Revision for taper corrosion at the neck-body junction following total hip arthroplasty: pearls and pitfalls

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Abstract The management of the patient with a recalled, modular neck-body total hip arthroplasty can be complex, as it involves a combination of clinical, technical, and medicolegal challenges. Management begins with a thorough history and physical exam, radiographic evaluation, infection work-up, and serum metal ion levels. Three-dimensional imaging is obtained based on patient symptomatology and metal ion levels and is used to evaluate for the presence of an adverse local tissue response as well as the integrity of the existing soft tissue envelope. The decision to perform revision surgery is based on a combination of patient symptomatology, laboratory values, and imaging findings. Revision surgery involves the entire armamentarium of femoral revision techniques, and the acetabulum may need to be revised at the surgeon's discretion. The femoral implant can often be removed without disrupting the femoral bone envelope; however, the surgeon should have a low threshold to perform an extended trochanteric osteotomy.

Keywords Corrosion · Modular neck · Revision hip arthroplasty · Adverse local tissue reaction

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Introduction

Since the success of the monoblock Charnley low-friction total hip arthroplasty (THA) system [1], interest has abounded in the development of modular THA systems to increase intraoperative flexibility and aid in accurately restoring native hip biomechanics. The introduction of modular neck-body femoral stem designs was a logical extension of this trend, allowing for customization of neck length, offset, and version. Unfortunately, this stem design is susceptible to corrosion at the neck-stem interface, leading to early implant failures, metal ion release, adverse local tissue reactions (ALTRs), and a higher than expected revision rate [2•, 3•, 4•, 5–8]. The complications resulting from this design directly led to the voluntary market recall of two modular neck THA systems in 2012 (Stryker ABG II and Stryker Rejuvenate, Stryker Orthopaedics, Mahwah, NJ) [9]. Unfortunately, due to the popularity of these devices, several thousand were implanted in the USA prior to the recognition of this design flaw. The management of a patient with these recalled implants can be quite challenging from clinical, technical, and medicolegal standpoints. In order to provide optimal care, the surgeon should be familiar with the clinical presentation and management of this patient population and well versed in revision total hip arthroplasty principles and techniques.

Clinical presentation and workup in the patient with a painful, recalled, dual taper modular neck total hip arthroplasty

History and physical exam

The surgeon should perform a careful history and physical exam on the patient presenting to the office with a painful

recalled total hip arthroplasty. There are numerous etiologies of the painful THA, which are still applicable to the patient with a modular neck implant, that need to be ruled out as pain generators including lumbar spine disease, iliopsoas impingement, femoral or inguinal hernia, peripheral vascular disease, trochanteric bursitis, infection, and mechanical loosening [10]. Many patients with a recalled modular neck THA are actively engaged in litigation, making it critically important to correctly diagnose the etiology of the pain. The most common presenting symptom in a patient with ALTR is the delayed onset of groin, thigh, or buttock pain after a 1–2-year postoperative pain-free interval [2•]. The absence of a pain-free interval following the index surgery should make the surgeon more suspicious of infection or mechanical loosening of the implant as the pain generator. The surgeon should elicit a history of any postoperative wound healing complications, recent dental or gastrointestinal procedures, or urinary tract infections that might indicate periprosthetic joint infection (PJI) as an underlying cause of pain. Although described as a complication relating to metal-on-metal THA, the surgeon should nonetheless be alert to the possibility of systemic cobalt toxicity, so-called arthroprosthetic cobaltism, and should obtain a review of systems noting any fatigue, decreased exercise tolerance, palpitations, dyspnea, change in vision or hearing, new onset tremors or seizures, headaches, or unexplained mood changes [11, 12].

After obtaining a thorough patient history, the surgeon should perform a detailed physical examination. The physical exam begins by assessing the general appearance of both legs for symmetry, as some patients with ALTR have been reported to experience unilateral swelling of the affected lower extremity [2•]. The skin of the affected lower extremity should be examined for erythema, warmth, and any draining sinus tracts; the soft tissue surrounding the hip should be palpated for any masses or areas of fluctuance. Next, the hip should be brought through a range of motion, testing internal and external rotation in both flexion and extension, noting any painful arcs of motion. The patient is then instructed to perform straight leg raises against gravity and resistance, again noting any pain. The motor strength of the abductor complex is then assessed with the patient in the lateral decubitus position. Lastly, the patient is asked to ambulate, and any limp with an associated pathologic gait pattern is noted. The common physical exam manifestations of ALTR include pain with straight leg raise, abductor weakness, and limp during ambulation [2•].

