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Case report

Impingement Resulting in Femoral Notching and Elevated Metal-Ion Levels After Dual-Mobility Total Hip Arthroplasty

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ABSTRACT

A 60-year-old woman underwent revision total hip arthroplasty with a modular dual-mobility articulation for recurrent dislocation. At 1-year follow-up, the patient reported no dislocations but had occasional clicking and discomfort with extreme motion. A Dunn radiograph identified notching of the femoral stem, attributed to impingement. Metal ions were elevated without adverse local-tissue reaction. After 4.5 years of observation, the notch size remained stable. She denied pain. Neither stem fracture nor prosthetic dislocation occurred. Impingement against cobalt-chromium acetabular bearing surfaces can result in notching of titanium femoral components after total hip arthroplasty. Increased anteversion intended to protect against posterior dislocation may be a risk factor. Posterior notching is best visualized on Dunn views, so incidence may be underestimated. No associated femoral implant fractures were identified on literature review.

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Introduction

Component impingement in total hip arthroplasty (THA) can cause implant damage, dislocation, or both. Dual-mobility (DM) implants are thought to reduce dislocation risk, but no available implant design has eliminated impingement or its consequences. Originally conceived more than 40 years ago [1], DM hip implants use small-diameter femoral heads to decrease wear while minimizing dislocation through the use of large-diameter polyethylene bearings. The femoral head articulates with the inner surface of polyethylene bearing, and the outer surface of polyethylene bearing articulates with the acetabular component. The majority of the motion occurs at the small inner bearing, potentially reducing volumetric wear, whereas the large-diameter outer articulation allows for an increased "jump distance" before dislocation [2,3]. DM components in primary THA have been shown to reduce dislocation risk in patients at high risk of instability due to concomitant spinal, muscular, soft-tissue, or neurologic pathology [4-11]. The original DM acetabular components were monolithic, but newer modular versions allow screw fixation and extend indications by allowing DM bearings to be used with acetabular bone loss. Indeed, DM implants may be ideally suited for revision surgery after THA dislocations [6,12,13].

DM bearings carry established risks including polyethylene wear, intraprosthetic dislocation, incomplete liner seating, and taper corrosion [14-17]. Several reports [18-23] have mentioned femoral stem notching related to impingement against a DM shell or liner, but the associated clinical and radiographic findings have not been formally described, and the natural history is not established. Femoral neck notching has also been described secondary to impingement against acetabular implants in metal-on-metal (MOM) [24-33] and ceramic-on-ceramic (COC) THA [34,35]. The phenomenon is not widely recognized, and its potential relationship to the elevated metal-ion levels sometimes noted after THA

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with DM components is not routinely discussed. Prior investigations of elevated ion levels after DM THA [36,37] have understandably focused on taper corrosion at the head-neck or shell-cup junctions, but prosthetic impingement represents a second possible source of such ions.

We present a case after revision THA for recurrent dislocations in which prosthetic impingement against a modular DM liner resulted in notching of the femoral stem and elevated metal-ion levels. The patient consented to have data from her case submitted for publication, and this investigation received approval from the hospital's institutional review board.

Case history

A 60-year-old woman presented for a second opinion regarding recurrent dislocation of her right THA. She had experienced 3 posterior right hip dislocations since THA 7 years prior. She also had experienced one dislocation of her left hip, replaced 9 years prior. Both arthroplasties had been performed through direct lateral approaches to the hip. She had reported no hip pain after recovering from dislocation episodes.

She walked without a limp or the use of assistive devices. Inspection of the hips revealed well-healed laterally based incisions. The right hip had normal 5/5 abductor function and a functional range of motion with full extension, greater than 90 degrees of flexion, approximately 50 degrees external rotation, 15 degrees internal rotation, 40 degrees of abduction, and 20 degrees of adduction. Leg lengths were equal.

