Current Controversies in Joint Replacement
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Current Controversies in Joint Replacement

Editors
Matthew S Austin MD
Gregg R Klein MD

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Dedication

Matthew S Austin
Dedicated to my parents for their constant support, love, and inspiration throughout my life

Gregg R Klein
To my wife, Julie, and our daughters, Samantha and Sydney, for their love, patience, and never-ending support
Also dedicated to the memory of my father, Allan Klein, for his love, guidance, and encouragement

Drs Austin and Klein would also like to express their sincere appreciation to the talented contributors to World Clinics in Orthopedics, without whom this wonderful work would not have been possible
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Editorial

World Clinics in Orthopedics is intended as a practical resource for both orthopedic surgeons in practice and in training. It is a detailed overview of the newest information in the field of orthopedics, arranged by subspecialty.

We have sought to provide the reader with the most pertinent and recent developments written by thought leaders in each of the major orthopedic subspecialties: spine, hip preservation, hip and knee arthroplasty, sports medicine, shoulder and elbow, foot and ankle, hand and wrist, oncology, trauma, pediatrics, and basic science. Furthermore, we are excited to have contributions from internationally renowned surgeons in Europe, Asia, and Central and South America. This lends a truly international perspective to this work and alerts the reader to challenges faced by surgeons the world over.

It is our sincerest hope that World Clinics in Orthopedics will serve as a compendium of the newest in orthopedic knowledge. We hope that you, the reader, will find this as a unique, practical source for the latest information as you care for your patients.

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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3D</td>
<td>Three-dimensional</td>
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<tr>
<td>ACL</td>
<td>Anterior cruciate ligament</td>
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<tr>
<td>ALVAL</td>
<td>Aseptic lymphocytic vasculitis-associated lesion</td>
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<td>AP</td>
<td>Anteroposterior</td>
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<tr>
<td>ASIS</td>
<td>Anterior superior iliac spine</td>
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<td>AVN</td>
<td>Avascular necrosis</td>
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<tr>
<td>BMI</td>
<td>Body mass index</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<tr>
<td>COC</td>
<td>Ceramic-on-ceramic</td>
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<tr>
<td>COP</td>
<td>Ceramic-on-polyethylene</td>
</tr>
<tr>
<td>COX-2</td>
<td>Cyclooxygenase-2</td>
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<tr>
<td>CPE</td>
<td>Conventional polyethylene</td>
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<td>CR</td>
<td>Cruciate-retaining</td>
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<tr>
<td>CRP</td>
<td>C-reactive protein</td>
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<tr>
<td>CT</td>
<td>Computed tomography</td>
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<td>DAA</td>
<td>Direct anterior approach</td>
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<td>DVT</td>
<td>Deep vein thrombosis</td>
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<tr>
<td>ESI-TOF-MS</td>
<td>Electron spray ionization time-of-flight mass spectrometry</td>
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<td>ESR</td>
<td>Erythrocyte sedimentation rate</td>
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<tr>
<td>FAI</td>
<td>Femoral acetabular impingement</td>
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<tr>
<td>FDA</td>
<td>Food and Drug Administration</td>
</tr>
<tr>
<td>FNB</td>
<td>Femoral nerve block</td>
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<tr>
<td>FRR</td>
<td>Failure rate ratio</td>
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<td>HHIS</td>
<td>Harris hip score</td>
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<td>HOOS</td>
<td>Hip disability and osteoarthritis outcome scores</td>
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<td>HXPE</td>
<td>Highly cross-linked polyethylene</td>
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<tr>
<td>IL</td>
<td>Interleukin</td>
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<tr>
<td>LCE</td>
<td>Lateral center-edge</td>
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<tr>
<td>LFCN</td>
<td>Lateral femoral cutaneous nerve</td>
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<tr>
<td>MI</td>
<td>Minimal incision</td>
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<td>MIS</td>
<td>Minimally invasive surgery</td>
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<td>MOM</td>
<td>Metal-on-metal</td>
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<tr>
<td>MOP</td>
<td>Metal-on-polyethylene</td>
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<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
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<tr>
<td>MRSA</td>
<td>Methicillin-resistant <em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td>NSAID</td>
<td>Nonsteroidal anti-inflammatory drug</td>
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<tr>
<td>OA</td>
<td>Osteoarthritis</td>
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<tr>
<td>ON</td>
<td>Osteonecrosis</td>
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<td>OR</td>
<td>Operating room</td>
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<tr>
<td>PA</td>
<td>Posteranterior</td>
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<tr>
<td>PAO</td>
<td>Periacetabular osteotomy</td>
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<tr>
<td>PCL</td>
<td>Posterior cruciate ligament</td>
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<tr>
<td>PCR</td>
<td>Polymerase chain reaction</td>
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<tr>
<td>PDPH</td>
<td>Postdural puncture headache</td>
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<tr>
<td>PE</td>
<td>Pulmonary embolism</td>
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<tr>
<td>PFA</td>
<td>Patellofemoral arthroplasty</td>
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<tr>
<td>PGE2</td>
<td>Prostaglandin E2</td>
</tr>
<tr>
<td>PMN</td>
<td>Polymorphonuclear neutrophil</td>
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<tr>
<td>POM</td>
<td>Polyethylene-on-metal</td>
</tr>
<tr>
<td>PRN</td>
<td>Pro re nata</td>
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<tr>
<td>PROSTALAC</td>
<td>Prosthesis with Antibiotic-loaded Acrylic Cement</td>
</tr>
<tr>
<td>PS</td>
<td>Posterior stabilized</td>
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<tr>
<td>PSI</td>
<td>Patient-specific instrumentation</td>
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<tr>
<td>RCT</td>
<td>Randomized clinical trial</td>
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<tr>
<td>RMS</td>
<td>Root mean square</td>
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<tr>
<td>ROM</td>
<td>Range of motion</td>
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<tr>
<td>RR</td>
<td>Relative risk</td>
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<tr>
<td>RSA</td>
<td>Radiostereometric analysis</td>
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<tr>
<td>SCFE</td>
<td>Slipped capital femoral epiphysis</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SF-36</td>
<td>Short Form 36</td>
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<tr>
<td>TAA</td>
<td>Total ankle arthroplasty</td>
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<tr>
<td>TFL</td>
<td>Tensor fascia lata</td>
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<tr>
<td>THA</td>
<td>Total hip arthroplasty</td>
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<tr>
<td>THR</td>
<td>Total hip replacement</td>
</tr>
<tr>
<td>TJA</td>
<td>Total joint arthroplasty</td>
</tr>
<tr>
<td>TKA</td>
<td>Total knee arthroplasty</td>
</tr>
<tr>
<td>TKR</td>
<td>Total knee replacement</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>TSS</td>
<td>Tissue-sparing surgery</td>
</tr>
<tr>
<td>UHMWPE</td>
<td>Ultrahigh molecular weight polyethylene</td>
</tr>
<tr>
<td>UKA</td>
<td>Unicompartmental knee arthroplasty</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual analog scale</td>
</tr>
<tr>
<td>VMO</td>
<td>Vastus medialis obliquus</td>
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<tr>
<td>VTE</td>
<td>Venous thromboembolism</td>
</tr>
<tr>
<td>WBC</td>
<td>White blood cell</td>
</tr>
<tr>
<td>WOMAC</td>
<td>Western Ontario and McMaster Universities Arthritis Index</td>
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Hard-on-hard Bearing Surfaces in Total Hip Arthroplasty: What to Do When It All Goes Wrong

