Surgical technique

Direct Anterior Cup-Half Cage for Revision and Complex Primary Total Hip Arthroplasty: Surgical Technique

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ABSTRACT

As surgeons’ comfort with the direct anterior approach (DAA) for total hip arthroplasty continues to increase, there is a growing interest in performing complex surgeries through this approach. Acetabular bone loss and/or pelvic discontinuity in the primary or revision setting often requires specialized implants such as a cup-cage construct. We describe our surgical technique for implanting modified cup-half cages through the DAA and show 2 case examples of how this technique was utilized in the setting of complex acetabular bone loss. In our experience, this is an effective method for complex total hip arthroplasty, with the potential added benefits of the DAA of reduced soft-tissue dissection, direct measurement of leg length, and ease of fluoroscopic navigation for implant positioning.

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Introduction

The incidence of primary total hip arthroplasty (THA) continues to rise significantly, with a resultant higher demand for revision hip surgeries [1,2]. The direct anterior approach (DAA) through the Smith-Peterson interval has become increasingly common for primary THA in recent decades [3,4]. Compared to the posterior approach, the minimally invasive DAA may allow faster recovery with reduced hospital stays and improved functional outcome, particularly in the early postoperative period [5]. The learning curve for the DAA is significant, and thus, complication rates are reduced as surgeons gain more experience with the approach [3]. The extensile DAA has further expanded indications for the anterior approach to include revision hip surgeries [6]. Knowledge of the extensile DAA is also important in primary THA when intra-operative complications arise [7,8].

In the setting of revision THA with acetabular bone loss, a majority of defects can be treated with a hemispherical cup and screws alone, with good results even when <50% contact exists between implant and bone [9,10]. However, complex acetabular bone loss (Paprosky 3A, 3B), particularly pelvic discontinuity (PD), often requires additional fixation techniques [11,12]. In 2005, the cup-cage construct was introduced by Hansen and Lewallen [12]. A trabecular metal (TM) cup is first implanted with screws, and an antiprotrusio cage is then placed atop the cup. The cage provides additional initial stability for the cup ingrowth while the cup then seeks biological integration and, therefore, long-lasting fixation [12]. Early studies have shown promising results for cup-cage constructs in treating complex acetabular bone loss [12]. More recently, promising results have been shown with the use of only the iliac portion of the antiprotrusio cage in these cup-cage constructs [11].

Recent literature describes the use of DAA in multiple revision settings, including cup revisions, acetabular augments, and triflange implants [5,13–16]. A recent review article by Siddiqi et al. includes a radiographic example of a cup-cage construct performed through an extensile DAA [17]. However, their article is a broad overview of revision through DAA, not a specific discussion of the cup-cage technique in this setting [17]. We are not aware of any other literature describing the use of the extensile DAA with a true cup-cage construct. In this article, we detail our surgical technique and show 2 case examples in which a cup-cage construct was used with the extensile DAA in the setting of complex acetabular bone loss.

Surgical technique

Patient positioning

DAA revisions can be performed using a standard operating room table or a dedicated traction table (HANA table; Mizuho OSI, Utah, USA).
Union City, CA). While there are advantages to each, our preference is to use a standard table such as a radiolucent flat top table (Modular Table System; Mizuho OSI, Union City, CA) or a standard operating table (AMSCO Surgical Table; Steris Healthcare, Mentor, OH) with both legs prepped into the surgical field and table leg flexion allowing for better femoral access in our hands (Fig. 1).

Having both legs prepped in allows for easy clinical determination of leg lengths, which is especially useful in revision settings where there may be a loss of normal proximal femoral architecture to use for radiographic leg length determination. After the anterior approach to the hip is performed, the surgical limb can be flexed, externally rotated, and adducted across the contralateral limb. This position relaxes the femur so that the retained stem can be moved posteriorly behind the posterior wall of the acetabulum, fully exposing the articular surface and part of the posterior wall, column, and ischium. Between those 2 options, a radiolucent table allows for extensive fluoroscopic imaging without C-arm impingement, making imaging for column and pubis screws more easily visible. Conversely, a standard operating table can interfere with imaging but makes it possible to drop the foot of the table, allowing for extension of the hip to improve femoral exposure for femoral instrumentation as needed. To overcome this disadvantage, the standard table can be flipped such that the base is toward the head and there is more room distally under the table for the fluoroscope to maneuver (Fig. 2).

