor is introduced in the midanterior portal and positioned in the central compartment under arthroscopic control. The arthroscopic camera is in the proximal anterolateral portal. The assistant applies an axial load (50 N) to the knee load cell to ensure uniform loading conditions in all measurements. *, Knee load cell; #, hip sensor. (A, anterior; D, distal; P, posterior; Pr, proximal.)

Fig 8. The hip sensor is inserted through the midanterior portal, and its position in the central compartment is controlled with arthroscopic vision. The joint is positioned at 80° of flexion with neutral rotation for femoroacetabular contact force measurement in this configuration. A digital goniometer verifies the degree of hip flexion. *, Knee load cell; #, hip sensor. (A, anterior; D, distal; DG, digital goniometer; P, posterior; Pr, proximal.)

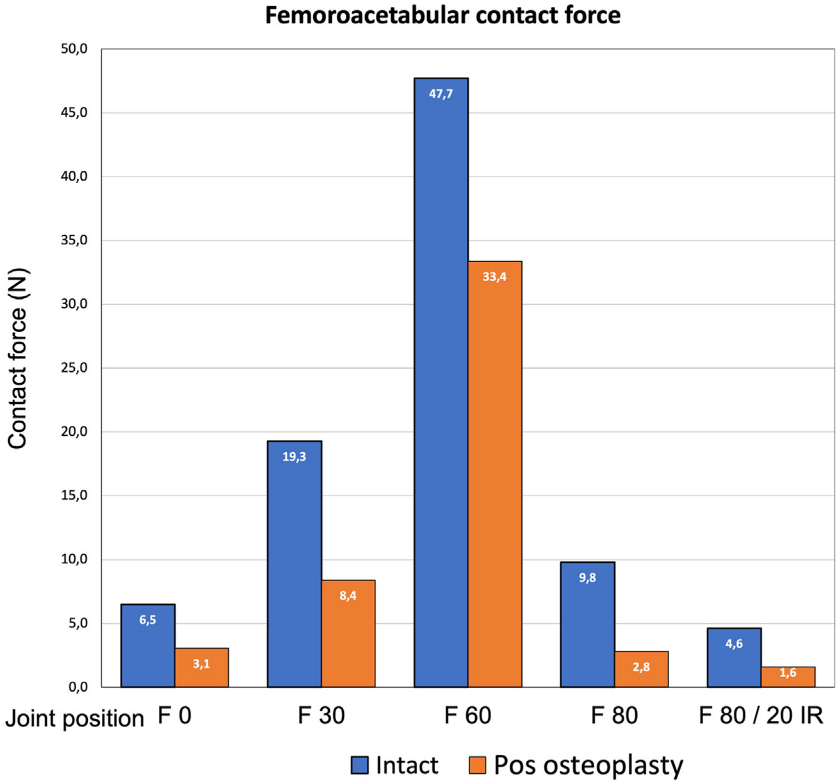

Fig 9. Femoroacetabular contact force (N) in different hip positions (flexion [F] of 0°, 30°, 60°, and 80° and flexion (F) of 80° and internal rotation [IR] of 20°), before and after femoral osteoplasty, of the hip featured in the video.

with the joint in different positions. For each condition, 3 measurements are recorded, and a digital goniometer (Digital angle finder, Model HG08763B; OWIM GmbH, Neckarsulm, Germany) is used to accurately measure hip flexion and rotation (Fig 8).

We conduct measurements with the hip at 0°, 30, 60°, and 80° of flexion, as well as with the hip flexed at 80° combined with 20° of internal rotation. Although dynamic measurements of contact forces are possible, our focus is on static measurements at predetermined joint positions to ensure reproducibility.

In this example, the femoroacetabular contact force decreased after femoral osteoplasty in all the analyzed joint positions. We provide an overview of the contact pressures in different hip positions, before and after femoral osteoplasty of the hip featured in the video (Fig 9). The alpha angle decreased from 70° preoperatively to 49° postoperatively (Video 1).

