Technical Note

Computer-Assisted Hip Arthroscopic Surgery for Femoroacetabular Impingement

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Abstract: Precise osteochondroplasty is key for success in hip arthroscopic surgery, especially for femoroacetabular impingement (FAI) caused by cam or pincer morphology. In this Technical Note, we present computer-assisted hip arthroscopic surgery for FAI, including preoperative planning by virtual osteochondroplasty and intraoperative computer navigation assistance. The important concept of this technique is that navigation assistance for osteochondroplasty is based on planning made by computer simulation analysis. The navigation assistance allows us to perform neither too much nor too little osteochondroplasty. Specifically, computer simulation was used to identify the impingement point. Virtual osteochondroplasty was then performed to determine the maneuvers that would improve range of motion. Thereafter, the planning data were transported to a computed tomography-based computer navigation system that directly provided intraoperative assistance. Thus, computer-assisted technology including preoperative simulation, virtual osteochondroplasty planning, and intraoperative navigation assistance may promote precise hip arthroscopic surgery for FAI.

In the past decade, it has become clear that hip arthroscopic surgery can effectively correct several hip disorders, including femoroacetabular impingement (FAI) and labral tears.[1] However, surgery remains quite difficult for many orthopaedic surgeons and involves a relatively long learning curve[2,3] because the intraoperative procedures are relatively complicated and must be preceded by extensive and elaborate preoperative planning. In particular, it is quite difficult to determine the extent of the area that should undergo osteochondroplasty. This is important because the osteochondroplasty must eliminate the deformity (particularly for morphological abnormalities such as the cam-type deformity in FAI[4]) without inducing excessive resection. The latter can lead to femoral neck fracture,[5] a rare but severe complication of hip arthroscopic surgery.[6]

In computer-assisted surgery, a computer system generates 3-dimensional images that aid preoperative planning and provide intraoperative navigation assistance. Such images are mainly used in total joint arthroplasty to ensure precise implantation of the

Table 1. Three Steps of Computer-Assisted Hip Arthroscopic Surgery

1. Preoperative evaluation	Identification of impingement point by computer simulation
2. Planning by virtual osteochondroplasty	Confirmation of improved range of motion after virtual osteochondroplasty
3. Intraoperative navigation assistance	
3A. Central compartment	Synovial debridement and labral repair Pincer resection (if needed)
3B. Registration	Point-to-point registration under fluoroscopy Surface registration including distal femur
3C. Tracker device setting	Solid fixation of device to abrader burr, not to interfere the operation
3D. Osteochondroplasty with navigation	Accurate resection without residual deformity or overresection under navigation assistance

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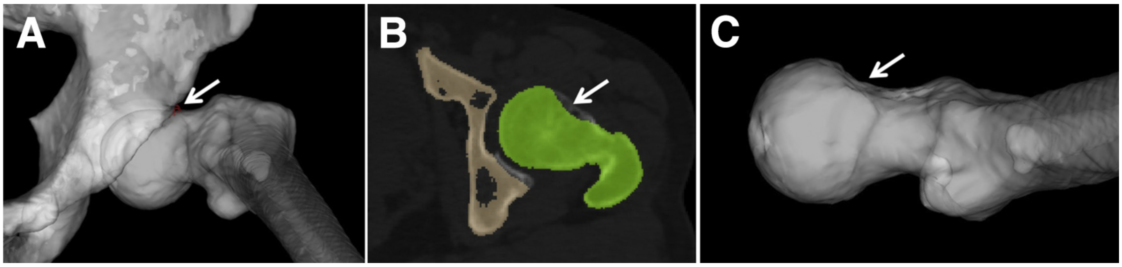

Fig 1. Impingement simulation (A), virtual osteochondroplasty (B), and post-virtual osteochondroplasty (C). The impingement point is identified (arrow) (A), after which virtual osteochondroplasty is performed at each axial slice (B). The shape of the femoral head-neck junction after virtual osteochondroplasty is then confirmed by the 3-dimensional model (C).

prosthetic joint.[7,8] Computer-assisted surgery has also been used in the sports medicine field for procedures such as anterior cruciate ligament reconstruction.[9] However, the actual clinical application of FAI surgery is very limited.

Here we introduce the technical tips of each step (Table 1) in computer-assisted hip arthroscopic surgery for FAI.