Radiographs revealed bilateral cementless THAs (Fig. 1). Measurement of the right acetabular component position according to the technique of Widmer and Zurfluh [38] revealed 52 degrees of inclination and 8 degrees of anteversion. In addition, a standing lateral lumbar spine radiograph (Fig. 1c) revealed multilevel degenerative disc disease and spondylosis. Measurements of spinal balance [39] revealed a pelvic incidence of 65.9 degrees (normal 55 $\pm$ 10 degrees), lumbar lordosis of 39.0 degrees (normal 46 $\pm$ 11 degrees), and pelvic tilt of 47.5 (normal 13 $\pm$ 6 degrees). Such a large pelvic incidence—lumbar lordosis mismatch (26.9 degrees, normal 0 $\pm$ 10 degrees)—is a risk factor for THA dislocation [40].

She was deemed high risk for further right hip dislocations and indicated for right acetabular revision. Surgery was performed via the posterolateral approach. The well-fixed femoral component (Accolade TMZF; Stryker Orthopaedics, Mahwah, NJ) was well aligned and demonstrated no evidence of damage, so it was retained. The acetabular component was replaced with a new 54-mm cementless titanium acetabular component (Trident; Stryker Orthopaedics, Mahwah, NJ) positioned in additional anteversion and diminished inclination. Supplemental screw fixation was used. The system's modular DM articulation was selected to enhance stability. This included a 42-mm cobalt-chromium alloy acetabular liner, a mobile highly cross-linked polyethylene bearing with 28-mm inner diameter and 42-mm outer diameter, a 28-mm ceramic femoral head, and a titanium taper adapter with +4 mm neck length. Achieved acetabular inclination measured 35 degrees and anteversion measured 28 degrees on supine radiographs [38]. Standing radiographs revealed posterior pelvic tilt resulting in 39-degree functional inclination and 34-degree functional anteversion.

Recovery was uneventful without any concerning symptoms or dislocations. At routine 1-year clinical follow-up, the patient reported no further dislocations and was very happy with her outcome. The patient reported occasional twinges of discomfort at extremes of motion. Discomfort was not common, severe, or disabling. On physical examination, a mechanical click was felt over the hip during combined flexion, abduction, and external rotation. Of note, the patient had a large arc of motion with 105 degrees of flexion, 65 degrees external rotation, and 75 degrees of abduction. Radiographs are shown in Figure 2. A small notch in the posterior neck of the beta titanium (titanium, molybdenum, zirconium, fluoride) femoral prosthesis was identified on the Dunn view but not on anteroposterior or false profile views. The location of the notch suggested damage from mechanical impingement of the titanium femoral stem on the cobalt-chromium DM liner.

Magnetic resonance imaging (MRI) with metal-artifact reduction showed no evidence of adverse local soft-tissue reaction.