Laboratory studies

Blood work should be obtained at the initial visit and sent for erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). It is not uncommon for these acute phase reactants to be elevated in patients with ALTR, and if either is elevated, the joint should be aspirated and sent for cell count and culture to

rule out infection. Interpretation of the cell count should be done with care, as ALTR causes a cellular tissue reaction that may elevate synovial white blood cell counts above accepted cutoffs resulting in false-positive identification of PJI [2•, 13]. A recent study by Yi et al. suggested the optimum cell count cutoff for the diagnosis of PJI in patients with metal-on-metal (MoM) bearings or corroded THA to be >4350 WBC/ μ L with a differential of >85 % polymorphonuclear cells [14•]. A manual cell count may also be needed as metal debris and cellular conglomeration caused by ALTR can make it difficult to obtain an accurate automated cell count [14•].

Serum cobalt (Co) and chromium (Cr) levels should also be obtained during the initial visit and trended at subsequent follow-up visits. These specimens need to be collected in trace metal-free blood collection tubes in order to avoid contamination and erroneously elevated ion levels [15•]. In patients with modular neck THA and ALTR, there is a differential elevation of cobalt to chromium in a ratio of 1–5:1 [2•, 4•, 16, 17, 18•, 19•]. The differential elevation in serum cobalt to chromium has been attributed to the greater solubility of cobalt and the propensity for local precipitation of chromium on the implant at modular junctions in the form of chromium orthophosphate [2•, 3•, 4•, 5, 6]. A longitudinal study of well-function metal-on-polyethylene THA by Levine et al. suggested that serum CoCr levels should be below 1 part per billion (ppb) [20•]. However, consensus has not been reached regarding absolute cutoff values of serum CoCr in modular neck THA. A risk stratification algorithm outlined by Kwon et al. (Tables 1, 2, and 3) suggests that serum Co <1 ppb can be considered low risk, serum Co 1–5 ppb can be considered medium risk, and serum Co >5 ppb can be considered high risk, when combined with patient symptomatology, physical exam, and imaging findings [19•]. In the symptomatic and asymptomatic patient, elevated serum CoCr levels should be further evaluated with advanced imaging [19•].

Imaging

Plain radiographs should be obtained, including an anteriorposterior (AP) view of the pelvis, and AP, frog lateral, and cross-table lateral of the affected hip. The most common area to see osteolysis as a result of ALTR is in the medial calcar region in Gruen zone 7, as it is directly adjacent to the neck-stem junction [17, 18•, 21•]. However, in the many cases, the radiographs are unremarkable and demonstrate a well-fixed and ingrown stem [15•, 19•]. Pivec et al. recommend obtaining advanced three-dimensional imaging, either metal artifact reduction sequence magnetic resonance imaging (MARS MRI) or ultrasound, following the initial visit for symptomatic patients [15•]. In the asymptomatic patient with normal plain films, the decision to obtain advanced imaging is based on the presence of abnormal serum cobalt and chromium laboratory findings [15•, 19•]. Typical imaging findings

Table 1 Modular trunnion adverse local tissue reaction “low” risk group

Low-risk group stratification	
Patient factors	Low activity level patient
Symptoms	Asymptomatic (including no mechanical or systemic symptoms)
Clinical examination	No change in gait (i.e., no limp), no abductor weakness, no swelling
Femoral implant modularity type	Head-neck modular stem; “dual taper” stems: titanium modular neck with titanium stem (Ti/Ti), stem-sleeve modular stem, mid-stem modular stem
Radiographs (two views ± serial for comparison when available)	No implant osteolysis/loosening
Infection workup (ESR, CRP, ±hip aspiration)	Within normal limits
Metal ion level test (if available)	Low cobalt level (<1 ppb), low cobalt/chromium ratio (<1)
Cross-sectional imaging (if performed) these studies include MARS MRI; ultrasounds or CT when MRI contraindicated or MARS protocol not available	Within normal limits
Treatment recommendation	Routine annual follow-up

Source: Kwon YM, Fehring TK, Lombardi AV, Barnes CL, Cabanela ME, Jacobs JJ. Risk Stratification algorithm for management of patients with dual modular taper total hip arthroplasty: consensus statement of the American Association of Hip and Knee Surgeons, the American Academy of Orthopaedic Surgeons, and the Hip Society. J Arthroplasty. 2014;29(11):2060-4. Reproduced with Permission.