**The approach**

The standard and extensile DAAs are well described and utilize the Huerter (Smith-Peterson) interval between the tensor fascia lata (TFL) and sartorius [7,18]. With careful, deliberate extension in a step-wise fashion as outlined below, almost any acetabular defect can be addressed. A standard DA incision is drawn out with the addition of a proximal segment extending to curve along the outer border of the iliac crest (Fig. 3). This allows for access of the TFL origin just posterior to the anterior superior iliac spine. A tenotomy of the leading edge of the TFL origin on the pelvic brim can be performed to improve visualization and excursion (Figs. 4 and 5). This can later be directly repaired as long as an adequate cuff of soft tissue is left. We use a vicryl whip-stitch of the TFL tendon edge as a rip stop stitch for later closure of the pelvic brim soft tissue. TFL release also aids with femoral exposure if femoral revision is also performed. If further femoral mobilization is necessary, the incision can be extended distally along the posterolateral aspect of the femur. The iliotibial (IT) band can be found by tracing TFL distally and incised longitudinally to relax the TFL proximally. It is important to note that the TFL insertion into the IT band should not be released from the IT band, but rather the longitudinal incision in the IT band should be made just anterior to the TFL insertion. The capsular ligaments (pubofemoral, medial iliofemoral) can also be released from the femoral neck to further mobilize the femur.

For placement of a cup-cage construct, it is necessary to expose the supraacetabular region of the outer table of the ilium. The TFL release exposes the underlying abductor musculature, which can be subperiosteally elevated as a single sleeve to allow for implant placement. The abductor origins are proximal to our working cup/cage window and thus are not violated. Due to the anterior position of the half cage and its relatively small footprint, only a small portion of gluteus minimus requires elevation (Figs. 6-8). Avoiding a longitudinal split of the abductors also minimizes the risk of injury to the superior gluteal neurovascular bundle [19]. The superior gluteal nerve (SGN) exits the sciatic notch and immediately rises above the minimus and runs between the minimus and medius muscle bellies, eventually innervating the TFL. This exposure enables adequate exposure without significant risk to the SGN.

**Figure 1.** Example of both legs prepped into the field to allow for leg length testing at the heels. Positioning of the fluoroscopy equipment is also demonstrated.

**Figure 2.** A standard operating table with base turned toward the head to allow for fluoroscopic imaging of the entire pelvis. A Montreal post can be placed midline as a peroneal post to allow for traction without the patient drifting down the table.

**Figure 3.** The planned incision: a standard DA approach with proximal extension, curving along the iliac crest.
via traction or direct injury and eliminates the need for postoperative abductor limitations.

Further exposure is possible if access to the inner table is required such as in cases of pseudotumor decompression or with intrapelvic cup migration. Sartorius origin and external obliques can be taken down in a single sleeve or as part of a digastric anterior superior iliac spine osteotomy. If further access is still required, iliacus can be elevated. Intrapelvic iliac vessel protection can be facilitated when cup screws are directly adjacent. Finally, in chronic intrapelvic cup migration, the cup and femoral head can be trapped in the pelvis. A tenotomy of rectus allows for external rotation of the femur and liberation of the construct. In many cases only the previously described TFL tenotomy is necessary for visualization. Figure 9 demonstrates how TFL can be repaired back to its origin at the time of closure (Fig. 9).

Cup-cage specifics

The extensile DA approach described above is well-suited for the implantation of a cup-cage construct and allows exposure of the ischium, pubis, and anterior ilium, which can be easily palpated or visualized. After adequate exposure, the acetabulum is prepared by reaming for a hemispherical cup. A trial cup implant is placed, and the optimal positions for ischial and pubis screws are identified and marked on the trial with a pen using a combination of fluoroscopy, palpation, and direct visualization. Of note, the position of the cup often has more neutral version and vertical inclination than normal—this is due to the fact that the cage overlaps the cup superiorly and posteriorly. This effectively increases the inclination, decreases the anteversion, and ultimately allows for the cage to be placed directly on iliac bone without gapping.