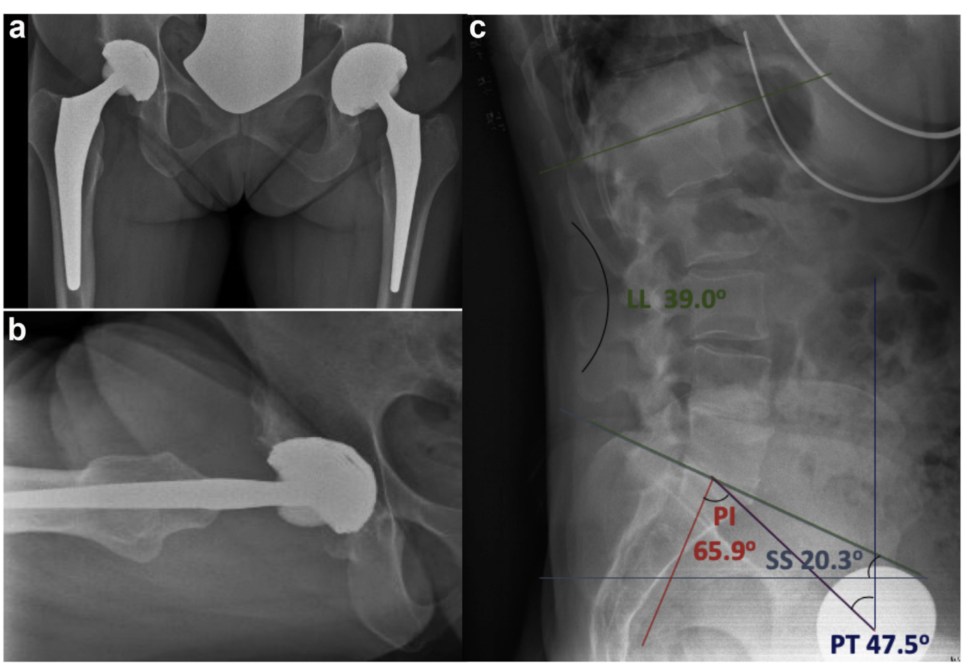

Figure 1. Anteroposterior (a), Dunn (b), and lateral lumbar (b) views of the patient presenting with recurrent dislocation of the right cementless total hip arthroplasty. The right hip had dislocated posteriorly on 3 separate occasions before presentation. LL, lumbar lordosis, PI, pelvic incidence, PT, pelvic tilt, SS, sacral slope.

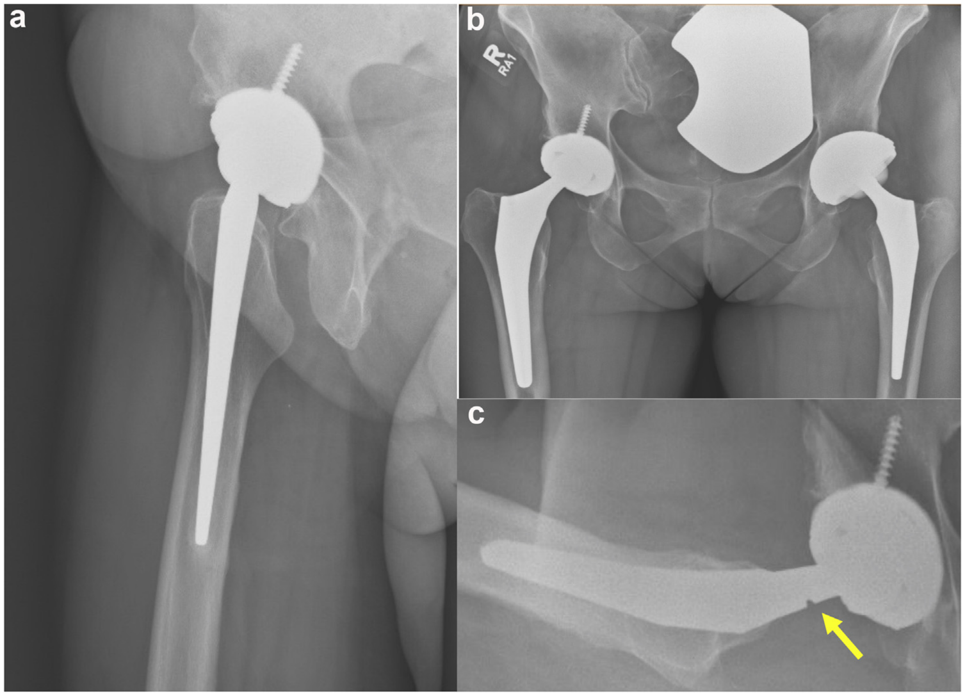

Figure 2. False profile lateral (a), anteroposterior (b), and Dunn (c) views 1 y after revision THA. Femoral component notch is visible only on Dunn view (closed arrow).

Titanium (20 mcg/L, normal <10 mcg/L) and cobalt (9.1 ug/L, normal 0-0.9 ug/L) were elevated, but chromium (0.5 ug/L, normal 0.1-2.1 ug/L) was not.

Given the minor and intermittent nature of her symptoms and the lack of adverse local-tissue reaction, the patient was given the option of observation with serial radiographs and follow-up MRI and labs as clinically warranted. The alternative of elective revision surgery was also discussed. She was informed that notching of the femoral stem might eventually result in stem fracture, that the biologic response to metal debris can result in pseudotumor and soft-tissue damage including abductor deficiency, and that higher metal-ion levels have been associated with systemic toxicity.