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ABSTRACT

Total hip arthroplasty (THA) is being performed at increasing rates with excellent results being reported in the vast majority of patients. Despite these encouraging results, long-term follow-up has targeted the bearing surface as the weakest link in the system. Continuous efforts are being put forth to improve upon both performance and survivorship of primary THA; as a result, developments, such as hard-on-hard bearing, were developed to solve the “wear issues”. Early enthusiasm for these so-called alternative bearings has been tempered by the development of unique complications and reports of early failure mechanisms. The following article will discuss the background, workup of hard bearing complications, and their treatments when trouble arises.

INTRODUCTION

In the United States, the prevalence of total hip arthroplasties (THAs) being performed continues to increase at a rapid rate with favorable results being reported in the majority of patients.1 Furthermore, demographic studies have predicted the rate of THAs to increase exponentially over the next two decades, as a greater number of patients are entering the elderly population range.1 Despite the clinical success of THA, continuous efforts are being set forth to improve the performance and longevity of these implants as indications for primary surgeries have expanded to younger and more active patients. Such endeavors have included
the advent of “hard-on-hard” bearings to address the potential shortcomings of such standard “soft bearings” like metal-on-polyethylene (MOP) [this includes standard ultrahigh molecular weight polyethylene (UHMWPE)].

The two most commonly utilized “hard-on-hard” articulations include metal-on-metal (MOM) and ceramic-on-ceramic (COC) bearing surfaces\(^2\) (Figures 1 and 2). Moreover, in the search for the ultimate bearing surface, the advent of diamond, ceramicized metal, and ceramic-on-metal bearings are currently being investigated as viable alternatives to enhance the longevity of primary THA components.

Advantages of these bearing surfaces are predicated on decreased wear rates; therefore, potentially culminating in improved survivorship.\(^3\)–\(^5\) Other attractive features of these bearing surfaces, including greater hip stability with MOM THA, as larger femoral heads, can be utilized to improve the head-to-neck ratio and jump distances. Unfortunately, as short- and mid-term follow-up has demonstrated,
unforeseen and unique complications can arise with these new technologies.6-9 Understanding these failure mechanisms may lead to future improvements in the next generation of alternative bearing surfaces.

**METAL-ON-METAL TOTAL HIP ARTHROPLASTY**

Metal-on-metal THA is not a novel concept as early generations of these bearing surfaces were utilized in the past with limited success. These early MOM designs were essentially abandoned secondary to their high failure rates, and the improved results demonstrated with MOP bearings at the time.6 The major issues with these early generation MOM bearings were poor manufacturing and engineering processes.2 Recently, MOM bearings experienced a revival as a result of improved metallurgy and fabrication techniques, and a potential to remedy the conundrum of THA instability.2 Another potential advantage hinges on the favorable wear rates of MOM THA (in simulator modules) as compared to more traditional MOP bearing surfaces, leading to the speculation of greater long-term survivorship.3-5 Furthermore, hip resurfacing further contributed to the resurgence of these articulations with the proposed advantages of bone preservation, improved stability, greater range of motion, and more natural kinematics (Figure 3). The allure of a greater range of motion, enhanced stability, and low wear rates made MOM bearings a viable alternative, especially in younger and more active patients with osteoarthritis of the hip.

In registry and early clinical data, it was noted that MOM THAs may be associated with several unique concerns not commonly experienced in the past. Multiple reports have since described the occurrence of increased serum cobalt and chromium levels in patients with MOM bearing surfaces.6,7 The long-term consequences of this phenomenon are currently unknown due to the lack

Figure 3: Birmingham hip resurfacing.
of long-term data with these newer implants. Fortunately, thus far, a direct relationship between elevated serum ion levels and malignancy or deleterious systemic effects has not been definitively proven. However, there have been case reports of potential systemic issues that have been observed, such as acute renal failure and neurological illnesses seen with elevated ion levels.\(^{10,11}\) Furthermore, these metal ions do cross the placenta and thus implantation of MOM THAs is not recommended in women of child-bearing age.\(^{12}\)

Again, true validity and a direct causal relationship of these happenstances are not possible without further investigation and cases demonstrating similar findings. Despite a paucity of reports on systemic issues, there are a plethora of reports in the literature discussing localized effects and morbidity associated with metal sensitivity, metallosis, newly described pseudotumors, and aseptic lymphocytic vasculitis-associated lesions (ALVALs)\(^{6-9,13-18}\) (Figure 4). As a result, revisions of MOM THAs are being undertaken for reasons rarely if ever encountered before. There is a wide spectrum of presentation of adverse local tissue reactions, many attributing the etiology to be related to component malposition, female gender, and femoral head size.\(^{19,20}\) Additionally, important consideration must be placed on manufacturer design, recent implant recalls, and the material science associated with components with such unacceptable high early failure rates.\(^{21,22}\)

**CERAMIC-ON-CERAMIC BEARINGS**

Like MOM bearings, the impetus behind the development of COC bearings was to improve upon UHMWPE wear and THA survivorship. Similar to MOM
bearings, unforeseen complications surfaced throughout the short- and mid-term follow-up of these implants. With early generation COC bearings, femoral head and/or liner fracture was a serious cause for concern with reported rates as high as 13.4% in ceramic heads manufactured before 1990. This concerning fracture rate was in part due to materials that were manufactured by companies that are no longer in the current market. With later generations of ceramic heads, this occurrence has decreased exponentially to a reported rate of 0.004%. Fortunately, this risk of fracture has been reduced significantly, and newer generation ceramic bearings have demonstrated improvement in performance compared to older generation ceramic femoral heads. The conundrum behind ceramic femoral head fracture lies in the exorbitant amount of ceramic debris encountered at the time of revision surgery as well as determining the best articulation couple for the subsequent revision THA. Often, complete removal of debris is not possible and a substantial risk for third-body wear as well as an adverse local tissue reaction (pseudotumor) remains.