Table 2 Modular trunnion adverse local tissue reaction “moderate” risk group

Moderate-risk group stratification	
Patient factors	Moderate activity level patient
Symptoms	Symptomatic, mild local hip symptoms, no systemic symptoms
Clinical examination	Change in gait (i.e., limp), no abductor weakness, no swelling
Femoral implant modularity type	Head-neck modular stem with CoCr femoral head (unexplained pain), “dual taper” stems: CoCr modular neck with titanium stem (CoCr/Ti), CoCr modular neck with CoCr stem (CoCr/CoCr)
Radiographs (two views ± serial for comparison when available)	No implant osteolysis/loosening
Infection workup (ESR, CRP, ±hip aspiration)	Within normal limits
Metal ion level test (if available)	Moderately elevated cobalt level (1–5 ppb), moderately elevated cobalt/chromium ratio (1–5)
Cross-sectional imaging (if performed) these studies include MARS MRI; ultrasounds or CT when MRI contraindicated or MARS protocol not available	Presence of abnormal tissue reactions <i>without</i> involvement of surrounding muscles and/or bone; simple cystic lesions or small cystic lesions without thickened wall
Treatment recommendation	Follow-up in 6 months
Revision surgery	Consider revision surgery <i>if</i> symptoms progress, imaging abnormality progresses, and/or <i>rising</i> metal ion levels/ratio over 6 months

Source: Kwon YM, Fehring TK, Lombardi AV, Barnes CL, Cabanela ME, Jacobs JJ. Risk Stratification algorithm for management of patients with dual modular taper total hip arthroplasty: consensus statement of the American Association of Hip and Knee Surgeons, the American Academy of Orthopaedic Surgeons, and the Hip Society. J Arthroplasty. 2014;29(11):2060-4. Reproduced with Permission.

Table 3 Modular trunnion adverse local tissue reaction “high” risk group

High-risk group stratification	
Patient factors	High activity level patient
Symptoms	Symptomatic, severe local hip, and/or mechanical symptoms; recurrent instability; systemic symptoms
Clinical examination	Change in gait (i.e., limp), abductor weakness, swelling
Femoral implant modularity type	Head-neck modular stem with CoCr femoral head (unexplained pain), “dual taper” stems: CoCr modular neck with titanium stem (CoCr/Ti), CoCr modular neck with CoCr stem (CoCr/CoCr)
Radiographs (two views ± serial for comparison when available)	Medial calcar erosion, trochanteric erosion, implant osteolysis/loosening
Infection workup (ESR, CRP, ±hip aspiration)	Within normal limits
Metal ion level test (if available)	High cobalt level (>5 ppb), high cobalt/chromium ratio (>5)
Cross-sectional imaging (if performed) these studies include MARS MRI; ultrasounds or CT when MRI contraindicated or MARS protocol not available	Presence of abnormal tissue reactions <i>with</i> involvement of surrounding muscles and/or bone: solid lesions, cystic lesions with thickened wall, mixed solid and cystic lesions
Treatment recommendation	Consider revision surgery

Source: Kwon YM, Fehring TK, Lombardi AV, Barnes CL, Cabanela ME, Jacobs JJ. Risk Stratification algorithm for management of patients with dual modular taper total hip arthroplasty: consensus statement of the American Association of Hip and Knee Surgeons, the American Academy of Orthopaedic Surgeons, and the Hip Society. *J Arthroplasty*. 2014;29(11):2060-4. Reproduced with Permission.

in patients with ALTR include peritrochanteric fluid collections, soft tissue masses, and tendon avulsions [21•]. In patients with medical comorbidities that preclude the use of MRI, ultrasound has been shown to be a suitable alternative for the identification of ALTR [21•].

Surgical planning

The decision to perform revision hip arthroplasty in a patient with modular dual tapered implants has been greatly aided with the development of a risk stratification profile by Kwon et al. (Tables 1, 2, and 3) [19••]. We recommend that surgeons undertaking revision hip arthroplasty in this patient population be well versed in revision surgical techniques and have a variety of revision instruments and implants available to them. It is also important to note if the patient will need their explanted components returned to them for independent analysis, as many of these patients are involved in ongoing litigation with the device manufacturer.