The patient and surgeon engaged in a shared decision-making process informed by review of the pertinent literature. This revealed reports of femoral stem notching in association with DM [18-23], MOM [24-33], and COC bearings [34,35], but no reports of subsequent stem fracture, suggesting mechanical failure may not be a rapid or inevitable consequence. In the absence of significant symptoms or clear data justifying revision, the patient elected management with observation.

The patient was monitored every 6 months over the next 3.5 years. Her mild symptoms became even less noticeable when she learned to avoid extreme flexion, abduction, and external rotation. Radiographs revealed no progression of the femoral notch size and no evidence of gross mechanical failure, as seen in Figure 3. One year after diagnosis (2 years after surgery), repeat MRI revealed no evidence of adverse local-tissue reaction. Metal-ion levels revealed slightly reduced but still elevated titanium (12.4 mcg/L) and cobalt (cobalt 8.4 ug/L); chromium (0.9 ug/L) remained normal.

At the recent 4.5-year follow-up, the patient denied right hip pain and reported no mechanical symptoms. The size of the notch was stable with no stem fracture. She is scheduled to follow up annually for surveillance.

Discussion

DM implants are thought to reduce dislocation risk by increasing impingement-free range of motion and/or jump distance compared with fixed-bearing implants with standard head diameters. DM constructs are not invulnerable to impingement, however. Indeed, the specific modular DM design involved in our reported cases apparently has a smaller impingement-free arc of motion than a 36-millimeter fixed-bearing construct [5], suggesting its stability benefits may come primarily through an increased jump distance.

Here we report a case of symptomatic impingement between the femoral stem and a DM acetabular component placed to address recurrent posterior THA dislocation. Contributory factors

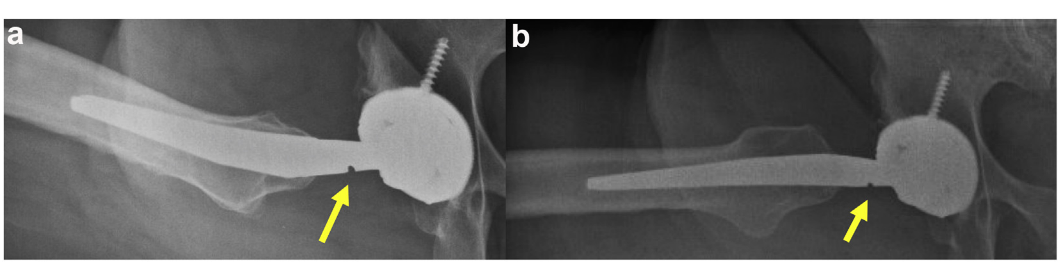

Figure 3. Dunn radiographs 2 years (a) and 3.5 years (b) after DM implantation, indicating no progression of impingement notch (closed arrow).

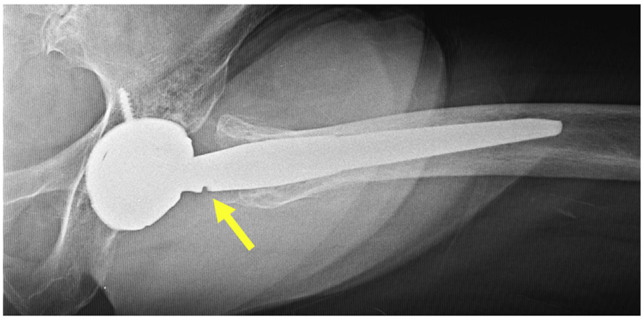

Figure 4. Dunn radiograph 4.5 y after DM implantation revealing a stable impingement notch, unchanged from 1 year after surgery (closed arrow).

likely included (1) intentional anteversion of the acetabular component to minimize posterior dislocation risk, but exacerbated by posterior pelvic tilt, (2) ligamentous laxity that allowed extreme flexion, abduction, and external rotation range of motion to be achieved, and (3) a stiff spine resulting in increased need for hip motion to accomplish activities of daily living. Although we selected one primary case to report, other cases of femoral stem notching demonstrate the spectrum of severity and clinical presentations associated with this phenomenon.

