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Pre- and post-operative evaluation of pincer-type femoroacetabular impingement during squat using image-matching techniques: A case report

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ABSTRACT

INTRODUCTION: Although combined evaluation of hip joint kinematics and bone morphology is necessary for accurate assessment of femoroacetabular impingement (FAI), there are no report which evaluated hip kinematics of pincer-type FAI.
PRESENTATION OF CASE: The pre- and postoperative hip kinematics of a 46-year-old man, with a pincer-type FAI during squat were evaluated using image-matching techniques and the rim-neck distance was measured. Preoperative simulation of squatting was also performed using patient's bone models and healthy subject's kinematics data to detect the overlapping lesion between the acetabulum and the femur. Post-acetabuloplasty, right coxalgia during squat disappeared, and the Harris Hip Score improved from 79 to 92 at one year after surgery. Posterior pelvic tilt, femoral and hip flexion angle changed from 24.0°, 101.1°, and 70.8° to 23.3°, 92.6°, and 63.3°, respectively. The minimum rim-neck distance at maximum hip flexion improved from 1.8 mm to 7.3 mm.
DISCUSSION: We could evaluate both of hip kinematics and morphology with image-matching techniques, and could visualize the clearance between the femoral head-neck junction and the acetabular rim.
CONCLUSION: Image-matching techniques were clinically useful to assist surgeons in detecting the location of the impingement and confirming resection of the pincer lesion post-operatively.

1. Introduction

Femoroacetabular impingement (FAI) has been increasingly recognized as a cause of coxalgia and early osteoarthritis in young adults [1–3]. As the symptoms of FAI are caused at the weight-bearing deeply flexed hip posture in most cases [4], it is difficult to identify which lesion causes impingement by morphological assessment only. Evaluation of patient-specific hip joint kinematics and bone morphology is necessary for accurately identifying the lesion causing impingement and to provide effective surgical treatment. Furthermore, *in vivo* 3D visualization of clearance between the femoral head-neck junction and the acetabular rim during weight-bearing activities would be clinically meaningful. However, to the best of our knowledge, no study has assessed the *in vivo* 3D kinematics of pincer-type FAI under weight-bearing conditions.

Preoperative simulation analyses also could help surgeon to identify the lesion causing impingement. However, previous simulation studies for patients with FAI did not assume *in vivo* kinematics [5,6]. Patient-specific bone models with *in vivo* weight-bearing kinematics of healthy hips [7] could help in preoperative assessment of the extent and depth of acetabular rim resection through visualization of the overlapping lesion between the acetabulum and the femur.

In this case report, we assessed the pre- and postoperative *in vivo* 3D kinematics of a patient with pincer-type FAI during squat and measured the rim-neck distance using image-matching techniques [7–9]. Preoperative simulation of squatting was also performed to detect which site of the acetabular rim overlapped the femoral head-neck junction. This work has been reported in line with the SCARE criteria [10].