Surgical Technique

Computer Simulation Assessment

ZedHip (Lexi, Tokyo, Japan) software was used for the impingement simulation analyses. Thus, the Digital Imaging and Communication in Medicine file data for each patient were transferred to ZedHip, which then created a 3-dimensional model of the acetabulum and femoral head. The functional pelvic plane served as a reference plane for the acetabulum. The femoral head center was defined by 4 reference points. The femoral plane was set with respect to 2 reference points, namely, the center of the femoral head and the midpoint of the femoral condyle. Next, segmentation between the acetabulum and femur was performed. The range of motion (ROM) at maximum hip flexion and maximum internal rotation at 90° and 45° hip flexion was then evaluated by simulation using preoperative models. The impingement point at maximum internal rotation at 90° and 45° of hip flexion was identified (Fig 1A).

Preoperative Planning Using Virtual Osteochondroplasty

Based on the identified impingement point, we performed a virtual osteochondroplasty using the ZedHip software (Fig 1B). Virtual osteochondroplasty is conducted in each axial computed tomography (CT) image around impingement point. The virtual femur model after osteochondroplasty was then obtained (Fig 1C). The ROMs at maximum hip flexion and maximum internal rotation at 90° hip flexion were then evaluated by simulation. ROM improvement was defined as an improvement in the maximum internal rotation at least by ≥10°. The planned 3-dimensional model was then transferred to the navigation system (Orthomap 3D; Stryker, Kalamazoo, MI).

Surgical Procedures

Hip arthroscopic surgery was performed using a traction system with the patient in the supine position

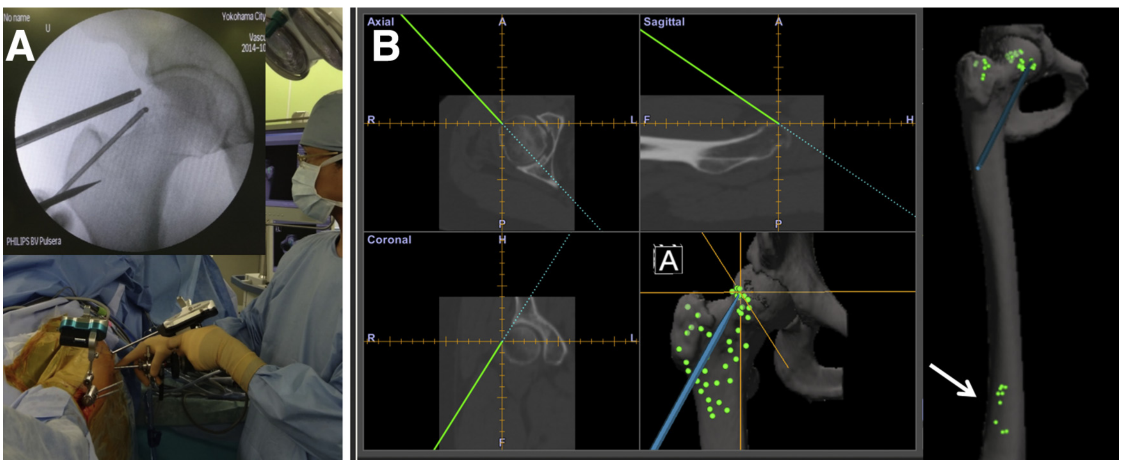

Fig 2. Point matching under fluoroscopic guidance (A) and surface matching (B) during navigation system registration. Point matching is performed under fluoroscopic guidance for 5 to 6 landmark points (A). Thereafter, surface matching is performed without fluoroscopic guidance for 40 to 50 points, including on the distal femur (arrow) (B).

Table 2. Pearls and Pitfalls

Pearls	Pitfall
Preoperative planning (virtual osteochondroplasty) using computer simulation is an important factor.	Loosening of tracker device will result in the variance of navigation.
Accurate point-to-point registration and surface registration including distal femur.	Poor verification result (mean error deviation ≥1 mm) is not desirable for accuracy.