**DIAGNOSIS**

In terms of establishing a diagnosis for the painful hard-on-hard bearing THA, both COC and MOM must be discussed individually based upon their unique failure mechanisms. First and foremost, as with all painful THAs, infection must be ruled out prior to revision surgery, starting with a laboratory assessment to include a sedimentation rate and C-reactive protein (CRP) as well as hip aspiration and cell count when appropriate. Particularly with adverse tissue reactions, purulent looking material may be associated with necrotic cells and not infection when found during aspiration.

**Evaluation of Painful Metal-on-metal Total Hip Arthroplasty**

With regards to establishing a diagnosis for painful MOM THA, we have reported on a detailed algorithm to workup this situation (Figure 5). In the past, MOM complications were considered a diagnosis of exclusion once more common reasons for THA failure, such as instability, aseptic, and septic loosening and particulate-induced osteolysis, were thoroughly investigated with standard and advanced imaging modalities when appropriate.

In the setting of negative screening laboratories, routine hip aspiration is not recommended with standard THAs in the past. However, one needs to be aware that distinction between septic failure and MOM-related failures can be quite difficult to differentiate. MOM reactions can mimic infection with elevated inflammatory markers [erythrocyte sedimentation rate (ESR) and CRP], increased synovial white blood cell counts (need a manual count as necrotic debris
often leads to inaccurate results) and large joint effusions that grossly resemble purulent material (Figure 6). There are published case reports discussing these findings in significant detail.

In the workup of a painful MOM THA, we highly recommend preoperative hip synovial fluid aspiration despite the results of the screening lab tests. Analysis of the synovial fluid white blood cell count and cell differential was initially thought to be a vital element of the workup. Unfortunately, cell counts and differential are often equivocal, and culture results take several days to finalize. With experience, the fluid color and soft tissue appearance intraoperatively will portray the underlying diagnosis of an adverse local tissue reaction (Figures 4 and 6). The preoperative cell count and culture results can ultimately be used to guide perioperative antibiotic

**Figure 5:** A proposed algorithm to investigate painful metal-on-metal total hip arthroplasty.

MOM, metal-on-metal; THA, total hip arthroplasty; MRI, magnetic resonance imaging; WBC, white blood cell.
treatment after the revision THA. In addition, intraoperative cultures are necessary to address the possibility of a false-negative preoperative culture.

As with other THA components, scrutiny of serial radiographs with a particular focus on acetabular cup position, identification of component manufacturer, and signs of loosening is essential to elucidate the cause of failure. When loosening is ruled out either with stable serial radiographs and/or a negative triple phase bone scan, serum metal ion level analysis should be drawn. In reality, in the absence of gross component migration or overt septic arthritis, it is suggested to obtain metal ion levels in all painful MOM THAs. This is advisable in order to achieve a baseline level such that return to normal standards can be followed. Elevated serum metal ion levels in the setting of a painful and well-fixed acetabular cup suggest the presence of a local soft tissue reaction that can range from a painful effusion to severe soft tissue necrosis or pseudotumor. In the setting of a malpositioned well-fixed acetabular cup (particularly vertical and/or retroverted position), this diagnosis should be entertained as edge loading and high contact stresses can be expected in vivo. In this scenario, preoperative imaging with ultrasonography, magnetic resonance imaging (MRI), or computed tomography (CT) is recommended. If a localized fluid collection is identified, an intra-articular aspiration is recommended with lab analysis to inspect the presence of metal debris/ions. Additionally, physical examination should look for the presence of a soft tissue mass. If present or suspected, there should be a low threshold to obtain the aforementioned advanced imaging studies.

Figure 6: Intraoperative image demonstrating the gross appearance of a metal sensitivity/metallosis effusion and how it mimics the gross appearance of purulence. This effusion ultimately was aseptic in nature.
In actuality, obtaining a CT, MRI, or ultrasound in the setting of elevated metal ion levels and pain to investigate for the presence of an intra-articular effusion or pseudotumor is commonly performed despite the suggestion to follow an algorithmic approach. The confirmation of such soft tissue findings provide further indication for revision THA as well as prepare the surgeon for what will be encountered at the time of revision THA. The soft tissue destruction may be mild or involve a greater area leading to difficulties with a large dead space or abductor compromise during the revision THA.

Other important examination findings include pain with resisted hip flexion, which potentially indicates the diagnosis of iliopsoas impingement, especially in the setting of a retroverted acetabular cup or high-profile cup and articulation. Iliopsoas impingement can be confirmed with an interventional radiology-guided iliopsoas injection (Figure 7). As previously mentioned, component types, when necessary, should be identified by radiograph, previous operative report, or implant stickers. This is essential, as there are now well-known problematic acetabular cups with significantly high early failure rates related to aseptic loosening and joint seizing.21,22

**Evaluation of a Painful Ceramic-on-ceramic Total Hip Arthroplasty**

Unique to COC, THA is the incidence of clinically audible “squeaking”. This phenomenon has a reported incidence range of 0.7–20.9%.24 Causes of this
occurrence are currently unknown; however, proposed etiologies include edge-loading, stripe-wear, component malposition, and altered fluid mechanics of the bearing surface. Diagnosis of this clinical scenario is often straightforward as patients present with noticeable and very audible squeaking. Scrutiny of serial radiographs is essential as malpositioned components can potentially clue you into this problem. Revision in this scenario is an option as squeaking can be very disheartening, embarrassing, and disruptive to the patient. Squeaking can also indicate a more severe issue with the bearing as a large amount of ceramic wear can occur with or without underlying metal wear as complete ceramic surface delamination can be seen. Thus, this can result in serious local soft tissue involvement and alteration.

Another distinct issue with COC bearings is the incidence of liner and/or femoral head fracture (Figure 8). Earlier generation COC bearings and ceramic heads alone had a high incidence of fracture with bearing produced before 1990 demonstrating a rate of 13.4% as states previously. Newer generation ceramic heads and liners have fortunately improved upon this complication and now have an extremely low incidence of fracture with a reported incidence of 0.004%. Diagnosis of head and liner fracture is relatively straightforward as this is often noticeable on plain roentgenograms (Figure 9). Revision in this situation must be performed urgently to prevent further soft tissue and component damage.

**TREATMENT**

Once the diagnosis and reason for failure is elucidated, revision THA should take place. The details of each specific scenario and cause of failure dictate the
necessary treatment. Utilizing an algorithmic approach to diagnosis can help with having the correct preoperative studies in acquiring the appropriate intraoperative equipment required for a successful revision surgery.