A similar posterior femoral notch was observed in a second patient with posterior pelvic tilt, also revised to a DM acetabular component for treatment of recurrent posterior dislocation. Although the affected femoral stem (ZMR, Zimmer Biomet, Warsaw, IN) was manufactured from a different titanium alloy (Ti6Al4V), this patient has also remained asymptomatic without stem fracture or progression of notch depth at 4.5-year radiographic follow-up (Fig. 4).

A distinct pattern of femoral notching was noted in a 51-year-old man who presented with hip pain and mild mechanical symptoms 4 years after primary left THA with a modular DM component and a ceramic femoral head. Physical examination reproduced clicking with hip flexion and abduction. Radiographs revealed a subtle impingement notch in the superior prosthetic femoral neck and an incomplete fibrous interface behind the acetabular component, which was more horizontal and less anteverted than in the aforementioned cases (Fig. 5). Laboratory testing revealed elevated cobalt (ranging 1.4-2.9 ug/L on multiple samples) but normal chromium and titanium levels. Metal-artifact reduction MRI demonstrated only a small pocket of fluid in the hip pseudocapsule. Revision was elected based on poorly tolerated symptoms, incomplete acetabular osseointegration, and theoretical risks from ongoing impingement. At surgery, metal staining was confined to the synovial lining, with no pseudotumor or osteolysis. The DM liner was well seated with no evidence of corrosion affecting the femoral or acetabular modular junctions. The acetabular component demonstrated central osseointegration but was revised to change the orientation and eliminate the prominent DM liner. The notched Ti6Al4V alloy titanium femoral stem (Accolade II, Stryker Orthopaedics, Mahwah, NJ) was not revised, given the absence of literature reporting stem fractures, our experience with larger impingement notches in the aforementioned cases, and the known risks associated with revising well-fixed femoral components. Symptoms resolved, and metal-ion levels normalized (chromium 0.5 ug/L, normal 0.1-2.1 ug/L; cobalt 0.0 ug/L, normal 0-0.9 ug/L) by recent follow-up 3 months after revision.

In a final case affecting a 57-year-old woman with a multiply revised left THA and prior lumbar fusion, we observed greater than 60% diameter prosthetic femoral neck notching with displacement of the metal modular DM acetabular liner in the setting of a loose revision acetabular component (Fig. 6). The relationship of the femoral notch to impingement on the DM acetabular liner was easily established on gross inspection of the prostheses (Fig. 7), and copious metallosis was noted at the time of revision. Although this catastrophic failure was primarily mediated by bone loss and failure of acetabular osseointegration, it illustrates the severity of femoral stem damage impingement can cause.

Literature review querying PubMed, EMBASE, and Google Scholar using the combination of search terms “dual mobility”,”notching”, “impingement”, “femoral neck”, and/or “fracture” identified several studies reporting similar femoral impingement damage related to DM components [18-23] and also identified the occurrence of notching in association with MOM [24-33] and COC [34,35] articulations. A 4% incidence of femoral neck notching was observed with one early cementless DM implant, but no such notching was reported after the metal shell was modified to reduce posterior prominence, reinforcing the relationship between notching and impingement [21]. The report did not describe clinical sequelae but acknowledged such impingement could be a source of metallosis. Recent literature reveals that “the notch” persists with some modern DM components. Minimum 2-year follow-up of 410 modular DM cases found one case of “trunnion notching” secondary to impingement, subsequently treated with cup and stem revision [18]. An additional report from the same group noted one case of symptomatic femoral notching against an anteverted cup among 249 modular DM THAs for patients deemed a high dislocation risk [19], but this may in fact be the same patient. Epinette et al [22,23] reported additional instances of femoral notching, including 2 cases among 321 patients younger than 55 years implanted with DM components [22]. Angular measurements of the component position were not reported, but excessive acetabular anteversion was noted in both cases. Although asymptomatic, both patients were treated with revision of the malpositioned