(Video 1). Two portals (an anterolateral and a mid-anterior portal) were used for the labral repair, synovial debridement, and osteochondroplasty. After the central compartment procedures were performed, the traction was released and the peripheral compartment procedures were performed. We set the patient tracker device on the distal femur using 2 pins and performed fluoroscopic-guided point registration using 5 or 6 points (Fig 2A), followed by surface matching with 40 to 50 points, including on the distal femur (Fig 2B). The stability of tracker device fixation is important for navigation accuracy (Table 2). It is important to add these distal femur points for accurate registration. Then verification of registration accuracy is performed (Fig 3). As the calculated mean deviation error, we set the threshold at 1 mm; therefore, we retry the registration process in a case with a mean deviation error >1 mm.

After the registration, an instrument tracker device was set on the abrader burr (Fig 4). It is important to set the device not to interfere with the operation of the abrader burr (Table 2). Thereafter, all navigation registration procedures were completed. The resection area and depth were monitored by the computer in real time during the osteochondroplasty (Fig 5). After the osteochondroplasty, we can evaluate the resected area and depth by pointer (Fig 6).

Rehabilitation

Flexion ROM exercise by using continuous passive motion is performed from postoperation day 1, for 4 hours per day for 2 weeks. The patient was allowed partial weight bearing from the 14th postoperative day and full weight bearing from the 4th postoperative week. Three months after the operation, the patient was allowed to jog. There were no changes in rehabilitation program compared with standard arthroscopic surgery for FAI without a computer navigation system.

Discussion

This Technical Note presents the practice of computer-assisted hip arthroscopy for FAI with cam morphology cases. The procedures include preoperative simulation, planning by virtual osteochondroplasty, and intraoperative navigation assistance (Table 1).

The cam morphology is an important cause of FAI, especially in young patients who are relatively active in

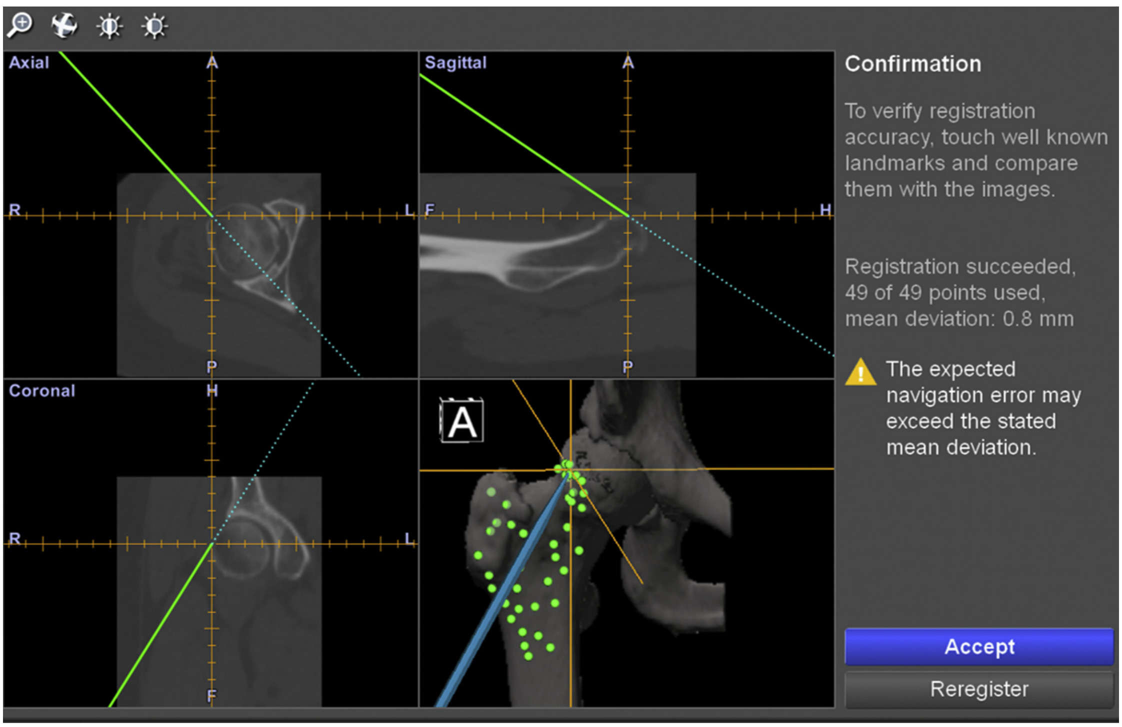

Fig 3. Verification of registration accuracy. Verification is performed using a pointer, confirming the concordance between arthroscopic monitor and navigation monitor. The threshold of mean error deviation is set at 1 mm.