Once the decision to undertake revision hip arthroplasty has been made, the preoperative imaging becomes a critical portion of the surgical planning. The surgeon needs to carefully evaluate the femoral and acetabular bone stock, evidence of osteolysis or loosening of the femoral and acetabular components, presence or absence of pseudotumors, and the integrity of the abductors and surrounding soft tissue envelope on the preoperative cross-sectional imaging. Attention should also be paid to examining the extent of any fluid collections.

Typically, patients suffering from neck-stem taper corrosion can be treated with revision of the femoral component and isolated liner exchange. However, a well-fixed cup containing cobalt may need to be revised if there is clinical concern for cobalt hypersensitivity. The surgeon should be aware that controversy exists regarding the diagnosis of this clinical entity [22–27], as well as with regards to appropriate preoperative testing for cobalt hypersensitivity, such as skin patch testing or lymphocyte transformation test (LTT), and the interpretation of the results of these tests [28–32]. A joint statement issued by the American Academy of Orthopaedic Surgeons Biomedical Engineering and Biological Implants Committees suggests the avoidance of reaction producing metals in patients with metal hypersensitivity undergoing primary total joint arthroplasty [32]. At present, no such recommendations have been issued regarding metal hypersensitivity in the revision of a corroded THA.

Patients should be appropriately counseled that prognosis following revision of a corroded modular neck THA is guarded, as literature regarding short- and long-term outcomes data is lacking. However, limited short-term outcome data is available regarding outcomes following revision of MoM THAs and could potentially be extrapolated to the revision of a corroded modular neck THA. A retrospective review by Munro et al. regarding short-term outcomes in revised MoM THAs suggests a high complication rate (38 %) with instability being the primary culprit [33•]. Similarly, Wyles et al. found an increase in the incidence of periprosthetic joint infections following revision of MoM THAs (8.1 %) [34•]. Until outcome

data becomes available, patients should be counseled that they may be subjected to a higher complication rate following revision of a corroded modular neck THA, as compared to revisions of primary THA performed for other reasons. Following revision surgery, these patients should expect significant drops in their serum Co and Cr by 6 weeks postoperatively, with near normalization of ion levels by 6 months [18•].

Femoral revision pearls and pitfalls

Implant choice is dictated by femoral bone stock and surgeon preference. It is the senior author's (DDC) preference to use a titanium modular tapered fluted, diaphyseal engaging stem, due to familiarity and ease of use. Some concerns exist with revising a modular stem to another modular stem; however, the current generation of titanium modular tapered fluted stems has an excellent track record and implant survivorship. In addition, these implants have a titanium body on titanium distal stem design, eliminating corrosion-related cobalt and chromium metal ion release concerns. Furthermore, titanium modular tapered fluted stems are rapidly becoming the implant of choice for femoral revision surgery due to their ease of implantation and their ability to reconstruct a wide variety of femoral defects. Alternatively, if there is 4–6 cm or greater of supportive femoral diaphyseal isthmus remaining, the surgeon can elect to use a fully coated, cylindrical diaphyseal engaging stem. If less than 4–6 cm of isthmus remains, a monoblock titanium tapered fluted stem can be used.

Regardless of the stem extraction technique employed, we recommend that the surgeon should have the following tools available when performing femoral revision: manufacturer-specific stem extraction device, slap hammer, vice grips, high-speed pencil tip bur, flexible osteotomes, broad osteotomes, bipolar wound sealer, cerclage cables, and standard hip revision instruments. The surgeon should also be prepared to send intraoperative tissue specimens for frozen section and culture. During surgical exposure, it is important to excise all necrotic tissue and perform a thorough capsular debridement to facilitate dislocation of the prosthesis. Typical intraoperative findings include metal debris and sludge, calcar erosion, tissue necrosis, and pericapsular rind [17]. Once the hip has been dislocated, the senior author facilitates stem extraction using one of two techniques: either the modified Steinman pin technique or an extended trochanteric osteotomy (ETO).

Modified Steinman pin technique

The Steinman pin technique is a relatively new surgical technique for the removal of well-fixed proximally coated stems and was originally described by Shah et al. in 2013 [35•]. This

technique allows for stem removal without the use of an osteotomy, preserving proximal femoral bone stock while limiting the morbidity to the patient (Video 1, Fig. 1). Careful patient selection is critical to prevent intraoperative and postoperative complications, with the ideal patient possessing robust proximal femoral cortical bone without any deformity of the proximal femur.

