Technical Note

Arthroscopic Treatment of Cam-Type Impingement for Femoroacetabular Impingement Using Patient's Own 1:1 Three-Dimensional Printed Hip Model Without the Use of Fluoroscopy

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Abstract: The arthroscopic treatment of femoroacetabular impingement (FAI) has increased greatly in popularity over the past decades. Treatment involves the resection of abnormal bony morphology of the femoral head/neck (cam-type) and the acetabulum (pincer-type), which otherwise create damage from the pathologic contact between the 2 structures. More recently, in evaluating the postoperative success of FAI surgery, unsuccessful resection of the cam impingement has been identified as a leading cause for revision. To evaluate adequate cam resection intraoperatively, C-arm fluoroscopy is most commonly used. However, fluoroscopy has disadvantages, including its limited availability in smaller surgical centers, radiation exposure, and it only provides 2-dimensional information of a 3-dimensional problem. With the recent implementation of ultrasound-guided portal placement, a technique for adequate cam resection is the last barrier to eliminating the need for intraoperative imaging for FAI. We present a technique that uses a 1:1 3-dimensional printed model made from computed tomography scans that have the patient's unique anatomy, to better identify and quantify the resection of cam-type impingements. This technique is reproducible and can lead to better understanding of the cam resection for each individual patient. Further, when combined with ultrasound-guided portal placement, it eliminates the need for intraoperative fluoroscopy.

The arthroscopic treatment of femoroacetabular impingement (FAI) is relatively new, and our understanding of the procedure is still evolving. Successful treatment of FAI includes the removal of abnormal bony morphology on the femoral head/neck (cam-type), on the acetabulum (pincer-type), or both (mixed-type). Removing these offending impingements will reduce the primary source of FAI anterior groin pain and minimize its effects as a generator of secondary arthritis caused by irreversible damage to the cartilage and labrum. If the impingement is not removed, either because it was not addressed or there is a residual impingement from an incomplete resection, a recurrence of symptoms can occur. Ensuring adequate resection is a critical step of FAI treatment, as residual FAI is the leading cause for revision hip arthroscopy.[1]

Conventionally, preoperative planning for FAI consists of planar radiographs, possibly a computed tomography (CT) scan, with or without 3-dimensional (3D) reconstruction, and/or a magnetic resonance image. With these modalities, impingement types are diagnosed and surgical plans are made for resection. For the treatment of the impingement, intraoperative C-arm fluoroscopy is commonly used to evaluate the resection. However, intraoperative fluoroscopy comes with its own limitations and disadvantages, including radiation exposure for the patient and those in the operating room, limited availability in smaller surgical centers, and it only provides 2-dimensional information for a 3D problem. One addition that our technique makes to the preoperative planning of FAI is the use of a 1:1 3D-printed model created from the patient's own CT scan. This 3D-printed model allows for free manipulation and a tactile understanding of the patient's specific morphology for preoperative planning

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and intraoperative resection of the impingement.[2] We describe our technique for cam resection using a 3D-printed model, as well as visualization techniques to ensure adequate cam resection for the arthroscopic treatment of FAI.

Surgical Technique (With Video Illustration)

Preoperative Planning

Preoperatively, a 1:1 3D-printed model is created with the patient's own CT scan as described by Murphy and Wong (Fig 1 A-C).[2] Models for the purpose of this technique were printed on MakerBot Replicator printers (MakerBot Industries, New York, NY). The 3D-printed model provides a tactile representation of the patient's specific anatomy while also allowing for free manipulation of the model. With this model, anatomical landmarks of the hip can be compared with the same seen during arthroscopy. By comparing between these 2 intraoperatively, better understanding can be had about the extent of the lesion and the required depth of resection. Important preoperative landmarks are defining the most medial and lateral aspects of the cam impingement. In addition, the depth of resection can be estimated preoperatively as well to allow for restoration of femoral head sphericity. To mirror the positioning of the hip during cam resection, the model can be placed into an expected 15° of forward flexion. When this is done, the cam resection now becomes parallel to the acetabulum and will be the preferred positioning for the marking and resection of the cam impingement (Fig 1B).