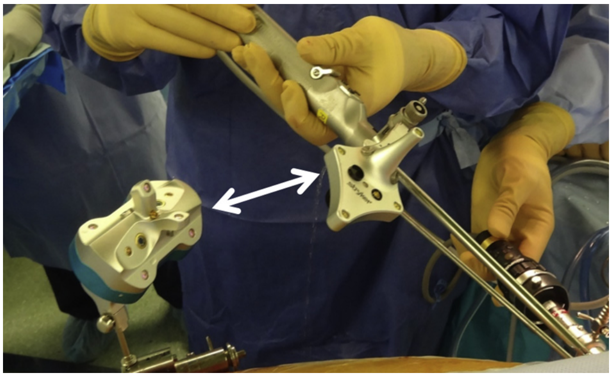

Fig 4. Setting of tracker devices. It is important to set the tracker devices so that they do not loosen during the procedure and do not interfere with the operation of the abrader burr between the 2 trackers (arrows).

sports.[10] Regarding the surgical treatment of FAI, the most important objective is sufficient cam resection. In other words, osteochondroplasty should be performed to leave no residual deformity.[4,11] Currently, hip arthroscopic surgery for FAI generally has good clinical outcomes.[12] However, the procedure is associated with a relatively long learning curve because it takes considerable experience to fully comprehend the procedure.[2,3] This is due to 2 particularly difficult aspects. First, it is not easy to precisely identify the impingement point and then determine the location of the cam lesion and the extent of bone that should be resected during osteochondroplasty. This point reflects the fact that the impingement point cannot be readily predicted using plain x-ray alone.[13,14] For this reason, computer simulation analysis would be very useful for planning osteochondroplasty. Indeed, a pilot study conducted by Tannast et al. in 2007 showed that noninvasive CT-based 3-dimensional assessment accurately evaluated ROM and allowed simulation of the surgical maneuvers for FAI. Moreover, the investigators discussed the future potential of this method as a navigation system.[15] Brunner et al.[16] were the first investigators to apply a navigation system for hip arthroscopy in the clinical setting. They concluded that use of the navigation system could not improve the radiographic and clinical assessment; however, they did not elaborate the planning using computer simulation. Recently, Kuhn et al.[17] also emphasized the usefulness in FAI surgery of precise preoperative planning on the basis of such 3-dimensional assessments. Second, the field of vision during arthroscopic techniques is limited. This could result in residual deformity or overcorrection of the impinging lesion. Both outcomes will worsen the patient's clinical situation.[4,6] This problem can also be resolved by providing computer navigation assistance during osteochondroplasty. Indeed, a study on bone models and cadaver hips showed that this approach supports safe and sufficient resection of the impinging lesion.[18] In the current report, we presented our method of computer-assisted hip arthroscopic surgery for FAI, including preoperative planning composed of computer simulation and virtual resection