We use fluoroscopy, obtaining inlet and outlet views to guide drilling of the pubis. Once intracortical position of the drill is determined with fluoroscopy, a short k-wire can be placed to hold the position. The screw positions from the trial implant which were previously marked are then translated to the real implant, adding additional holes as needed (Often, the pubis and ischial screws are added closer to the rim of the cup due to deep cup positioning.) using a metal cutting burr on a mayo stand away from the patient. The cup orientation is chosen in order to maximize pre-existing screw holes and bony cup contact and to permit cage placement from dome to ilium. The floor of the previously reamed acetabulum is filled via gentle reverse reaming with a mixture of cancellous bone chips, demineralized bone matrix, and vancomycin powder.

The final implant is impacted into the previously determined orientation over the previously placed k-wire in the pubis and then impacted with a 40-mm head impactor (the TM cup ring already

Figure 4. Location of the tenotomy at the TFL origin drawn in black (just posterior to the anterior superior iliac spine) leaving a small cuff of tissue for later repair.

Figure 5. Capsular exposure with the TFL origin released; scissors pointed to rectus tendon.

Figure 6. Cup in place, showing the exposed surface of the ilium where the half-cage will rest. Please note the intact abductors (manually retracted by digit) which have been partially peeled off the bony surface allowing exposure for cage placement. The superior gluteal nerve is on the outer surface of the muscle belly and thus protected.

Figure 7. The cup and contralateral half-cage in position. The half-cage is positioned on the outer table of the ilium deep to the abductors and TFL.
having been removed) with screws placed, first the pubis, then the dome, and then the ischial screws (Figs. 10 and 11. Fluoroscopy is then used to verify screw position and length using inlet, outlet, and Judet views prior to placement of the cage. At least 1 or 2 dome screw holes are left vacant for placement of screws that will pass through both Figure 9 cup and cage to unitize the construct. Often the screw is placed though the cup first and verified with fluoroscopy and then removed for placement of the cage.

Occasionally a trial cage is opened and molded to match the cup/iliac contour. With experience, a trial step is eliminated, and we open up the real cage implant, usually one size larger than what is designated for the implanted cup as removing the inferior portion will reduce the diameter of the cage in the cup. We use a cage for the contralateral side (ie, a right cage for a left hip) and cut it in half in the style mentioned by Sculco et al. [11] (Fig. 12). The shape of the contralateral-sided cage allows the superior flange to sit more anterior in the supra-acetabular region and allows for safer and simpler screw placement using the DAA extensile exposure (Fig. 13). Once the cage trial has been cut in half, it is placed into the dome of the trial cup and molded superiorly to the shape of the exposed ilium. In cases where the cage seems to be overstuffing the cup, we have cut the cage trial down to one-third of its original size without any early mechanical failures to permit an even larger liner to be cemented in. The trial implants are then removed, and the real implants opened. The cage, after being cut on a spare mayo stand and molded to match the trial, is positioned in the cup. Supraacetabular and then superior flange screws are placed through the cage and the positions/lengths confirmed using obturator and iliac oblique fluoroscopic views. Finally, a liner with its back surface roughened with a saw is cemented into the cup-cage construct (Fig. 14). Alternatively, a cemented dual mobility construct can be used. It can be difficult to assess liner inclination and version when cementing, so we often use a liner impactor to position and hold the liner in place. It is important to avoid overly increasing the version of the liner, which can increase the risk for posterior impingement and anterior dislocation.

Case examples

Case 1

Case 1 is a 72-year-old female with polymyositis who had a primary left THA performed in 2011. Her postoperative course was complicated by recurrent dislocations and 3 revision surgeries over the next 2 years. The patient presented to our clinic in 2019 with the complaint of anterior and lateral left hip pain associated with locking and catching. She had significant postural weakness on examination secondary to polymyositis. In the standing position, her imaging showed an outlet view of the pelvis with posterior tilt causing significant cup anteversion and inclination (Fig. 15). In the supine position, her imaging showed an inlet view of the pelvis with notably less anteversion and inclination (Fig. 16). Preoperative CT scan showed loosening of her acetabular component and a Paprosky 3B acetabular defect with superomedial acetabular erosion and PD (Fig. 17). We attributed her symptoms to acetabular component loosening and aberrant cup positioning, particularly in the standing position, causing eccentric poly wear and anterior instability. Inflammatory labs were obtained and within normal limits, suggesting aseptic loosening rather than infectious etiology.
We therefore felt she was indicated for a revision THA with cup-cage construct given her severe acetabular defect.