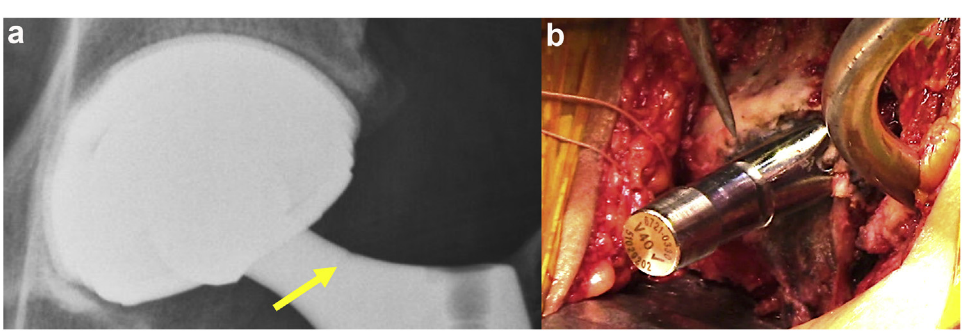

Figure 5. Subtle notching of the superior neck with a relatively horizontal acetabular orientation was best observed on the anteroposterior radiograph (a). Notching on the superior aspect of the femoral neck was confirmed intraoperatively (b).

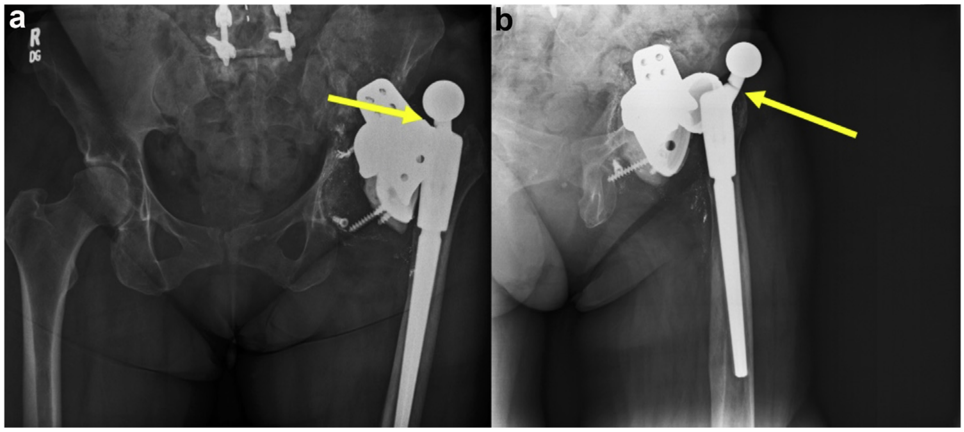

Figure 6. Severe femoral component notching visible on anteroposterior-view radiograph (a) and false profile lateral-view radiograph (b) in a case with gross acetabular loosening and disengagement of the modular dual-mobility liner.

acetabular components. The study did not report femoral revision, suggesting the notched femoral components were retained. The series included 174 monobloc shells with rim cutouts and 147 modular implants with circumferential extended coverage; one case of stem notching was reported with each component design [22].

Importantly, none of the identified English-language studies reporting femoral notching with DM, MOM, or COC articulations described prosthetic femoral implant fractures through the impingement notch. Although we identified one reported case of femoral implant fracture in a patient with a DM articulation [41], personal communication with the corresponding author revealed this was a failure at the neck-stem junction possibly related to femoral implant design, with no evidence of impingement notching.

Although femoral notching can occur with MOM and COC implants, we focused this report on its association with DM articulations because all femoral notches observed in our practice involved DM constructs. Furthermore, although current utilization of MOM and COC articulations is low in the United States, the use of DM is increasing and is often specifically advocated in patients at risk for prosthetic impingement due to functional demands or abnormal spinopelvic parameters. MOM THA was not widely embraced in our geographic region; thus, the absence of MOM cases in our series should not be taken to imply a higher risk of notching with DM vs MOM bearings. Indeed, the bearing diameter, arc of coverage, acetabular rim geometry and material, and femoral neck geometry and material are likely the critical implant-related parameters. Ceramic liner fracture has been the primary concern when neck impingement occurs with a COC bearing. Cases of neck notching with COC bearings reported in the literature have typically been less striking than several of the cases described here with DM bearings; it is possible that ceramic fracture may occur before severe stem damage [34,35,42].