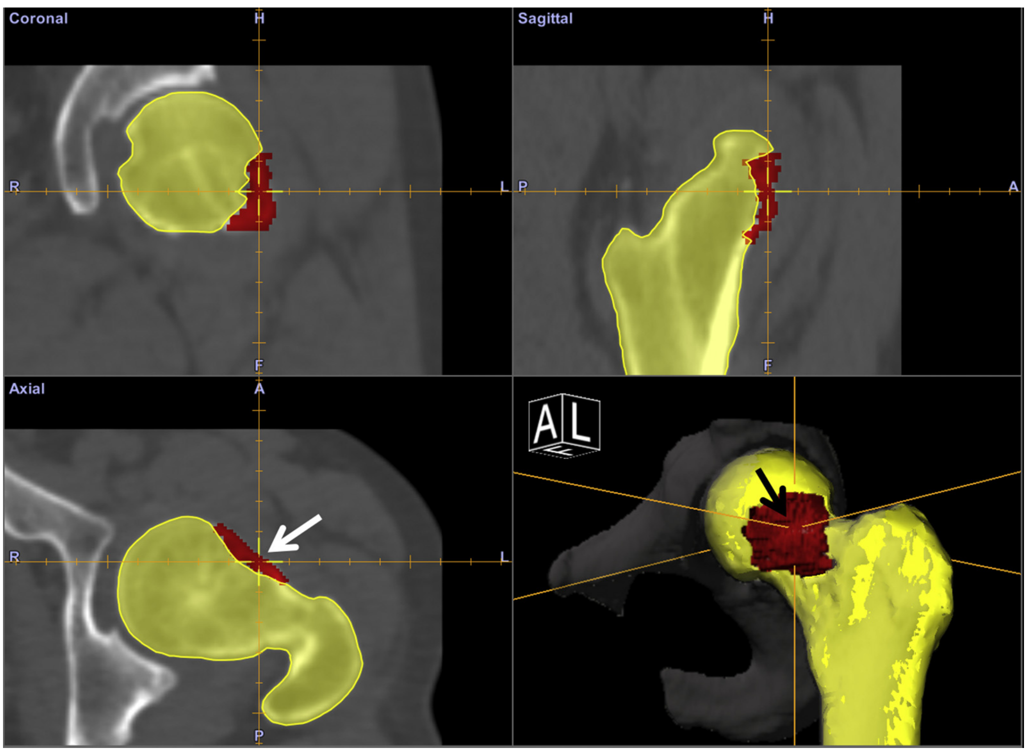

Fig 5. Navigation assistance during osteochondroplasty. The center of the cross (arrow) indicates the tip of the abrader burr located in the planned resection area (red area).

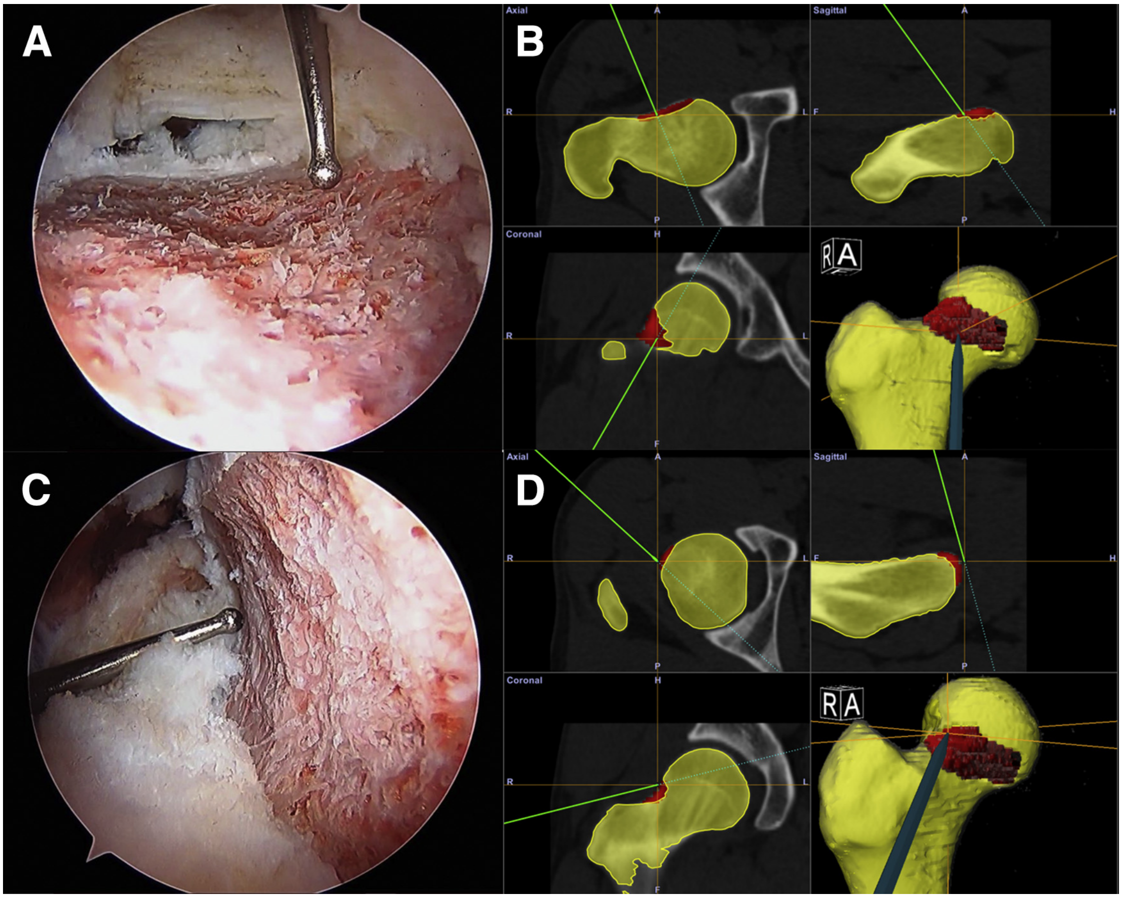

Fig 6. Verification of resected area and depth by pointer. The pointer device indicates the distal margin of resected area from the anterolateral portal view with the pointer via the midanterior portal (A), which is also identified by the computer navigation monitor (B). The lateral margin of the resected area is clearly verified from the midanterior portal view with the pointer via the anterolateral portal (C, D).