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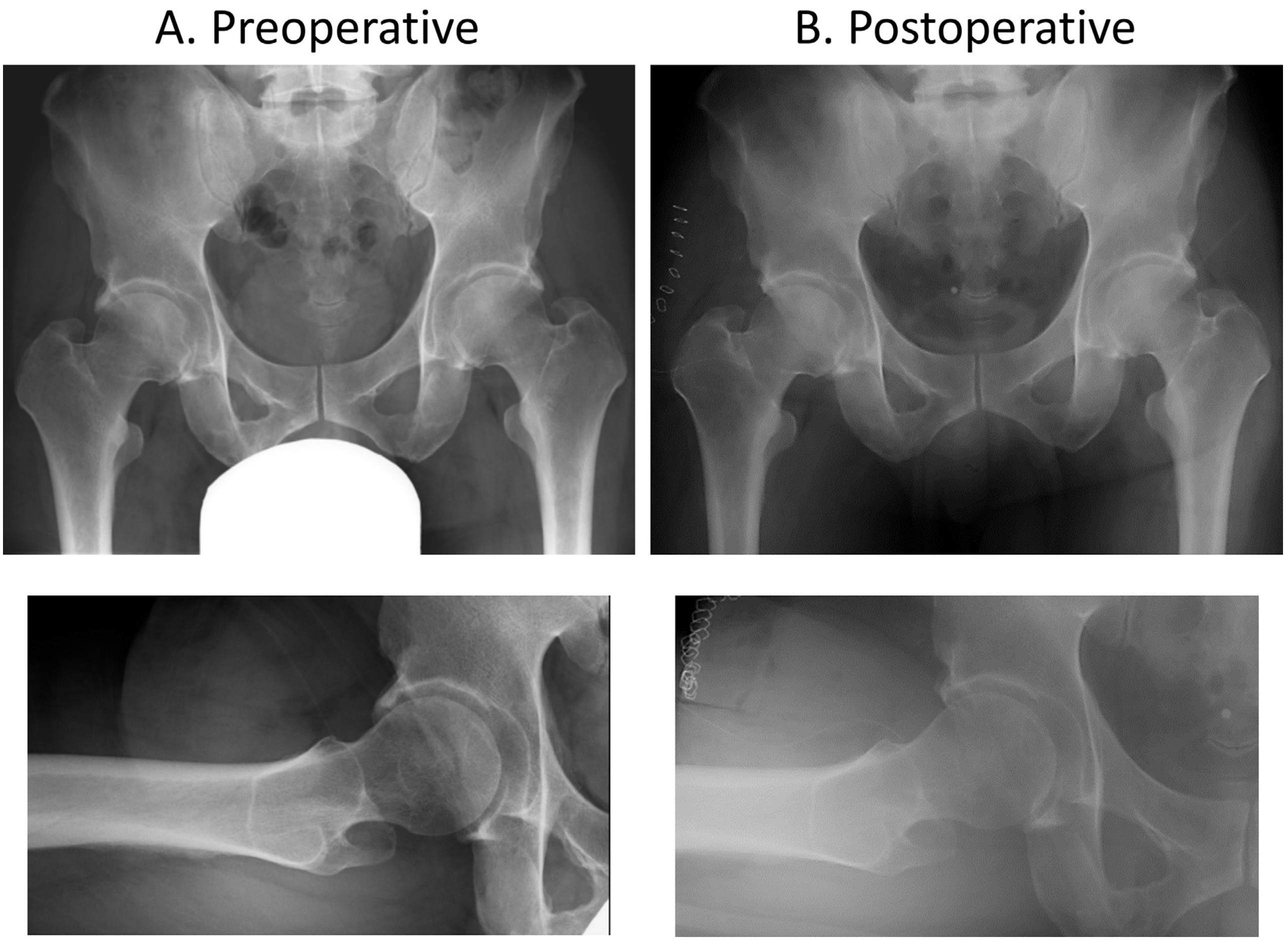

Fig. 1. Preoperative plain radiographs of the hip joint (A). The center-edge angle of the right hip was 65°. Postoperative plain radiographs of the hip joint (B). The center-edge angle was improved to 43°.

2. Case presentation

A 46-year-old man (height 178.3 cm; weight, 77.8 kg; body mass index, 24.5 kg/m^2) was assessed at our clinic for symptoms of right coxalgia with deep hip flexion that limited his ability to perform squats. Plain hip radiographs revealed a pincer deformity with center-edge angle (CEA) [16] of 65°, which was larger than the reported upper limit of normal of 38° [11] (Fig. 1A).