With a loose acetabular component, cup revision should be performed with a conversion of the hard-on-hard bearing surface to a hard-on-soft articulation [i.e., MOP or ceramic-on-polyethylene (COP)]. Bearing choice can be dictated by patient age and surgeon preference. In the setting of a hard-on-hard articulation failure, we do not recommend revision with a MOM or COC bearing surface. In the following sections, we will discuss treatment options for MOM THA and COC THA troubles separately.

**Metal-on-metal Total Hip Arthroplasty**

With a stable ingrown cup that is malpositioned and with associated elevated metal ion levels, acetabular cup revision should be considered particularly with a vertical component as this can predict an increase in the risk of polyethylene liner edge-loading and ultimately early failure either via liner fracture or early liner wear from edge-loading. In an ingrown, retroverted cup revision is recommended to avoid further iliopsoas irritation as well as difficulties with hip stability. The risks of cup revision involve addressing bone loss after cup extraction and obtaining stable fixation; however, with current explant osteotomes, bone loss is typically kept to a minimum. The other option in treating iliopsoas impingement requires maintaining the cup and performing an iliopsoas release; however, the potential pitfalls of this are hip flexion weakness with the advantages of not having to address issues associated with acetabular cup revision. Use of a MOP or COP articulation can be utilized when revision for iliopsoas impingement is performed.

![Figure 9: Radiographs depicting ceramic head fracture.](image)
In scenarios of potential adverse local tissue reactions, especially coupled with elevated serum metal ion levels, the surgeon must always be aware that the soft tissue envelope around the hip may be significantly affected. These soft tissue ramifications range from minimal to severe. Presentations can be seemingly insignificant, such as scarring or an effusion, and can expand further to catastrophic necrosis of the abductors (Figure 10). We have devised a classification scheme describing modes of failure and the range of soft tissue involvement seen in MOM THA revisions (Tables 1 and 2).

Table 1: Fabi-Levine Mode of Failure Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Treatment</th>
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<tr>
<td>1</td>
<td>Metal sensitivity—stable, well aligned acetabular component, elevated metal ions, and pain</td>
<td>Revise bearing only to metal-poly (m-poly) or ceramic-poly (c-poly), if cup modular; if cup monoblock revise cup with m-poly or c-poly, bearing</td>
</tr>
<tr>
<td>2</td>
<td>Malpositioned cup—stable malaligned acetabular component, elevated metal ions, and pain</td>
<td>Revise cup with m-poly or c-poly bearing</td>
</tr>
<tr>
<td>3</td>
<td>Loose cup</td>
<td>Revise cup with m-poly or c-poly bearing</td>
</tr>
<tr>
<td>4</td>
<td>Early failure cups—acetabular components with known high early failure rates</td>
<td>Revise cup with m-poly or c-poly bearing</td>
</tr>
<tr>
<td>5</td>
<td>Iliopsoas impingement—ion levels within normal limits, cup retroverted</td>
<td>Iliopsoas release or revise cup to optimal position with m-poly or c-poly bearing</td>
</tr>
</tbody>
</table>

Figure 10: Intraoperative photograph of patient with complete abductor necrosis from a failed metal-on-metal total hip arthroplasty during one of the authors’ cases.
Table 2: Fabi-Levine Metal-on-metal Total Hip Arthroplasty Soft Tissue Complication Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intracapsular effusion, capsule intact</td>
<td>Revise bearing and/or cup if needed, stability less of an issue</td>
</tr>
<tr>
<td>2</td>
<td>Extracapsular effusion, capsule affected, abductors intact</td>
<td>Revise bearing and/or cup if needed, stability more of an issue</td>
</tr>
<tr>
<td>3</td>
<td>Capsule affected, abductors affected</td>
<td>Revise bearing and/or cup if needed, stability severely compromised, consider constrained liner, other salvage options</td>
</tr>
</tbody>
</table>

As with all revision THA, postoperative dislocation is a concern, but cannot be underestimated in the setting of failed MOM THA (large femoral head will decrease and abductors may be compromised). At the time of revision surgery, we recommend having multiple component options, such as large femoral heads, tripolar articulations, elevated liners, and constrained liners available to address potential instability issues. Further, it is advisable to use the least constraint possible during revision THA and maintain adequate polyethylene thickness for better long-term survival. Elevated rim liners are utilized when standard ones require minor supplementation to achieve optimal stability. If this is not successful with trialing, then attempts with “tripolar” articulations should be undertaken either with standard or elevated polyethylene liners with bipolar heads, or possibly with newer dual-mobility articulations (i.e., anatomic dual mobility or modular dual mobility. If stability is affected by a malpositioned cup, then revision of the cup should be performed to optimize component position and enhance stability. Finally, if stability still cannot be obtained with a well-positioned cup and the options above, then the use of a constrained liner is warranted. We recommend against the use of constrained liners in conjunction with concomitant cup revision as this can lead to failure of cup ingrowth and/or early cup loosening. However, if an excellent press-fit is obtained with concomitant fixation using multiple screws, constrained liners can be placed with the understanding that early failure and altered ingrowth are possible. Another option is to place a constrained liner in a staged fashion after cup ingrowth has occurred (minimum of 6 weeks) in the setting of repeated early dislocations of an unconstrained articulation. Overall, we do not recommend the use of a constrained liner unless absolutely necessary and all other options have been exhausted.

When adverse metal reaction, metallosis, pseudotumor, and metal sensitivity are diagnosed, revision to a MOP or COP articulation should be performed. We will typically utilize a titanium sleeve over the femoral trunnion in cases with significant Morse taper corrosion.
Ceramic-on-ceramic Total Hip Arthroplasty

Pertaining to COC THA failure, squeaking can be addressed via conversion of the bearing to a “soft bearing”—either MOP or COP articulation. Modular, well-fixed and appropriately positioned cups require a straightforward femoral head and liner exchange. However, with damaged liner locking mechanisms, malpositioned cups, or nonmodular cups; acetabular cup revision is highly recommended.

When femoral head and/or liner fracture occurs, conversion to a MOP or COP bearing should take place (authors favor ceramic head use as metal femoral head easily scratches against retained ceramic debris). Well-positioned ingrown cups should be maintained, and cup revision should be considered in malpositioned cups and must take place in monoblock cups with ceramic liner fracture. The difficulty often encountered intraoperatively is the amount of ceramic debris present at the time of revision THA. Removal of this debris can be extremely time-consuming, difficult, and frustrating to the surgeon; however, removal is essential to decrease third-body wear and thus, early component failure. Often, complete removal is not possible but all attempts must be made to minimize the amount of debris within the joint.