We performed an extensile DAA in our standard fashion, with partial reflection of TFL off of the anterior superior iliac spine to improve exposure. We noted that the anterior wall of the acetabulum had been previously reamed away and the acetabular component had been placed in nearly 90 degrees of anteversion with significant inferior impingement noted intraoperatively. The acetabular cup was loose, and we removed it without difficulty. We implanted a press-fit Zimmer Biomet TM cup (ZimmerBiomet, Warsaw, IN) with a contralateral half cage (Fig. 18). We cemented a dual-mobility liner into place with appropriate abduction and version and impacted a new metal head on the retained femoral stem. Postoperatively, we made the patient 50% weight-bearing for 2 weeks followed by full weight-bearing with anterior hip precautions. At her most recent in-person follow-up visit 1 year after surgery, she was doing well without complications. At 2 years postoperatively, she was contacted via telephone—at this time, she reported no dislocations, infections, or reoperations.

Case 2

Case 2 is a 93-year-old male who sustained a left minimally displaced acetabular fracture in 2019 after a ground-level fall. He was initially treated nonoperatively by outside care providers but presented to our clinic 5 months later with increasing pain and inability to bear weight. Imaging at that time showed nonunion of the acetabular fracture with dome impaction, progressive superomedial migration of the femoral head, acetabular protrusion, a Paprosky 3b defect, and advanced osteoarthritis (Fig. 20). We felt that the appropriate treatment at this time would be a THA with cup-cage fixation for increased acetabular stability.

We performed a DAA in our standard fashion without the need for additional extensile exposure techniques. We reamed the

Figure 11. A left hip with a right-sided half-cage trial. The superior flange sits more anteriorly than with an ipsilateral half-cage.

Figure 12. Intraoperative image, left hip: Zimmer TM cup with contralateral half cage. Pubis rim screw and iliac wing fixation through the half cage can be visualized.

Figure 13. Example of our sequence for pubis screw insertion through the predrilled holes in the cup. The hole is drilled, and correct location confirmed with fluoroscopy (not shown). The cup is then placed over the drill bit to assure that it will fit appropriately with one of the predrilled holes lining up with the drill trajectory for the pubis screw (a). The drill bit is then removed, the depth measured (b), and the cup and screw placed (c). This example demonstrates the use of fluoroscopy with posterior approach discontinuity treated with posterior column plate and cup-cage.
acetabulum and then placed femoral head autograft and 30cc of allograft to augment the acetabular bone loss. We implanted a press-fit Zimmer TM cup with a contralateral half cage and multiple screws in the pubis, ilium, and ischium. We cemented a neutral polyethylene liner into the cup-cage construct with appropriate version and inclination. We then addressed the femur with a Zimmer Avenir (ZimmerBiomet, Warsaw, IN) cemented stem. Postoperatively, we made the patient 50% weight-bearing with no formal hip precautions. At his most recent follow-up visit at 6 weeks, he was doing well without additional complications (Fig. 21). His subsequent 6-month follow-up visit was performed with a surgeon in his home state who reported he was doing well; the patient could not be reached for further questioning.

**Discussion**

With the rising popularity of the DAA for primary THA over the last 2 decades, there has been growing interest in its utility in revision settings. Revision THA is known to have significantly higher complication rates than primary THA. Dislocation is the most common complication, often attributed to greater soft-tissue damage and scarring after revision surgery, resulting in muscle weakness [13,20]. The posterior approach in particular is associated with higher postoperative dislocation rates in revision surgery than the DAA [20,21]. In one large retrospective study of 468 patients, authors noted less extensive soft-tissue dissection and substantially less resultant scar tissue during the extensile DAA than the posterior approach in revision THA [6]. This allowed for faster recovery.

![Figure 14](image14.png)

**Figure 14.** Intraoperative image, left hip: Cup-cage construct with cemented polyethylene liner in place. Adjustments to acetabular version are performed independent to the cup and cage via the cemented liner.

![Figure 15](image15.png)

**Figure 15.** a, b: Preoperative radiographs, standing; AP (a) and lateral (b) view.

![Figure 16](image16.png)

**Figure 16.** a, b: Preoperative CT scout view, supine; AP (a) and lateral (b) view.
postoperative mobilization and ultimately resulted in zero dislocation events within the first 6 months after extensile DAA [6]. The soft-tissue dissection of abductor musculature to gain acetabular exposure has implications not only with muscle damage but also nerve injury. The posterior approach involves a gluteal split exposure, which often causes traction on the SGN. In contrast, the extensile DAA approach utilizes a gluteal elevation technique to access the outer table of the ilium. This avoids traction to the SGN and potentially reduces risk of nerve injury [19]. We therefore propose that a key advantage of the extensile DAA approach is fewer postoperative complications, particularly fewer dislocations and SGN injuries.