The 3D positions and orientations of the pelvis and femur during squat were determined using density-based image-matching techniques [7–9]. The patient could be exposed to a total of 33 mGy of radiation dose during the evaluation: approximately 8 mGy and 25 mGy for continuous radiographic surveillance and CT scan, respectively, and gave informed consent of the risk of radiation exposure required. The patient performed a full squat, in weight-bearing position, up to maximum hip flexion, under continuous radiographic surveillance using a flat-panel X-ray detector (Ultimax-I, Toshiba, Tochigi, Japan): image area, 420 mm × 420 mm; resolution, 0.274 mm × 0.274 mm/pixel; and frame rate, 3.5 frames/s. A 3D digital density-based volumetric model of the pelvis and femur was constructed in a virtual 3D space, using computed tomography (CT; Aquilion, Toshiba, Tochigi, Japan) data, and the anatomical coordinate system of the pelvis and femur were embedded in each bone model using previously published methods [7,8]. Thereafter, computer simulation was used to generate virtual digitally reconstructed radiographs (DRRs). Correlations of the pixel values between the DRRs and real radiographic images were used to finetune the 3D model, with a root-mean-square error of 0.37 mm for translations and 0.48° for rotation [7]. While squatting, maximum hip flexion angles reached 70.8° with 24.0° of pelvic posterior tilt, 101.1° of femoral flexion, 35.8° of hip abduction, and −5.9° of hip internal rotation (Table 1).

Preoperative simulation was performed assuming kinematics of healthy hips [7] while squatting using a CAD software program (SolidWorks® 2001Plus SP3.0, Solid Works Corporation, Concord, MA) to examine which site of the acetabulum overlapped the femoral head-neck junction. The anterosuperior to posterosuperior site of the overlapping acetabular rim overlapped the femoral head-neck junction, and preoperatively determined to be resected (Fig. 2A). Then, we prepared the 3D bone model of the pelvis in which the impingement site was resected, and confirmed that there was adequate clearance (Fig. 2B).

Acetabuloplasty was performed by SH, experienced hip surgeon, in the left lateral decubitus position with a forward convex arcuate incision extending from the distal 1 cm of the superior iliac spine to the posterior region of the greater trochanter. Kirschner wires were inserted in the acetabulum following the resection line determined by preoperative simulation analyses (Fig. 3A), and we used intra-operative radiography to confirm that the wires were inserted in the appropriate site (Fig. 3B). At the end of the procedure performed to resect ossified labrum, we confirmed that no impingement occurred during deep hip flexion posture. Histopathological examination of the resected labrum revealed osteo-cartilaginous tissue [12]. Radiographic images showed improvement of the CEA

Table 1
Hip range of motion and rim-neck distance before and after osteochondroplasty.

	Preoperative	Postoperative	Normal hips [8,9]
Maximum hip flexion (°)	70.8	63.3	102.4 ± 12.3 (92.6–112.2)
Pelvic posterior tilt (°)	24.0	23.3	10.8 ± 8.1 (4.3–17.3)
Femoral flexion (°)	101.1	92.6	108.5 ± 13.1 (98.0–119.0)
Hip abduction (°)	35.8	35.8	35.2 ± 7.0 (30.9–39.5)
Hip internal rotation (°)	−5.9	−14.4	6.4 ± 12.0 (−1.0 to 13.8)
Rim-neck distance (mm)	1.8	7.3	11.3 ± 5.2 (6.1–16.5)

The values are expressed as mean ± SD (95% confidential interval) in normal hips.