Positioning and Portal Placement

The patient is prepared routinely for hip arthroscopy in the lateral decubitus position and standard portal placement is done via ultrasound as described by Keough et al.[3] (Fig 2 and Fig 3). A diagnostic scope is then conducted. To prepare for the labral repair, and later the cam-osteoplasty, a capsulotomy is preformed, and traction sutures are placed to improve visualization. Later, these traction sutures can be converted to a capsular closure. Next, a standard labral repair is preformed, and the hip is reduced back into socket, with no more traction being used for the remainder of the surgery.

Cam Resection

To begin the cam resection, the hip is externally rotated and placed in 15° of forward flexion and slight abduction, allowing for the cam lesion to run parallel to the labrum (Video 1). Next, the cam is marked with cautery, first starting from the anterolateral portal to mark the most medial extent, and then continues posteriorly following along the area of cartilage damage while remaining parallel with the labrum. To reach the

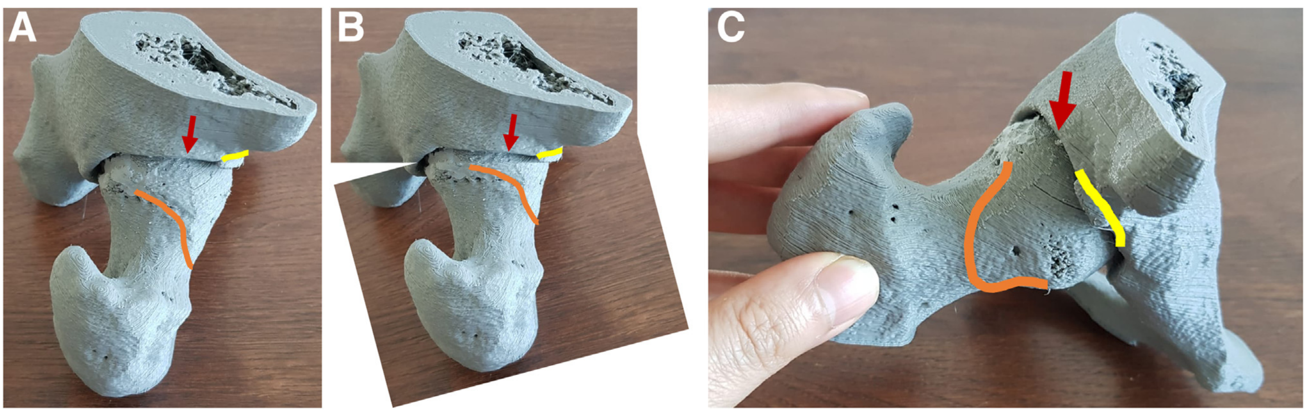

Fig 1. (A) Three-dimensional printed hip model using the patient's own computed tomography scan. The tactile model is used preoperatively to define the extent of the cam lesion. The red arrow estimates 12-o'clock position as viewing from the mid-anterior portal, the yellow line represents the boundary of an os acetabuli fracture, and the orange line represents the extent of the cam impingement. This shows the ability of a 3D-printed model to capture the anatomical structure of a patient's cam lesion for future surgical resection. (B) Three-dimensional printed hip model using the patient's own computed tomography scan, displaying the cam impingement running parallel with the acetabulum positioned at approximately 15° of forward flexion. The red arrow estimates 12-o'clock position as viewing from the midanterior portal, the yellow line represents the boundary of an os acetabuli fracture, and the orange line represents the extent of the cam impingement. Creating a parallel line of the cam impingement to the acetabulum allows for a standardization of viewing in order to mark the cam lesion intraoperatively. (C) 3D-printed hip model using the patient's own computed tomography scan. Viewing anteriorly, the anteromedial aspect of the cam can be appreciated. The red arrow estimates 12-o'clock position as viewing from the midanterior portal, the yellow line represents the boundary of an os acetabuli fracture, and the orange line represents the extent of the cam impingement. This represents the expected view of the lesion intraoperatively from the midanterior portal. (3D, 3-dimensional.)