It is certainly possible that femoral notching could also happen despite the use of polyethylene acetabular bearings, but this would

Figure 7. Femoral component notching (a) caused by impingement on the modular cobalt-chromium bearing in a dual-mobility construct (b).

presumably require sufficient wear of the bearing to allow stem impingement against a metal acetabular shell. It is not clear, however, whether a titanium acetabular shell would cause similar notching to that reported here with cobalt-chromium acetabular liners impinging on titanium femoral stems. The senior author has used fixed-bearing metal-on-polyethylene or ceramic-on-polyethylene implants in 99% of THA cases and DM in less than 1% but has only observed femoral neck notching in hips with DM constructs. Although a case report cannot establish causation and lacks the scientific rigor and power associated with higher levels of evidence, the use of DM or other hard acetabular bearings may be a risk factor for femoral notch formation. Beyond the implant design features, there may be a higher risk of impingement among patients selected for DM related to the indication for their use, for example, in those with reduced spinopelvic mobility from degenerative disease or prior lumbar arthrodesis.

The cases described here involved 4 different femoral stem brands, 2 different manufacturers, and 2 different titanium alloys (both Ti6Al4V and TMZF). Although the risk of stem notching was not confined to a single femoral stem material, manufacturer, or design, we identified no affected cobalt-chromium stems. As cobalt-chromium cemented stems have been used for less than 10% of THAs in our practice over the past decade, further research would be necessary to determine of cobalt-chromium stems are protected from this form of damage.

Although increasing acetabular anteversion remains an important strategy in the treatment of posterior instability after THA, functional acetabular anteversion greater than 25-30 degrees may be a risk factor for posterior prosthetic femoral neck notching with DM components and other hard acetabular bearings [33], particularly with diminished spinopelvic mobility. We suggest intraoperative examination should specifically seek to identify posterior impingement on flexion, abduction, and external rotation. If such impingement occurs, the hip length and offset may be increased to limit extreme motion by tensioning soft-tissue restraints, or component position may be changed. Indeed, individual anatomy, deformity, and functional requirements may dictate the specific combination on anteversion and inclination that optimize the arc of impingement-free motion available, thereby reducing the risk of instability during activities of daily living.

Summary

Some degree of impingement may be inevitable in patients with stiff spines and hypermobile hip joints, but the component design and position likely contribute to prosthetic impingement risk. When a DM or other hard acetabular bearing impinges against a titanium femoral component, this can result in femoral notching. This phenomenon may result in mechanical symptoms and pain or may be asymptomatic. Such impingement should be considered in the differential diagnosis for elevated metal-ion levels after THA. None of our patients experienced femoral implant fracture through the impingement notch, although maximum follow-up was only 4.5 years, nor were reports of such fractures encountered on literature review. We therefore do not believe femoral notching is an absolute indication for revision surgery. We recognize that selecting less anteversion in our first 2 cases might have allowed posterior dislocation to recur. As compared to dislocation, femoral notching may indeed be the lesser of 2 evils. Further study is warranted to determine the clinical significance of various levels of femoral notch and to better define target patient-specific acetabular positions that optimize stability while minimizing impingement risk.

Conflict of interests

H.J.C. is a member of the speaker's bureau for KCI, is a paid consultant for KCI, DePuy, and Zimmer Biomet, receives research support from Smith & Nephew, is a member of the editorial or governing board of the *JBJS*, and is a board or committee member for the AAOS; M.S.H. receives royalties from Corin U.S.A. and Exactech Inc, is a member of the speaker's bureau for Stryker, is a paid consultant for Corin U.S.A., Exactech Inc, KCI, and Stryker, receives research support from CyMedica, Flexion Therapeutics, and Stryker, and is a board or committee member for the AAOS; all other authors declare no potential conflicts of interest.

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