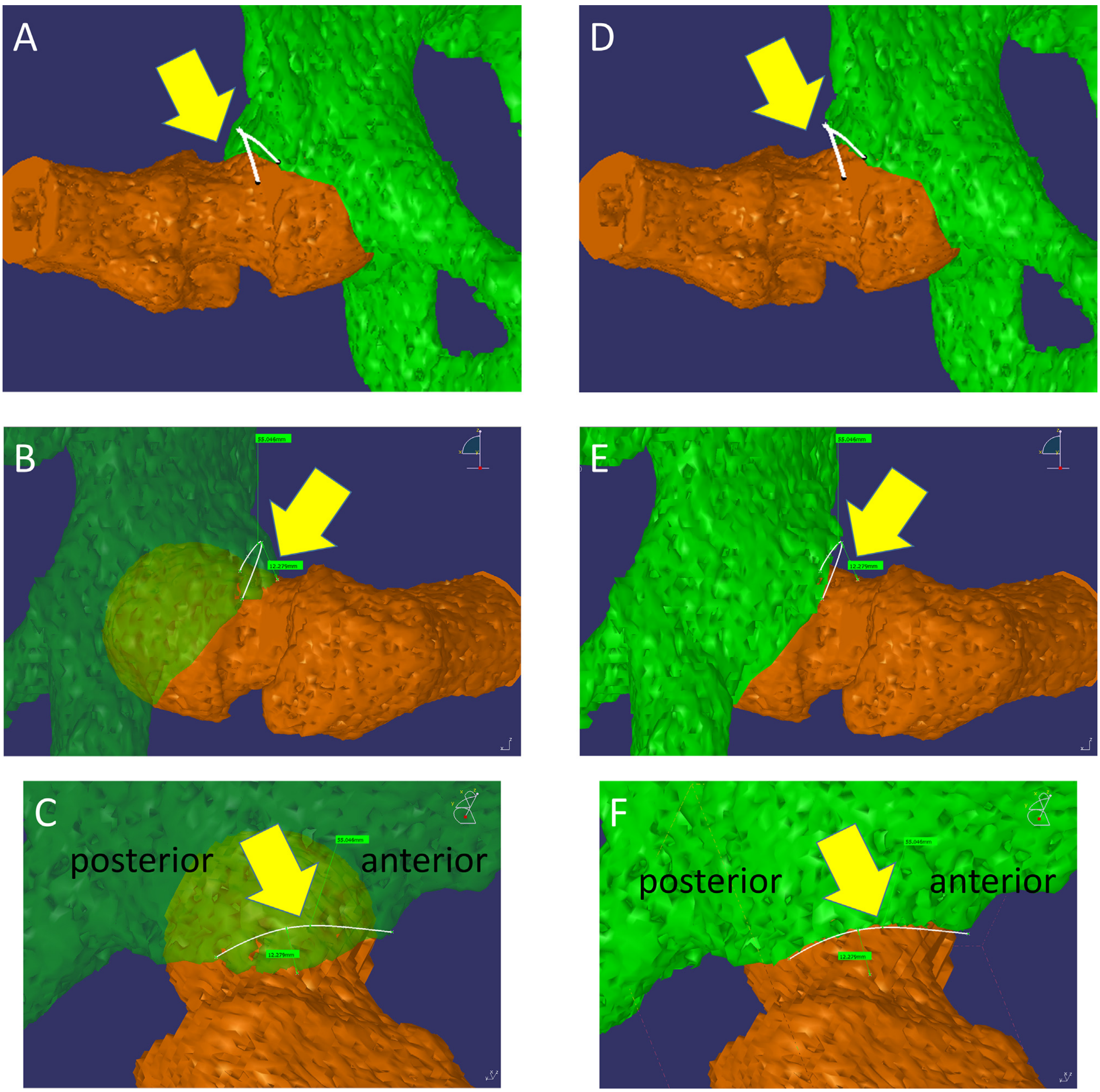

Fig. 2. Simulation analyses detected which site of the acetabulum overlapped the femoral head-neck junction (yellow arrow) in frontal (A), backward (B), and upside views (C). We prepared the model of the acetabulum in which the impingement site was resected, and confirmed that there was adequate clearance between the acetabulum and the femoral head-neck junction in frontal (D), backward (E), and upside views (F).

to 43° (Fig. 1B). Constructed 3D images using CT data revealed that the pincer lesion was resected as determined by preoperative simulation analyses (Fig. 4). His right coxalgia during squat disappeared, and Harris hip score improved from 79 to 92 one year after surgery. Postoperative hip kinematics showed 63.3° of maximum hip flexion with 23.3° of pelvic posterior tilt, 92.6° of femoral flexion, 35.8°