Another advantage of the anterior approach in the revision setting is excellent acetabular exposure. The minimally invasive DAA can provide satisfactory acetabular exposure for liner exchanges and certain cup revisions [7]. The extensile DAA can be used for all other complex acetabular cup revisions, with proximal extent achieved by TFL tenotomy at its origin and subperiosteal elevation of the abductor musculature. Patient positioning in the DAA is also advantageous for acetabular cup placement. With the patient positioned on a standard operating table, both legs can be prepped in for accurate clinical evaluation of leg length. Intraoperative fluoroscopy allows for evaluation of implant cup and screw placement as well as radiographic leg length and offset assessment. Horsthemke et al. studied a population of 48 patients undergoing aseptic cup revisions via the DAA and found that 87.5% were placed within the Lewinnek “safe zone” [13]. Of note, the validity of the Lewinnek “safe zone” is debated, as the majority of THA dislocations still fall within the safe zone [22]. More importantly, Horsthemke et al. reported zero postoperative dislocations with a mean follow-up of 65 months [13]. We believe that the combination of posterior capsule and external rotator preservation and fluoroscopic evaluation allows for a unique advantage in revision arthroplasty via the extensile DAA.

Limited additional studies exist reporting outcomes using the DAA in revision acetabular surgery. Thaler et al. reported promising midterm outcomes using the DAA for complex acetabular revisions with reconstruction cages and impaction grafting [5]. In a cohort of 64 patients, 6 patients required revision: 2 implant failures, 2 recurrent dislocations, and 2 prosthetic joint infections [5]. Other data on the extensile DAA in the revision setting have been limited to case studies and reports. Honcharuk et al. described the use of the extensile DAA in 3 patients who required acetabular augmentation for lateral rim defects [15]. Ramsey et al. described the use of the DAA on one patient who required a custom triflange component in the setting of PD [16]. Spanyer et al. described the use of the extensile DAA in 5 patients for placement of an anterior column plate [23]. Thus far, authors of case studies and reports describe promising outcomes with the use of the extensile DAA for revision acetabular surgery.

In the revision setting, significant acetabular bone loss increases the complexity of implant positioning and available constructs for reconstruction [13]. Several implant options exist to accommodate for severe bone loss or PD. These include highly porous hemispherical cups, metal acetabular augments combined with revision cups, custom triflange constructs, and cup-cage constructs. While many options exist, no real consensus exists on the ideal implant; surgeon experience, expertise, and patient-specific defects and bone quality lead to a rational variability in surgical solutions. Cup-cage constructs are a reliable option even in cases of PD, resulting in comparatively low rates of acetabular loosening and dislocation [24]. One systematic review performed by Wang et al. analyzed 11 studies and 232 patients with severe acetabular bone loss (AAOS III, IV; Gross IV, V; Paprosky 3A, 3B) treated with cup-cage constructs [12]. They report a revision rate of 8% and all-cause complication rate of 20%, most commonly dislocation (9%) and aseptic loosening (9%) [12]. Another systematic review performed by Changjun et al. evaluated outcomes of 151 cup-cage constructs across 6 different studies in the setting of chronic PD [25]. The overall complication rate was 23.8%, with 13.2% of cup-cage constructs requiring revision. Component loosening/screw breakage was the most common complication at 10.6%, followed by dislocation at 4%, and infection at 4%. The revision-free survivorship of the

![Figure 17. a, b: Preoperative CT scan with illustrative coronal (a) and axial (b) slices.](image)

![Figure 18. Postoperative radiograph.](image)
implant was 90.1%, which is consistent with or improved compared with that of other treatment methods [25]. Finally, a retrospective review by Sayac et al. studied a cohort of 77 revision THAs with severe acetabular bone loss (Paprosky ≥ 2C) [24]. They found a 3.89% aseptic loosening rate, 9.45% dislocation rate, and 1.3% chronic instability rate in this population [24].