CONCLUSION

As we garner more information on the performance of MOM and COC THA, the orthopedic community will be better informed as to the best indications/contraindications for this bearing surface and to elucidate if there is, in fact, a niche for these bearing surfaces in the field of THA. With information regarding success and failure scenarios of these bearings, we can optimize the performance of MOM and COC THA and thus take advantage of the benefits that these articular couples offer. A plethora of studies has already documented satisfactory performance of these bearing surfaces when ideal indication criteria are met.28-31 Our findings underscore that we are still learning about the outcomes of these bearings and their potential unique complications. However, it also reinforces that attempts at advancing the field of THA need to be regarded with tempered enthusiasm and appropriate precautions. Thus, as we embark on further industrial advancements in bearings, such as newer ceramic-on-metal bearing surfaces, we must not forget past failures so that we may avoid future unforeseen complications.

Conflicts of interest include the following

Consulting: Zimmer, Biomet, Janssen, Orthoview, Conmed
Royalties: Human Kinetics (book)
Research Funding: Zimmer and Biomet
Committees: AAOS Knee ICL subcommittee chairman and CORD Education committee.
Editor’s Comment

Hard-on-hard bearing surfaces were intended to improve the long-term outcomes of total hip arthroplasty, particularly in younger, more active patients. These bearing surfaces have advantages and disadvantages, some of which are clear and some of which are not yet fully elucidated. The patient with pain after total hip arthroplasty with a hard-on-hard bearing surface should undergo the same workup as those with traditional bearing surfaces prior to pursuing an evaluation for a unique bearing surface complication. The orthopedic surgeon must weigh the risks and benefits of newer technology prior to embracing it. The lessons learned from the hard-on-hard bearing surface experience should be remembered as we move forward.

Matthew S Austin
Gregg R Klein

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Surgical Approaches for the Hip: Evidence versus Advertising

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2Adult Reconstruction and Joint Replacement Division, Hospital for Special Surgery, New York, New York, USA

ABSTRACT

There are several approaches available for performing a safe and clinically successful total hip replacement. Many advertising claims regarding individual surgical approaches are not supported by peer-reviewed literature. Orthopedic literature lacks appropriate long-term level 1 data regarding the impact of surgical approach on outcomes after total hip replacement. Most differences between surgical approaches, if they exist, are only present in the early postoperative period, and often do not persist into medium or longer term follow-up. The most important factor in choosing a surgical approach for total hip replacement is that the surgeon chooses the approach with which he or she is most comfortable and has the most experience.

INTRODUCTION

Total hip arthroplasty is considered one of the most successful surgical procedures performed today. With regards to which approach to use, there is no evidence to support the superiority of one approach over the other. The challenge to surgeons (and patients) trying to stay abreast of an ever-changing medical field is to differentiate marketing hype from peer-reviewed evidence. There have been several recent examples of misguided efforts boasting of improved outcomes with technically demanding procedures that ultimately fell out of favor, such as the two-incision technique. It is imperative to critically evaluate the literature, assess the technical requirements, consider the potential learning curve, and weigh the

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Surgical Approaches for the Hip: Evidence versus Advertising

pros and cons prior to instituting a new technique and/or approach into one’s practice.

There is an abundance of advertising and marketing with respect to approaches to total hip arthroplasty; however, there remains a paucity of level 1 data comparing approaches. Hozack et al. evaluated the websites of the 106 members of the Hip Society in 2005 and showed that nearly 20% of these surgeons advertised some aspect of hip arthroplasty surgery. Despite the high number of reported benefits of specific approaches, only 25% of surgeons discussed associated risks, and there were no references to any peer-reviewed data. Even within the evidence for a single approach, conflicting data exists regarding complications as well as perceived or measurable benefits. In this article, we will examine several of the approaches that are more commonly discussed in advertising for total hip arthroplasty, evaluate the proposed risks and benefits, and compare them to the available peer-reviewed literature.

OVERVIEW OF APPROACHES

Standard Posterior Approach

The standard posterior approach is performed in the lateral decubitus position. A 15–20 cm skin incision is made centering over the posterior aspect of the greater trochanter and may be straight or curved posteriorly proximally to follow the fibers of the gluteus maximus. Dissection is carried down to and through the fascia in line with the incision. The gluteus maximus is bluntly split within its fibers in line with the fascial incision. The piriformis, conjoined tendon, and quadratus femoris are taken down from the posterior aspect of the greater trochanter and tagged for later repair. A trapezoidal capsulotomy is performed and tagged for repair as described by Pellicci et al. The hip can then be dislocated with internal rotation and gentle traction exposing the femoral head and proximal femur down to the level of the lesser trochanter. A standard arthroplasty can then be performed. After completion of the procedure, the posterior structures are repaired through drill holes in the posterior greater trochanter (Figure 1). Then the fascia, subcutaneous tissues and skin are closed. Posterior hip precautions are recommended for 6 weeks postoperatively to decrease the incidence of dislocation.

Minimally Invasive Posterior Approach

The mini-posterior approach, as described by Sculco, is performed in the lateral decubitus position. It involves a skin incision less than 10 cm, which is parallel to the posterior aspect of the femur, beginning 2–3 cm proximal to the greater trochanter and extending to the vastus flare (Figure 2). Accurate placement of this incision is necessary to facilitate an arthroplasty procedure though this limited skin incision. The incision in the fascia is carried 3–5 cm beyond the extent of the skin
incision, and the incision is treated as a mobile window throughout the case. The piriformis and conjoined tendons are released and tagged for later repair, but the quadratus femoris is left intact. The capsulotomy technique is similar to a standard posterior approach, as is the soft tissue repair at the conclusion of the procedure. Posterior hip precautions are again recommended for 6 weeks postoperatively, similar to the standard posterior approach.