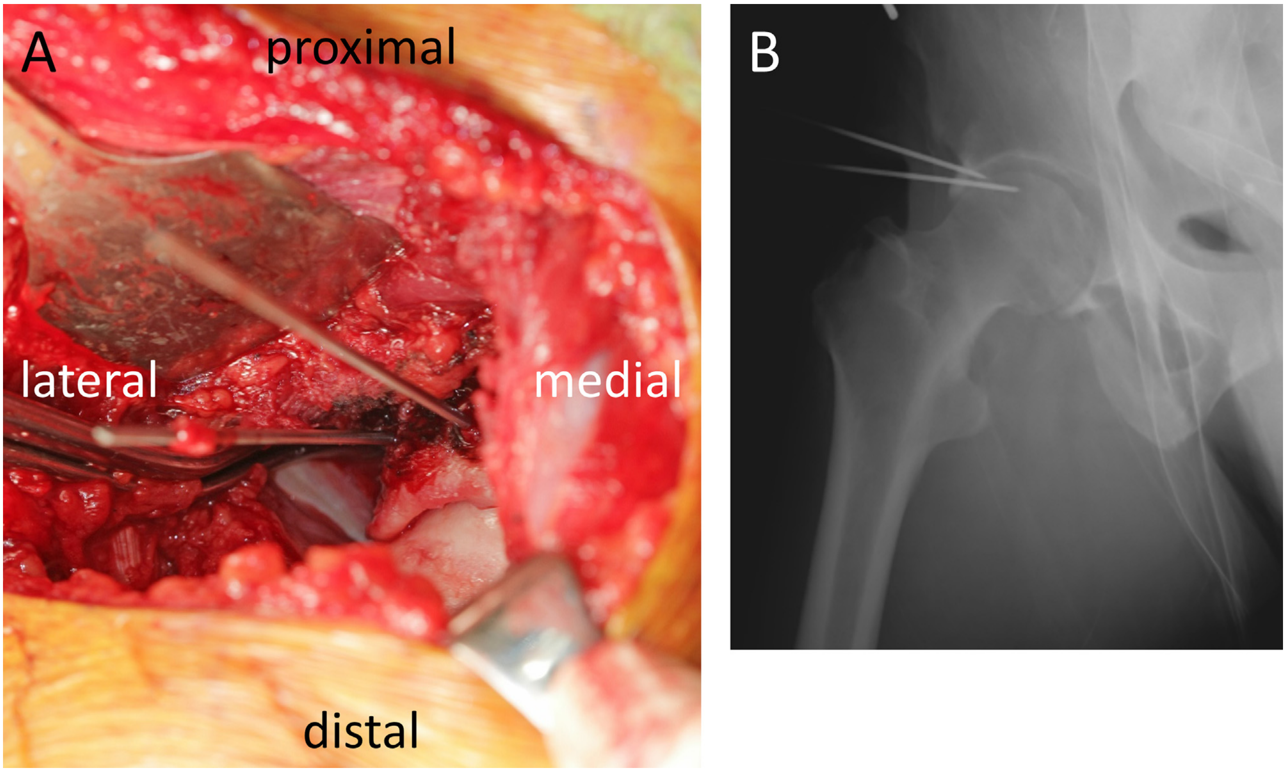

Fig. 3. Kirschner wires were inserted in the acetabulum following the resection line determined by preoperative simulation analyses (A), and we confirmed that the wires were placed in the target line under radiographic guidance (B).

of hip abduction, and −14.4° of hip internal rotation (Table 1). 3D bone models at maximum hip flexion (Fig. 5) showed increased clearance between the femoral head-neck junction and the acetabular rim with a minimal rim-neck distance of 7.3 mm instead of 1.8 mm (Table 1).

3. Discussion

CT or MRI scans have been widely used for characterization of morphological abnormalities or evaluation of articular cartilage and acetabular labrum providing valuable date [13–15]. However, these imaging modalities could evaluate only static morphology. Because the symptoms of FAI are a result of both morphology and dynamic kinematics, it is important to evaluate dynamic kinematics in addition to static morphology. To our knowledge, our case report provides the first kinematic analysis of weight-bearing activity in a patient with pincer-type FAI. Preoperative narrow clearance between the femoral neck and acetabulum due to pincer lesion was visualized under *in vivo* dynamic weight-bearing conditions.