The technique involves the passage of multiple smooth 2.0-mm Steinman pins past the proximal coating of the stem, disrupting the implant-bone interface. This process can also be supplemented with a pencil tip burr and flexible osteotomes. Once the implant-bone interface has been sufficiently disrupted, the femoral stem can be removed from the proximal femur using a slap hammer attached to an implant-specific extraction tool. The proximal femoral bone stock is then inspected for any defects that need to be addressed during the reconstruction. When employing this technique, the senior author most commonly uses a titanium modular tapered fluted revision stem for reconstruction. A single cerclage cable can be placed prophylactically around the proximal femur prior to reaming the femoral canal to prevent fracture of the weakened metaphyseal bone during seating of the final implant. Postoperatively, patients are allowed to bear weight as tolerated with the use of assistive devices as needed.

The surgeon should be cognizant of several potential pitfalls when using this technique. (1) Care should be exercised when passing the smooth Steinman pins to ensure that they do not perforated the cortex, as this may lead to fracture of the proximal femur during stem removal. The risk of perforation is greater in patients who have thin, osteoporotic cortical bone, making this a relative contraindication to using this technique. (2) The surgeon may also experience difficulty passing pins or flexible osteotomes past the lateral shoulder of the implant due to overhang of the greater trochanter. A small segment of bone can be removed from the lateral shoulder of the implant to improve access to this area, with extreme care taken to avoid fracture of the greater trochanter. (3) Lastly, this technique can potentially be very time-consuming. The authors recommend that the surgeon sets a 30-min time limit before converting to an extended trochanteric osteotomy to extract the stem.

The senior author has used the Steinman pin technique successfully in six cases of modular neck THA revision, one case of which was complicated by early postoperative fracture of the greater trochanter at 2 weeks postoperatively, which was treated with a trochanteric claw plate. Early results of this technique have been encouraging, as all patients have been ambulating without assistance by 4 months postoperatively.

Extended trochanteric osteotomy

The ETO was originally described by Younger et al. and is considered to be the gold standard technique for removal of

Fig. 1 Preoperative and postoperative radiographs demonstrating a dual taper modular neck femoral stem revision to a titanium modular fluted tapered diaphyseal engaging stem utilizing the modified Steinman pin technique for stem removal

well-fixed femoral stems [36]. Its indications for use are broader than that of the Steinman pin technique and can be applied to nearly any patient undergoing a femoral revision. It is the senior author's preference to employ this technique when revising patients with thin, osteoporotic proximal femoral cortical bone or if there is any varus remodeling deformity of the proximal femur (Video 2).

There are several pitfalls that the surgeon should aim to avoid when performing an ETO: (1) Meticulous hemostasis should be obtained to prevent postoperative hematoma formation. (2) The preservation of the soft tissue attachments of the vastus lateralis and gluteus medius to the vastus ridge is critical to prevent superior escape of the fragment, minimize Trendelenberg gait, and maintain the blood supply of the osteotomy fragment. (3) The perforating holes made by the pencil tip bur in the vertical limb of the osteotomy should be placed relatively close together to prevent aberrant fracture propagation when the fragment is hinged anteriorly. Alternatively, a small sagittal saw can be utilized to make the vertical limb of the osteotomy. (4) The intersection of the vertical and horizontal limbs of the osteotomy should be beveled and rounded to avoid stress risers that might cause fracture propagation of the femur during mobilization of the osteotomy fragment. (5) Care should be taken to protect the osteotomy fragment from intraoperative fracture, particularly when applying cerclage cables. Even in experienced hands, ETO can still result in complications such as nonunion (1.3–1.6 %), fracture (2.4–4 %), superior migration of osteotomy fragment (1.2–6.7 %), and reoperation (2.7–10.2 %) [37, 38].

Acetabular revision pearls and pitfalls

Typically, an isolated liner exchange is all that is needed to address the acetabular side in revision of modular neck THA, as long as the existing acetabular component is well fixed and appropriately positioned. However, stability can occasionally be difficult to achieve in modular neck THA revision, as ALTR can cause destruction of the capsule, short external

rotator complex, and abductor complex [2•, 13, 39]. A variety of implant choices are available to overcome intraoperative instability including jumbo heads, lipped or face changing liners, constrained liners, and dual-mobility constructs. Intraoperative decision-making regarding the appropriate choice of constraint can be difficult in these cases. Depending on their composition, constrained liner systems may be able to avoid issues associated with potential cobalt hypersensitivity. However, they are subjected to significant mechanical forces, primarily via repetitive impingement of the femoral neck, leading to locking mechanism failure, liner dissociation, and acetabular loosening, making them a non-ideal implant in younger, active patients [40, 41].