Discussion

The authors describe the use of a device to quantify the femoroacetabular contact force in arthroscopic hip surgery. This device was tested in cadaver surgery, revealing an increase in contact force at the anterosuperior femoroacetabular junction, when the hip was flexed to 30° and 60°. More importantly, it also showed a consistent reduction in contact force after cam resection for the different analyzed joint positions. Table 1 presents the key points of the femoroacetabular contact force measurement in hip arthroscopy.

To accurately compare the femoroacetabular contact force before and after cam removal, it's imperative to conduct the measurements in the exact same location in the anterosuperior acetabulum. Changes in position or sensor movement lead to modifications in the force readings. Its important to mark the sensor's position before cam resection, ensuring that the subsequent measurements after resection are performed in the same location (Table 2).

We had no sensor or cannula breakages, and there was no observable chondral or labral damage resulting from the use of the device. However, particular care should be taken when handling the sensor, and fluid pressure should be controlled to decrease the risk of fluid ingress through the cannula.

Table 1. Key Points

Measurement of the anterior contact force can confirm the improvement of hip biomechanics after femoral osteoplasty.
The device allows the measurement of contact force with the hip in different positions, in the intact joint and after femoral osteoplasty.
Pressure-sensitive films and piezoresistive pressure mats cannot be used in arthroscopic hip surgery because of their size.
For accurate data comparison, measurements should be conducted in uniform hip positions and at the exact same location in the anterosuperior acetabulum.

Table 2. Pearls and Pitfalls

Pearls	
	This device was designed for arthroscopic hip surgery.
	Intraoperative assessment of the contact force assists the surgeon in evaluating the joint biomechanics.
	Sensor position is controlled with arthroscopic vision.
Pitfalls	
	Joint mobilization may change sensor location.
	Sensor position must remain consistent before and after cam resection to ensure accurate assessment.
	Excessive bending of the sensor should be avoided.
	Like other arthroscopic tools, handling them carefully inside the joint is advisable to prevent chondral and labral damage.

The axial force applied to the knee is set to 50 N for the 30° and 60° of joint position, and it is possible to maintain the load during the measurements. At 0° of hip flexion, applying an axial load at the knee level is not feasible. Additionally, at 80° of flexion, 80° of flexion and 20° of internal rotation, the axial load moves the femoral head posteriorly, decreasing the anterior femoroacetabular contact. Consequently, we opt to exclude the axial load for the measurements in these 3 joint positions.

Measurement of the anterior femoroacetabular contact force before and after femoral osteoplasty can confirm the decrease in the force, and this could be another tool to confirm adequate cam resection and optimize hip biomechanics restoration. If this does not occur, a reassessment of the osteoplasty is recommended, and further resection is performed if required.

The device cannula has an external diameter of 12.5 mm, making it larger than most arthroscopic instruments. Depending on the surgeon's preferences, a periportal capsulotomy or a larger incision is necessary to facilitate the device entry and its maneuverability in the joint.

The force-sensitive resistor sensor was selected because its small size and flexibility (Table 3). A piezoresistive pressure mat offers various advantages over the force sensor, such as the analyses of the contact pressure, and contact area, and enables a pressure distribution mapping. Because its size, these mats cannot be used in arthroscopic hip surgery.

Table 3. Advantages and Disadvantages

Advantages	
	The procedure is performed with a capsular-preservation technique, whereas most hip biomechanics studies are conducted with periarticular soft tissues and capsular excision.
	The device is compatible with different hip arthroscopy techniques without changing the technique.
Disadvantages	
	Contact force measurement is limited to the anterosuperior acetabulum.
	There are no reference values for the femoroacetabular contact force. The assessment is based on the intact and after cam resection contact force measurement.
	Contact pressure and contact area are not evaluated.

We must emphasize that this force analysis is limited to the anterosuperior femoroacetabular junction, which is the most frequent location for labral and chondral pathology in cam-type FAIS.[4,10] We also found that changing the sensor position led to variations in force measurements. Therefore, ensuring a precise and consistent sensor position throughout different evaluations is imperative.

This device is used to assess the femoroacetabular contact force in a hip with cam morphology and shows a decrease in the force after femoral osteoplasty. The authors believe that it also can be used in the evaluation of the contact forces in other joint conditions.

Disclosures

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