Simulation analyses was performed in this case report with FAI assuming kinematics of the normal hip during squat [7] to examine which site of the acetabulum overlapped the femoral head-neck junction. Although several studies performed simulation analysis for FAI [5,6], they flexed and internally rotated the femurs until impingement occurred without considering the actual hip kinematics. The strength of our method was imputing the actual ROM of normal hip under in vivo weight-bearing conditions [8], and confirmed overlapping lesion between the acetabulum and the femur.

Both pre- and post-operative pelvic posterior tilt angles (24.0° and 23.3°, respectively) were larger than in normal hips (10.8° on average) [7] (Table. 1). According to the previous study for osteoarthritis hips, the pelvis could tilt posteriorly during squat to compensate for the decrease in hip flexion ROM [8], which is similar to this case. On the other hand, in some cases of cam-type FAI, the anterior pelvic tilt during deep hip flexion induces impingement [9,16,17]. Ninomiya et al. reported that the ROM of the hip did not recover to that of the opposite hip after resection of ossification of the acetabular labrum [12]. The maximum hip flexion angles in this case were limited to 70.8° before surgery and the residual angle at 63.3° after surgery probably due to soft tissue contracture. Further studies with more number of patients are necessary to conclude the difference of hip ROM between normal hips and FAI.

In our case report, we evaluated the kinematics of the hip joint only during squat because squatting induced the complaint of right coxalgia to the patient. Specific postures provide activity-dependent hip kinematics and impingement site. Therefore, additional analyses including different postures, e.g. combination of hip flexion and internal rotation, or hip extension and external rotation could be helpful for surgeons to detect anterosuperior or posterior lesion of the acetabular rim. Moreover, as previously mentioned, studies with larger cohorts are desirable to deepen the understanding of the kinematics of pincer-type FAI. Although kinematic processing of radiographic measurements is still challenging, time intensive, and require the risk of radiation exposure, it does represent an important data-driven approach to improve FAI diagnosis and provide feedback on the surgical technique.

Image-matching techniques enabled prospective visualization of hip motion during squat and quantification of the dynamic interaction between the proximal femur and acetabulum in patients with pincer-type FAI. *In vivo* 3D dynamic analyses could be clinically useful to assist surgeons in detecting the location of the impingement and confirming resection of the pincer lesion post-operatively during weight-bearing activities associated with symptoms. Future investigations are necessary to verify whether this technique provide improved clinical results more than other modalities of imaging.