In comparison, the following rates of aseptic loosening described with other implants are reported: 5.3% TM, 1.5%-9% jumbo cups, 0%-11.5% triflange component. The following rates of chronic instability in other implants are reported: 2.5% TM, 7.1% jumbo cups, 10.9% triflange components [26–28]. Ultimately, cup-cage constructs have comparable if not lower complication rates of aseptic loosening and dislocation as other accepted implant options in revision surgery for severe acetabular bone loss.

The use of the cup-cage construct can be technically challenging, particularly in the exposure and placement of the ischial flange component. Exposure of the ischial flange risks iatrogenic sciatic nerve injury while impaction of the flange onto the bone risks iatrogenic pelvis dissociation [11]. Sculco et al., therefore, describes a half cup-cage modification technique that utilizes a single iliac flange in an attempt to reduce these intraoperative complications [11]. The series of Sculco et al. comparing half cup-cage and full cup-cage demonstrated equal if not superior outcomes for a half cup-cage with fewer revisions and less iatrogenic nerve injury [11].

In this study, we chose 2 representative cases to demonstrate the described technique in the setting of significant acetabular bone loss. We acknowledge that the follow-up for these patients was limited and lacked patient-reported outcome scores. Cases requiring this type of intervention are often complex, and the intervention itself still relatively rare. While the lack of follow-up is a significant limitation, we still felt that these cases demonstrate our described technique.

Thus far, we have described our personal experience and the literature in support of the extensile anterior approach in revision acetabular surgery. However, we acknowledge that other approaches may be better utilized in certain revision settings. First, an alternate approach may be preferred in certain obese patients with significant pannus. Incisions involving the pannus can increase the risk of wound complications. This can be mitigated in many patients, but not all, by angling the incision laterally to avoid crossing the pannus crease. Second, an alternate approach might be considered in cases involving complex femoral revisions. The use of the extensile DAA for complex femoral revisions including extended trochanteric osteotomy has been described and can be performed safely, without injuring the nearby neurovascular structures, by surgeons familiar with the technique and surrounding anatomy [6–8,17,18,29]. However, surgeons without adequate prior exposure to this technique may find it difficult to safely perform an extended trochanteric osteotomy or the extensile
soft-tissue dissection necessary to achieve adequate femoral exposure through the DAA. This may be encountered in revisions of long porous coated femoral stems, marked retroversion of the femoral stem, and significant proximal femur bone loss [7]. Without adequate femoral exposure, instrumentation of the femur risks intraoperative femur fracture. We recommend that, in these complex cases, the surgeons use the approach that they are the most comfortable with to avoid intraoperative complications. Third, a posterior approach is preferred in cases that require extensive access to the posterior column. This is seen in cases of posterior column reconstruction or hardware removal [17]. Lastly, alternative approach should be considered until a surgeon feels that he or she has mastered the anatomy of the DAA, understands the complexity of implant positioning via direct visualization and fluoroscopy, and feels comfortable addressing any intraoperative complications through the DAA.

Summary

The number of primary THAs performed through the DAA continues to rise annually alongside the increasing need for revision surgery. As surgeons become more comfortable with the DAA, they are performing more complex revisions through this interval with promising outcomes. Benefits of the DAA include arguably reduced soft-tissue dissection, with preservation of the hip’s posterior capsule and external rotators, and supine positioning, which facilitates fluoroscopic guidance of implant positioning and leg length determination. We find the extensile DA approach to be especially useful when implanting a cup-cage construct using a contralateral half-cage as described in our technique section. We believe that with proper technique and revision skill set, many revision surgeries can be safely performed through the extensile DAA.

Conflict of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: J. Gilliland received royalties from OrthoGrid; is a paid consultant for DJ Orthopaedics, OrthoGrid, Smith & Nephew, Stryker, and Medacta; has stock options in OrthoGrid and CON-extensions; receives research support from Zimmer Biomet and Stryker; is in the editorial or publications board of Journal of Arthroplasty; and is a board member in AAHKS and AAOS. L. Anderson is a paid speaker and a paid consultant for Medacta; has stock options in OrthoGrid; and receives research support from Zimmer Biomet and Stryker.

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Informed patient consent

Please refer to Elsevier’s policy regarding written patient consent requirements: https://www.elsevier.com/about/policies/patient-consent#:~:text=That%20individual%2C%20legal%20guardian%20or, writing%20of%20all%20such%20conditions

The authors declare that informed patient consent was not provided for the following reason: This study was deemed exempt by the University of Utah Institutional Review Board (IRB#00071733).

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