**Standard Direct Lateral (Modified Hardinge)**

There are several varieties of direct lateral approaches to the hip that are modifications of the original approach described by Hardinge. The majority of these approaches are largely consistent with the modifications described by Moskal and Mann, with the patient either in lateral decubitus position as popularized by
Morrey⁶, or in the supine position as described by Hozack et al.⁷ With the patient in either position, a 10–15 cm skin incision is made just anterior to the midline of the trochanter with two-thirds of the incision proximal to the greater trochanter and one-third distal to the tip of the greater trochanter. The fascia is incised in line with the skin incision, and the fibers of the gluteus medius and vastus lateralis are identified. The gluteus medius is split between its anterior one-third, and posterior two-thirds, and the exposure is extended into the anterior fibers of the vastus lateralis (Figure 3). Care must be taken when splitting the fibers of the gluteus medius to avoid injury to the superior gluteal nerve which resides approximately 5 cm proximal to the greater trochanteric attachment of the gluteus medius. This soft tissue sleeve is reflected anteriorly, and the anterior hip capsule is identified. A capsulotomy or capsulectomy can be performed, and the hip is dislocated with external rotation of the leg. The arthroplasty is then performed, and the soft tissue sleeve of the gluteus medius and vastus lateralis is repaired to the remaining soft tissue when completed. The subcutaneous tissues and skin are closed in a standard fashion. Some levels of hip precautions are recommended for 6 weeks postoperatively; however, only limited precautions are recommended by some authors.⁸,⁹

**Minimally Invasive Direct Lateral**

The mini-lateral approach was described and popularized by Berger.¹⁰ The patient is placed in the lateral decubitus position. A less than 10 cm incision is made centered around a point 2 cm distal to the tip of the greater trochanter in the midline, and directed at a 30° angle to the long axis of the femur. The deep tissues
and fascia are incised in line with the incision and the muscle of the gluteus medius is exposed. The anterior one-fourth of the gluteus medius, referred to as the anterior-oblique fibers, and the underlying portion of the gluteus minimus are taken off of the anterior aspect of the greater trochanter as a single unit down to the level of the vastus ridge (Figure 4). The hip is then flexed to 45° and externally rotated to dislocate the hip. A high provisional neck cut can facilitate the exposure and identification of the lesser trochanter, and allows for space to make a proper measurement of neck cut length. The use of specially designed low profile and offset instruments can aid in the performance of the arthroplasty. After placement of the final implants, the sleeves of gluteus medius and minimus tendon are repaired to the greater trochanter through drill holes in the lateral trochanter and the split in the gluteus medius is repaired. The fascia, subcutaneous tissue and skin are closed in a standard fashion.

**Minimally Invasive Anterolateral**

The mini-anteralateral, modified Watson Jones, approach as described by Bertin and Röttinger\(^\text{11}\) is performed in the lateral decubitus position with the affected leg draped to allow for free motion of the leg and a table that allows for free motion of the operative leg below the level of the table. The approach can also be performed in the supine position. A less than 10 cm incision is made from the anterior tubercle of the greater trochanter to the anterior superior iliac spine (ASIS) with one-fourth of the incision distal to the tip of the greater trochanter and the remainder proximally. The deep tissues and fascia are incised in line with the incision, and the interval anterior to the gluteus medius and posterior to the tensor fascia lata (TFL) is developed bluntly with a finger. Hohmann retractors are placed outside the capsule, superiorly and inferiorly to the femoral neck.
A medially based, U-shaped capsulotomy is performed with borders at the anterior border of the gluteus medius and laterally at the insertion on the intertrochanteric ridge. The Hohmann retractors can then be repositioned inside the hip capsule. The femoral head is removed using a “napkin-ring” technique. The hip is then maximally externally rotated and the total hip arthroplasty performed. The operative leg can be placed in a sterile bag on the posterior aspect of the table to assist in femoral preparation. Upon closure, the capsulotomy can be loosely repaired to avoid impingement and the fascia, subcutaneous tissues, and skin can be closed in the standard fashion.

**Direct Anterior (Modified Smith-Peterson)**

The use of direct anterior approach for total hip arthroplasty was first described in the early 1980s by Light and Keggi. The procedure is performed with the patient in supine and can be done with or without the orthopedic table popularized by Matta. A 10 cm skin incision is made from a point 2 cm posterior and 2 cm distal to the ASIS and continued distally and slightly posteriorly to a point approximately 3 cm anterior to the greater trochanter. During subcutaneous dissection and throughout this approach, care must be taken to avoid injury to the lateral femoral cutaneous nerve (LFCN) whose variable course is almost always in the proximity of this exposure. The fascia can be incised in line with the skin incision and the underlying muscle bluntly dissected medially off of the fascia. Blunt dissection can be continued deep between the TFL and the sartorius, until the hip capsule is palpated (Figure 5). Curved retractors can then be placed above and below the neck outside of the capsule. A fat layer is identified, and the lateral femoral circumflex vessels should be identified, and cauterized in the distal portion of the exposure. The hip capsule can be cleared of remaining overlying fat and the reflected head of the rectus femoris can be elevated off of the anterior rim of the acetabulum to expose the entire capsule. A capsulotomy or capsulectomy can then be performed and the hip joint exposed. While not necessarily required, some authors advocate dislocation of the hip at this point to facilitate exposure of the femoral neck and mobilization for later preparation. The femoral neck osteotomy can be made with or without the use of fluoroscopy and the head removed using either a corkscrew or a second osteotomy and the “napkin-ring” technique. The acetabulum can then be exposed and prepared with the use of fluoroscopy. A femoral hook is then used to elevate the femur with or without the use of an orthopedic table and the femoral neck is exposed. Care must be taken during these steps to monitor tension on these retractors and avoid fracture of the greater trochanter. Often, further release of the hip capsule and sometimes the piriformis tendon and obturator internus tendon are needed.
to appropriately mobilize the femur. Preparation of the femur is facilitated with offset broaches and implant systems that do not utilize straight reamers. The fascia, subcutaneous tissues and skin are repaired in a standard fashion. Postoperatively, no strict hip precautions are recommended, but patients are instructed to avoid extreme hip extension and external rotation. Table 1 lists the risks of alternative approaches for hip arthroplasty.

**Figure 5:** Interval for the direct anterior approach.

**Table 1: Risks of Alternative Approaches for Hip Arthroplasty**

<table>
<thead>
<tr>
<th>Posterior approach</th>
<th></th>
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<tbody>
<tr>
<td>Risk of sciatic nerve injury</td>
<td></td>
</tr>
<tr>
<td>Need for posterior hip precautions</td>
<td></td>
</tr>
<tr>
<td>Possible increased risk of dislocation</td>
<td></td>
</tr>
</tbody>
</table>

**Direct lateral approach**

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterotopic ossification</td>
</tr>
<tr>
<td>Possible increased incidence of limp</td>
</tr>
<tr>
<td>Risk of gluteal nerve injury</td>
</tr>
</tbody>
</table>

**Direct anterior approach**

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury to lateral femoral cutaneous nerve</td>
</tr>
<tr>
<td>Risk of femoral nerve injury</td>
</tr>
<tr>
<td>Radiation exposure to patient and surgical team</td>
</tr>
<tr>
<td>Increased surgical complexity</td>
</tr>
<tr>
<td>Possible increased risk of fracture</td>
</tr>
</tbody>
</table>
CLAIMS MADE REGARDING SURGICAL APPROACHES

Claim 1: The Postoperative Dislocation Rate Varies between Different Surgical Approaches

Several reports have been published regarding the dislocation rates of the most common approaches for total hip arthroplasty. After the publication by Pellicci et al. describing the posterior soft tissue repair for the posterior approach for hip arthroplasty and reporting a dislocation rate of 0–0.8%, several other authors have also examined the dislocation rate after posterior approach for total hip arthroplasty. In their prospective, randomized trial, comparing the outcomes of standard posterior approach to mini-posterior approach, Dorr et al. reported a 0% dislocation rate for both approaches. A similarly low dislocation rate was demonstrated by Weeden et al. who reported a dislocation rate of 0.85%, as well as Sierra et al. who reported a rate of 1.2%.