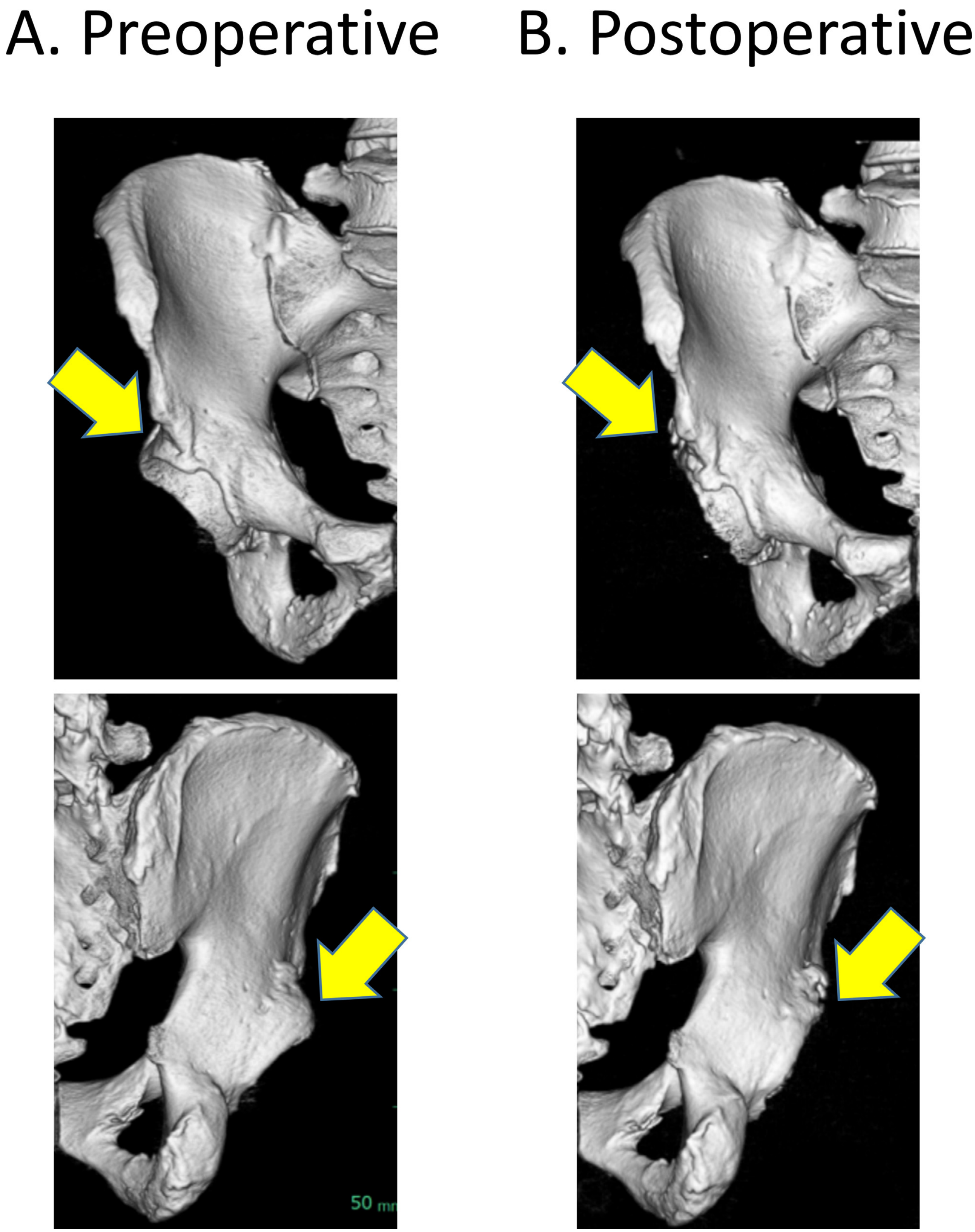

Fig. 4. Three-dimensional reconstructed images of the acetabulum using computed tomography images. Preoperative images showed an ossified pincer lesion (yellow arrow) (A). The pincer lesion was resected as determined by preoperative simulation analyses (yellow arrow) (B).