Dual-mobility constructs have been available in Europe since the 1970s but were only recently approved by the FDA for sale in the USA in 2009. They rely on articulations of a small diameter inner femoral head upon a larger diameter highly cross-linked polyethylene outer head, which itself articulates against a cobalt chrome liner mated to a titanium shell. This provides stability throughout a large arc of motion with minimal neck impingement. Recent reviews of the literature regarding dual-mobility constructs noted survivorship rates ranging from 90.8 to 98 % with 2–8 years of follow-up [42, 43]. However, these implants are not without drawbacks, including intraprosthetic dislocation and the potential for elevated wear rates due to the dual articulation [42–44]. The durability of these implants for revision THA in younger, active patients was examined in a Swedish registry data study which noted that younger patients (ages 50–59 years) were more susceptible to early failure when compared to patients over 75 years of age [45]. Additional drawbacks include the possibility of further metal corrosion and ion release on the backside of a cobalt chrome liner mated to a titanium acetabular component [46, 47], suggesting that dual-mobility constructs may not be ideal in modular neck THA revision.

Many patients presenting with modular neck THAs will have also had dual modular acetabular components implanted at the time of the index procedure, with most of these components osseointegrated at the time of revision surgery. Given

the risk of cobalt hypersensitivity and possibility for corrosion of the acetabular component, some surgeons have elected to eliminate all sources of cobalt and chromium during revision THA. In Walsh's series of 103 revisions of modular neck THAs, the acetabular component was noted to be well-fixed in 98 cases (95.1 %) [17]. However, they revised 43 well-fixed cobalt-containing dual-mobility constructs (42 % cases) due to the possibility of cobalt hypersensitivity. Similarly, in Barlow's series of 59 modular neck THA revisions, 57 cobalt-containing dual-mobility constructs were also revised to minimize the potential of cobalt hypersensitivity [18]. The decision to revise a well-fixed cup should be made preoperatively based on the surgeon's clinical concern for cobalt hypersensitivity and corrosion and in conjunction with the patient's wishes regarding removal of cobalt-containing implants. In the event of planned acetabular revision, the surgeon should be prepared with the appropriate tools available, including acetabular explant devices, high-speed burs, and round acetabular osteotomes. Any acetabular bone loss or defects should be identified on preoperative imaging, in order to have the appropriate implants available. Options for reconstruction depend on the remaining bone stock. Most cups in modular neck THA revision will be well-fixed with minimal bone loss. In this setting, we recommend reconstruction with porous, multi-hole hemispherical acetabular shells with screws in multiple planes to obtain initial stability and promote osseointegration.

There are several pitfalls the surgeon should avoid when performing an acetabular revision. (1) If an isolated liner exchange is planned, the surgeon should take care not to damage the locking mechanism when removing the previous liner. (2) If the cup is being revised, the surgeon should ensure that the osseointegration layer has been sufficiently disrupted prior to forcibly removing the shell, as failure to do so may cause significant bone loss or pelvic discontinuity. (3) Bone defects should be appropriately managed in order to obtain stability of the revision cup. (4) Optimal cup position should not be compromised in order to obtain more coverage as this can lead to increased shear stresses, edge loading, and instability. (5) The use of dual-mobility constructs in modular neck THA revision has not been well studied and should be used with caution.

It is the senior author's preference to revise patients to a ceramic on polyethylene articulation in most cases of modular neck THA revision. If the soft tissue envelope is significantly damaged from ALTR or if hip stability is difficult to achieve, then the senior author uses a dual-mobility construct. Acetabular components are retained as long as they are well-fixed and appropriately positioned.

Conclusions

The management of the patient with a recalled modular neck total hip arthroplasty is fraught with challenges. The surgeon must understand the workup, surveillance, and timing of surgical intervention. Intraoperative decision-making can be difficult due to the presence of well-fixed components. Advanced femoral revision techniques should be used to remove the modular neck femoral stem, and the surgeon should have a low threshold to perform an extended trochanteric osteotomy if removing the stem without one proves difficult. Significant uncertainty still exists with regards to short- and long-term outcomes following revision surgery in these patients. Studies examining these issues will greatly contribute to our ability to counsel patients and modulate their expectations appropriately.

Compliance with ethical standards

Conflict of interest Mitchell C. Weiser reports that he is a member of the AAOS Biomedical Engineering Committee.

Darwin D. Chen reports personal fees from KCI Acelity, outside the submitted work.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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