Fig 2. Lateral decubitus positioning for hip arthroscopy.

posterior aspect of the cam, the hip is internally rotated. At any point during both cautery and during the osteoplasty, the traction sutures placed during the capsulotomy can be placed in gentle tension and held in tension with a surgical hemostat outside of the portal or with direct tension by an assist to improve visualization (Fig 4A and B).

After marking is completed, the hip is placed back in external rotation and the cam resection is started at the most medial aspect with a burr through the anterior portal, while viewing through the anterolateral portal. The depth of resection is approximated via the use of the 3D print analyzed both preoperatively, compared with the intraoperative view, and by evaluating whether impingement still exists when the hip is placed through range of motion. The resection continues posteriorly following parallel with the labrum and keeping in line with the cautery outline that was made just proximal to the area of cartilage changes present from the cam impingement. To visualize and have access to the inferior section of the cam, the traction sutures placed earlier can be further tensioned to allow for the bur to have access without concern of damaging the capsule (Fig 4A and B). This inferior CAM resection is most important to identify, as many times there is a second ridge that can easily be see on the 3D model that may affect impingement (Fig 1 A-C). To better visualize the posterior extent of the cam resection, the hip is placed in internal rotation and extension to prepare for the resection of the posterior lateral corner. Further abduction also can be added to allow for greater access to any posterior−inferior CAM lesions. The posterolateral aspect of the CAM is the critical area to be identified on the 3D model, which is best to be done preoperatively. Also, the 3D model can help visualize the preoperatively determined shape of the resection (Fig 1 A-C and Fig 5).

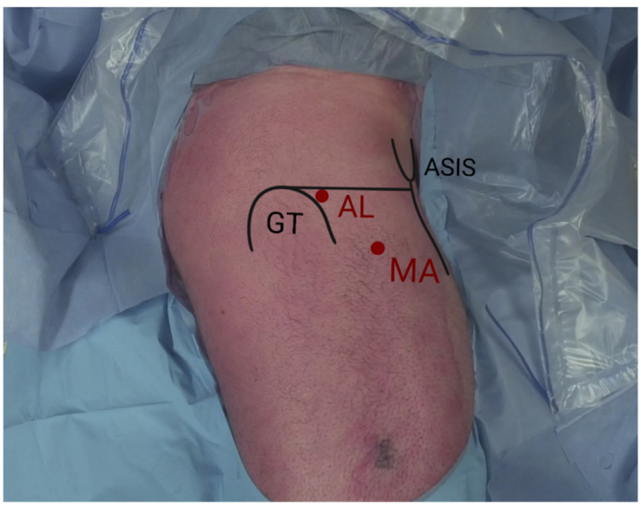

Fig 3. Standard portal placement for hip arthroscopy on a right hip. (AL, anterolateral portal; ASIS, anterior superior iliac spinel GT, greater trochanter; MA, midanterior portal.)

Once the resection is complete, the femoral neck is again inspected from anteromedial to posterolateral boundaries, to assess for any residual lesion. The hip is moved through its range of motion and is visualized with the camera to check for smooth motion of the labrum and resolution of impingement. Final inspection of the cam is completed with the hip in approximately 15° of flexion and maximum external rotation for the medial extent, and extension and internal rotation for the most lateral extent. If additional resection is required after the dynamic range of motion, then further burring can be done before closing. Lastly, during closing, the tension sutures are converted into a capsular closure.

Discussion

Treatment of FAI is characterized by osteoplasty of abnormal bony abnormalities to restore normal mechanics and proper cam resection can prevent further damage to the hip joint and better preserve the labrum and cartilage of the hip. Cam resection is one of the most important steps for FAI treatment, as unaddressed or residual cams are the leading causes of revision hip arthroscopy.[1] Conventionally, intraoperative fluoroscopy is used to review cam impingement resection to ensure a successful resection. However, this leads to additional radiation, and its use still can result in inadequate resection, as it is a planar image, which can obscure residual impingements.