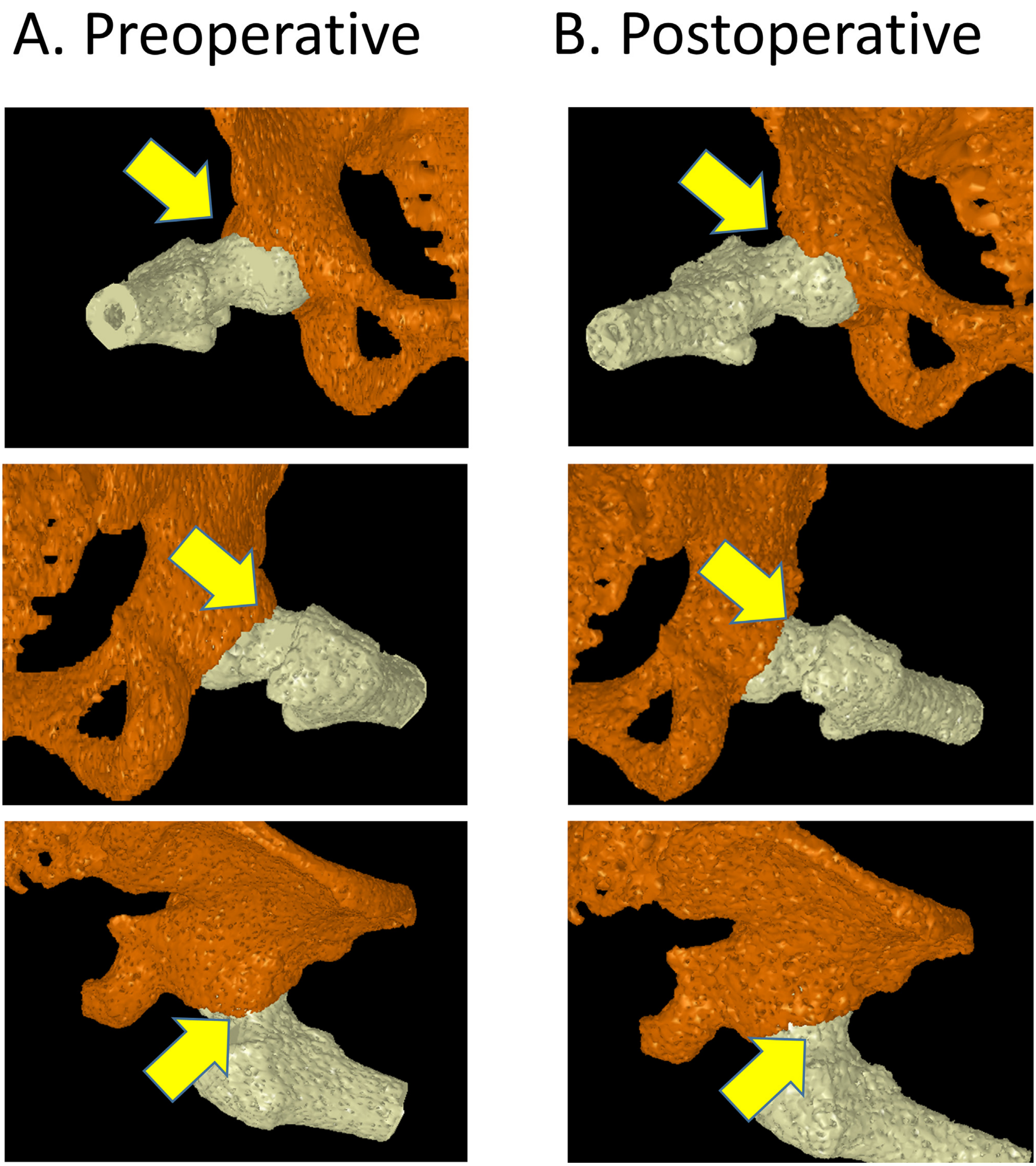

Fig. 5. Three-dimensional reconstructed images of the hip joint during squat using image-matching techniques. On the preoperative image, the pincer lesion (yellow arrow) was in close proximity to the femoral neck at maximum hip flexion (A). On postoperative images, the increased clearance between the femoral head-neck junction and acetabulum (yellow arrow) was demonstrated (B).

Conflicts of interest

None.

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All sources of funding were written in acknowledgement section. The study sponsor contributed to the collection and analysis of data.

Ethical approval

This study was approved by our institutional review board (IRB number 24–55).

Consent

We promise that written informed consent was obtained from the patient for publication of this case report and accompanying images. Patients' and volunteers' names, initials, or hospital numbers were not used in manuscript.

Author contribution

Kensei Yoshimoto and Satoshi Hamai have made contribution to the conception and design of the study, acquisition of data, and/or analysis and interpretation of data, as well as manuscript preparation. Hidehiko Higaki, Hirotaka Gondo, and Satoru Ikebe contributed to analysis and interpretation of data. Yasuharu Nakashima have made valuable suggestions to design and conception of the study. All authors critically reviewed the manuscript, approved the final version of the manuscript, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Guarantor

Satoshi Hamai.

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