The lateral approach has often been regarded as being superior to the posterior approach with respect to dislocation rate; however, this is not completely supported by recent literature. In their Cochrane review, Jolles and Bogoch found that the direct lateral approach was associated with a dislocation rate of 1.3% which was not significantly different than the posterior approach. Similarly, Kwon and associates performed a systematic review of the literature and found dislocation rates were not significantly different for the direct lateral approach, anterolateral approach, and posterior approach with posterior soft tissue repair.

More recently, much attention has been given to the direct anterior approach for total hip replacement and the claim that it is associated with lower dislocation rates than other approaches. Siguier et al. demonstrated a 0.96% incidence of dislocation in their published series. Similarly, Kennon et al. and Sariali et al. demonstrated dislocation rates of 1.3–1.5%, respectively, utilizing the direct anterior approach for total hip arthroplasty. These rates are not significantly different from those published for other approaches used for hip arthroplasty.

In conclusion, the claim that any particular approach to total hip replacement is associated with a decreased rate of dislocation is not supported by the peer-reviewed literature.

Claim 2: The Approach Used Can Be Associated with an Increased Incidence of Postoperative Limp

The debate over postoperative limping most often centers on the comparison of the direct lateral approach and the posterior approach. Since the direct lateral approach violates some portion of the abductor musculature, it is assumed that patients who have the direct lateral approach for their total hip arthroplasty will
limp more often than those who have a different approach. Meding et al. compared direct lateral approach to standard posterior approach and found no significant difference in the incidence of postoperative limp.23

In their Cochrane review, while there was a numerical increase in postoperative limp following direct lateral approach for total hip arthroplasty, Jolles and Bogoch found this difference not to be statistically significant.18 Finally, while no comparative, peer-reviewed studies have been identified regarding limping after a direct anterior approach, Siguier et al., in their single cohort study, found no patients had a persistent postoperative limp after direct anterior approach.20

In conclusion, although the direct lateral approach has often been associated with an increased incidence of postoperative limp, peer-reviewed data fails to support the claim that the direct lateral approach causes a statistically significant increase in persistent postoperative limp. Further, more data is necessary before any statements can be supported regarding the effect of the direct anterior approach on postoperative limping.

Claim 3: Specific Surgical Approaches More Accurately Reproduce Leg Lengths Postoperatively

Few peer-reviewed publications examine the incidence of leg length discrepancy after total hip replacement with regard to surgical approach. Weale et al. compared the posterior approach to the direct lateral approach and found that no difference existed in terms of postoperative leg length discrepancy.24 More recently, claims have been made by proponents of the direct anterior approach stating that leg length discrepancy would be less common utilizing that approach as opposed to other alternatives. In the only study of its kind to date, Nam et al. compared a computer navigated posterior approach, a conventional posterior approach, and the direct anterior approach with fluoroscopy and found that no significant difference was achieved in regards to leg length discrepancy using any of these approaches.25

In conclusion, no peer-reviewed data exists to support the claim that any particular approach is more effective than any other in preventing postoperative leg length discrepancy.

Claim 4: The Surgical Approach Used for Total Hip Replacement Affects Perioperative Blood Loss

Decreased blood loss during or after total hip arthroplasty has often been described as an advantage of the direct anterior approach, the posterior approach, as well as most less invasive techniques. With respect to published data regarding the
posterior approach, Weale et al. demonstrated significantly less blood loss using the posterior approach when compared to the direct lateral approach.\textsuperscript{24}

Conflicting data exists, however, regarding less invasive techniques. While Chimento et al. found that the use of the mini-posterior approach was associated with significantly less intraoperative and total blood loss when compared to the standard posterior approach,\textsuperscript{26} Ogonda et al. in their prospective, randomized, controlled trial of standard posterior approach compared to mini-posterior approach found no difference in transfusion requirements between the two approaches.\textsuperscript{27} When evaluating lateral approaches for total hip arthroplasty, de Beer et al. compared mini-lateral approach to the standard lateral approach and found no difference in intraoperative or total blood loss.\textsuperscript{28}

Finally, with respect to the direct anterior approach, Nakata et al. compared the direct anterior approach to the mini-posterior approach and found that, while intraoperative blood loss was similar between the two groups, the total perioperative blood loss was significantly greater for direct anterior approach than for mini-posterior approach.\textsuperscript{29}

In conclusion, evidence exists to support that the posterior approach produces less blood loss than the direct lateral approach. Conflicting evidence exists regarding whether the use of less invasive techniques significantly decreases perioperative blood loss. Finally, based on peer-reviewed literature, the use of the direct anterior approach does not result in a decreased blood loss when compared to other modern approaches.

**Claim 5: Surgical Approach Affects Recovery Time and Time to Return to Normal Function**

The effect of surgical approach on recovery time and return to function is often discussed in the setting of less invasive approaches as well as the direct anterior approach. These have both been touted as possible methods to allow patients to recover more quickly and to reduce the amount of time needed to return to normal function.