There is also a variety of other described techniques that focus on the intraoperative management of cam impingements. Many have created novel protocols/measurements with the use of intraoperative C-arm imaging, which may not be available in all settings and increases radiation exposure for both the patient and those in the operating room.[4-6] Other techniques for cam osteoplasty include computer-navigated resection,

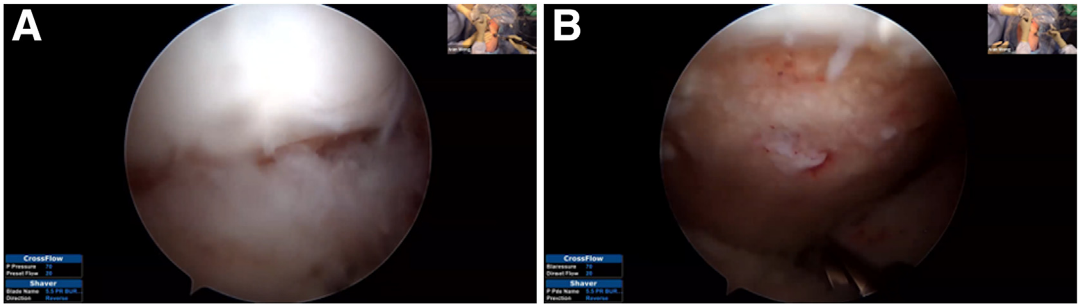

Fig 4. (A) Visualization of cam resection without tension from traction sutures on the right hip, viewing from the anterolateral portal. Without traction sutures, there is limitation in the field of view and direct visualization of the entire cam lesion is difficult. (B) Visualization of cam resection with tension from traction sutures on the right hip, viewing from the anterolateral portal. Traction sutures allow for increased field of view, allowing for direct visualization of the further extents of the cam lesion.

which requires optical tracking markers to be placed into the femur, calibration to tracking equipment, and C-arm fluoroscopy.[7] These techniques all still include further use of intraoperative imaging and do not address all of the limitations associated with fluoroscopy.

Our technique has strengths in increasing the understanding of the cam resection preoperatively with tactile and free manipulation of a 3D-printed model of the patient's own hip, as well as increasing visibility during the arthroscopy to ensure adequate resection of cam impingements (Table 1). If we can visualize and understand the cam better preoperatively and intraoperatively, we should be able to treat it without requiring additional intraoperative imaging, which does not always give an accurate picture. This is not the first time 3D-printed hip models have been suggested for FAI osteoplasty planning. Wong et al.[8] described that when surgeons were presented a 3D-printed hip model after conventional planning was completed, 70% of the surgeons said that they would increase the amount of bony resection in 70% of femur osteoplasties for cam impingements. Three-dimensional models do have limitations, including start-up costs and training to successfully print models from CT scans. However, prints costing $5-7 USD per hip and increased accessibility to 3D printers and software makes the 3D model a viable option for preoperative planning (Table 2).[2] Further, with this technique's addition to ultrasound-guided portal placement, intraoperative fluoroscopy can be eliminated in the arthroscopic treatment of FAI.[9]

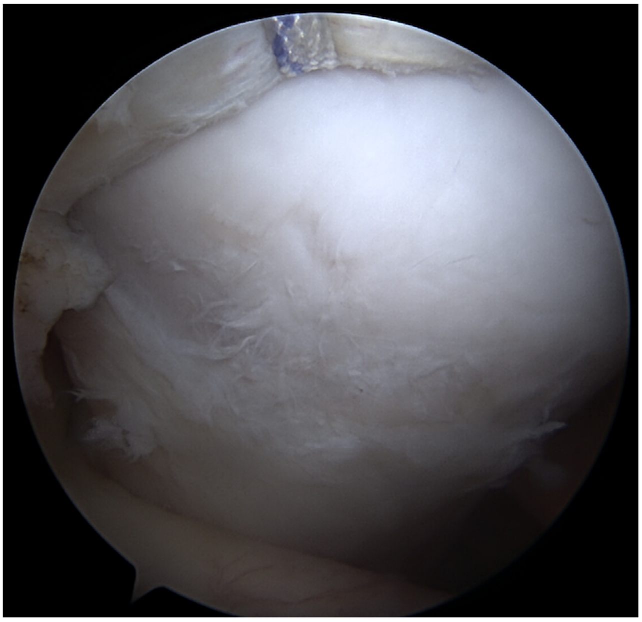

Fig 5. Replicated location of the posterolateral aspect of the cam lesion intraoperatively based on the shape on the 3D model on the right hip, viewing from the anterolateral portal. Here we are demonstrating the ability to mirror the preoperative planning with a 3D-printed model and how you can relate it to intraoperative views to ensure adequate resection. (3D, 3-dimensional.)