and the use of intraoperative navigation assistance during osteochondroplasty.

In computer navigation assistance for hip arthroscopy, an important technical requirement is that the surface registration synchronizes with the CT data. This is easier to obtain in open surgical procedures, such as total hip arthroplasty, because we can directly identify the reference landmark point. In contrast, in hip arthroscopy, fluoroscopy-guided registration is needed. The accuracy of the 3-dimensional fluoroscopic matching navigation system was validated by Takao et al.,[19] who reported a mean registration error of 0.8 mm for the pelvis and 1.1 mm for the proximal femur. We set the mean error threshold under 1 mm, which is acceptable for osteochondroplasty of cam lesions. To improve accuracy, it is important to register several surface points from the distal femur via trocar fixation pins (Fig 2). One advantage of the computer-assisted navigation approach is that, although fluoroscopic matching involves some radiation, the operators are not subjected to further radiation during the osteochondroplasty itself.

During the use of navigation assistance, the resection depth at each local position is indicated (Fig 5). This is the most important piece of information provided by this method. It is generally quite difficult to determine the resection depth using arthroscopic images. For this reason, intraoperative fluoroscopic guidance is often needed.[20] However, even with fluoroscopy, it is difficult to determine the actual depth of resection with 3-dimensional information. The importance of accurate resection depth information is supported by Rothenfluh et al., whose finite element analysis showed that resection depth is the most important determinant of mechanical bone strength. They also found that resection area width and length affected bone strength.[21] Thus, safe osteochondroplasty requires accurate recognition of the required resection area depth, width, and length. This can be achieved using computer-assisted navigation because it is based on cross-sectional images and 3-dimensional realization of the resection margin and cannot be achieved using 2-dimensional fluoroscopic imaging.

Table 3. Advantages and Disadvantages

Advantages	Disadvantages
Real-time monitoring of resection depth and area during osteochondroplasty without fluoroscopy.	Required time for registration of navigation system.
No radiation exposure during osteochondroplasty.	Radiation exposure by preoperative CT.
Prediction of improved range of motion by osteochondroplasty.	Additional skin incisions for setting the tracker device.

Effective computer-assisted surgery requires not only intraoperative assistance but also preoperative planning and postoperative evaluation. This is because, first, the preoperative identification of the impingement point is useful for determining the resection area. A previous computer simulation study showed that the impingement point varied widely[14] and could not be predicted on the basis of radiography alone.[13] Second, virtual computer-simulated osteochondroplasty can estimate the resection area range and depth that are needed to sufficiently improve the ROM; this usually requires an internal rotation angle improvement of >10°. This approach was validated in the present study via the examination of the patients' postoperative CT data. Although it is difficult to evaluate the actual ROM immediately after surgery due to exercise restrictions, the objective evaluation is realized by computer simulation analyses.

There are several limitations, risks, and disadvantages in the clinical application of computer-assisted techniques (Table 3). First of all, radiation exposure by CT is considerable, although CT evaluation may be needed for a diagnosis of FAI morphology in detail regardless of computer-assisted techniques application. In addition, we need certain time and fluoroscopic guides for the navigation registration process. Furthermore, it should be noted that we need additional skin incision for setting the navigation device in the distal femur. We must take notice of interference between the femur and navigation device, which possibly induces the error of the navigation system. The appropriateness of preoperative planning should be considered. Furthermore, we need to validate the accuracy of the navigation system itself compared with the preoperative planned model.

In conclusion, here we present the clinical applicability of computer-assisted hip arthroscopic surgery and describe its step-by-step procedures. A process of techniques that consists of preoperative simulation, planning by virtual osteochondroplasty, and intraoperative navigation assistance may improve the precision of hip arthroscopic surgery for FAI.

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