Disclosures

The authors report the following potential conflicts of interest or sources of funding: I.W. reports consulting fees from DePuy Mitek, Smith & Nephew, CONMED Corp, and Bioventus LLC, outside the submitted work; is an editorial board member for the *American Journal of Sports Medicine* (AJSM) and *Arthroscopy: The Journal of Arthroscopic and Related Surgery*; and is a board or committee member for AANA, International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine, and the Arthroscopy Association of Canada (AAC). The other author (R.M.) declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Table 1. Pearls and Pitfalls of the Technique

Pearls	Pitfalls
Use of traction sutures allows for direct visualization of the most anterior and posterior aspects of the cam impingement.	The printing of the 3D model has its own learning curve and the quality of the model is only as good as the quality of the CT scan.
Placing the hip in 15° of flexion allows for the cam impingement to run parallel with the acetabulum, allowing for easier marking for resection.	
To reach and visualize further anteriorly, the hip can be placed in external rotation. Equally to reach further posteriorly, the hip can be placed in internal rotation.	
Identify the location of the posterolateral cam initially and replicate this visual location based on the shape on the 3D model to the intraoperative view (Figs 1A and 5)	

3D, 3-dimensional; CT, computed tomography.

Table 2. Advantages and Disadvantages of the Technique

Advantages	Disadvantages
When combined with ultrasound-guided portal placement, it eliminates the need for intraoperative C-arm fluoroscopy and corresponding radiation exposure.	Requires 3D-printed models for preoperative planning. This requires separate training and learning curve to produce adequate models for the technique to be used.
Allows for hip arthroscopy to be done in smaller surgical center in which C-arm is not available.	To eliminate fluoroscopy, there are 2 learning curves, one for ultrasound portal placement, and one for learning the resection, described in the technique.
Provides a freely manipulable tactile preoperative planning tool that does not rely on planar imaging to assess the cam impingement.	There are additional staffing and production costs associated with 3D printing that exist outside of the standard of care.

3D, 3-dimensional.

References

1. Cvetanovich GL, Harris JD, Erickson BJ, et al. Revision hip arthroscopy: A systematic review of diagnoses, operative findings, and outcomes. *Arthroscopy* 2015;31: 2047-2055.
2. Murphy R, Wong I. Creation of a three-dimensional printed model for the preoperative planning of hip arthroscopy for femoral acetabular impingement. *Arthrosc Tech* 2021;10: e1143-e1147.
3. Keough T, Wilson D, Wong I. Ultrasound-guided portal placement for hip arthroscopy. *Arthrosc Tech* 2016;5: e851-e856.
4. Mortensen AJ, Duensing I, Aoki SK. Arthroscopic femoral osteochondroplasty for cam-type femoroacetabular impingement: Cortical—cancellous sclerotic boundary guides resection depth. *Arthrosc Tech* 2020;9: e1309-e1314.
5. Matache BA, Kaplan DJ, Fried J, et al. The femoroacetabular impingement resection (FAIR) arc: An intraoperative aid for assessing bony resection during hip arthroscopy. *Arthrosc Tech* 2021;10:e1431-e1437.
6. Lall AC, Annin S, Chen JW, et al. Achieving a perfectly spherical femoroplasty: pearls, pitfalls, and optimal surgical technique. *Arthrosc Tech* 2020;9:e303-e313.
7. Van Houcke J, Khanduja V, Nakano N, et al. Accuracy of navigated cam resection in femoroacetabular impingement: A randomised controlled trial. *Int J Med Robot* 2017;13:e1839.
8. Wong TT, Lynch TS, Popkin CA, et al. Preoperative use of a 3D printed model for femoroacetabular impingement surgery and its effects on planned osteoplasty. *AJR Am J Roentgenol* 2018;211:W116-W121.
9. Gordey E, Wong I. Comparison of complications in X-ray versus ultrasound-guided hip arthroscopy. *Arthroscopy* 2022;38:802-807.