In separate prospective, randomized studies both Chimento et al.\textsuperscript{26} and Ogonda et al.\textsuperscript{27} compared the mini-posterior approach to the standard posterior approach. Chimento et al.\textsuperscript{26} found no difference between the two approaches in regards to achieving rehabilitation milestones, cane usage, or hospital length of stay.\textsuperscript{26} Ogonda et al.\textsuperscript{27} similarly found no difference in early ambulation, length of stay, or 6-week outcome measures when comparing the two approaches. Dorr et al.\textsuperscript{30} went one step further and compared the mini-posterior, standard posterior, anterolateral, and direct anterior approaches and found no significant difference in their measured gait parameters for any of the approaches studied.
With respect to the proposed recovery benefits of the direct anterior approach, Mayr et al. performed a gait analysis study and showed that patients who had a direct anterior approach achieved improvement in more gait parameters by 12 weeks when compared to patients who had a standard anterolateral approach. Similarly, Nakata et al. found that patients who had a direct anterior approach for their total hip arthroplasty demonstrated faster recovery of hip function and gait ability when compared to a mini-posterior approach. While these early benefits were verified by Rodriguez et al., their consecutive, prospective, comparative study of direct anterior versus posterior approach for total hip replacement, they also demonstrated that there was little difference by 2 weeks and no significant difference by 6 weeks of all functional outcome measures between the two study groups. Finally, Barrett et al. performed a single surgeon prospective, randomized trial of the direct anterior approach versus the posterior approach and found that the patients who had a direct anterior approach recovered unlimited walking and stair climbing more quickly, as well as had higher hip disability and osteoarthritis outcome scores (HOOS) at 12 weeks. Again, these differences disappeared after 12 weeks.

In regards to patient reported clinical outcomes, Restrepo et al. performed a prospective, randomized study comparing the supine, direct lateral approach, and the direct anterior approach in 100 patients. They found a statistically significant improvement in several parameters of the Short Form 36 (SF-36) and the Western Ontario and McMaster Universities Arthritis Index (WOMAC) at 1 year. These improvement, however, did not persist at the 2-year follow-up time point.

CONCLUSION

In conclusion, there is little peer-reviewed data to support the claim that any surgical approach for total hip arthroplasty has an advantage with regards to dislocation, limp, leg length discrepancy, or blood loss. There are, however, several studies that support the claim that the direct anterior approach does afford patients a faster functional recovery than other modern approaches; however, these benefits do not persist beyond 6–12 weeks. Moreover, the benefit of a faster recovery must be tempered by the risks of radiation exposure and the possible increase in surgical complexity of the direct anterior approach which can lead to increased surgical times and fracture (Table 2).
Table 2: Summary of Claims versus Evidence

<table>
<thead>
<tr>
<th>Claims</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical approach affects dislocation rate</td>
<td>There is no evidence that different surgical approaches have significantly different rates of dislocation when modern surgical techniques are utilized</td>
</tr>
<tr>
<td>Surgical approach affects the incidence or severity of postoperative limp</td>
<td>There is no evidence that different surgical approaches have significantly different rates or severity of postoperative limp when modern surgical techniques are utilized</td>
</tr>
<tr>
<td>Leg length is more accurately recreated with certain surgical approaches</td>
<td>No peer-reviewed data exists to confirm that surgical approach affects postoperative leg length</td>
</tr>
<tr>
<td>Surgical approach affects perioperative blood loss</td>
<td>Evidence exists only to support that the direct lateral approach is associated with increased blood loss compared to the posterior approach</td>
</tr>
<tr>
<td>Surgical approach affects postoperative recovery</td>
<td>Evidence exists to support a quicker short-term recovery associated with the direct anterior approach, but does not persist beyond the 6–12 weeks</td>
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</table>

Editor’s Comment

Marketing in modern medicine has now become commonplace. Advertising has become pervasive on the internet, radio, print, and television. Patients are constantly seeking the newest surgical techniques and technology, often with the belief that newer is better. It is good for patients to take an interest in their care. However, it is possible that the marketing they are exposed to may be misleading and not supported by peer-reviewed literature. At extremes, the technique and technology can lead to significant harm. The surgeon must be careful and serve to educate patients to the risks and benefits of surgical techniques and technology.

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REFERENCES

Head Diameter with Modern Generation Poly: Does Size Matter?

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ABSTRACT

Over the history of total hip arthroplasty, there has been a tremendous range of sizes available for the prosthetic femoral head. Sir John Charnley made use of a 22.25 mm femoral head believing that this caused the lowest amount of friction at the bearing surface and would, therefore, lessen the risk of torsional stress on the cemented acetabular implant, which he worried could cause loosening. While very good long-term results have been obtained with such implants, there is an increased risk for hip instability and potential decreased range of motion with smaller femoral head sizes. Larger femoral head sizes have the advantage of providing greater range of motion while reducing the risk of instability. Additionally, surface wear patterns vary with femoral head size, with smaller femoral heads causing linear wear while larger femoral heads lead to more volumetric wear against conventional polyethylene. The use of highly cross-link polyethylene as an acetabular bearing surface has been shown to dramatically decrease the rate of bearing surface wear and, therefore, may allow for the use of larger femoral head sizes. This article will discuss how femoral head size influences hip range of motion as well as joint stability, will review the literature regarding the use of highly cross-linked polyethylene articular surfaces in total hip arthroplasty, and will discuss a potential problem caused by larger femoral heads, i.e., corrosion at the head-neck junction.
LARGER FEMORAL HEAD SIZES AND THE RISK OF DISLOCATION

While very good results have been reported on for total hip arthroplasties using smaller femoral heads, such as the Charnley hip replacement, larger femoral heads have gained popularity because of their lower rates of dislocation. A lower rate of dislocation with larger femoral heads has been shown in multiple large registry data studies. Hailer et al. reviewed 78,098 total hip arthroplasties extracted from the Swedish Hip Arthroplasty Registry performed between 2005 and 2010. They found that the use of 22 mm heads resulted in a greater rate of revision for dislocation than the use of 28 mm heads [relative risk (RR) = 2.0]. They concluded that femoral head sizes of 28 mm or greater, or the use of dual mobility cups, reduce the risk of dislocation in a clinically relevant manner. In a similar study, Bystrom et al. reviewed the Norwegian Arthroplasty Register for risk factors for prosthesis instability leading to revision. 42,987 primary total hip arthroplasties were included in the register between 1987 and 2000. The authors of this study found that femoral head size is an important risk factor for dislocation, with 28 mm heads leading to a greater rate of revision than did 32 mm heads [failure rate ratio (FRR) 4.0, 95% confidence interval (CI) 2.2–7.3]. Looking specifically at the Exeter hip replacement, 26 mm heads had a greater rate of revision secondary to instability than did 30 mm heads (FRR 4.1, 95% CI 2.2–8.1). Prokopetz et al. performed a well-crafted meta-analysis of 86 high quality articles published from 2000 to 2010 to quantitate risk factors for total hip arthroplasty revision. To ensure that only high-quality studies were included with sufficient sample size and follow-up, articles with less than 2,500 person-years of follow-up or with less than 25 cases in a case-control study were excluded. Three papers included in this review specifically addressed femoral head size as a risk factor for dislocation and showed a statistically significant increased risk for dislocation with femoral head sizes smaller than 28 mm as compared to femoral head sizes of 28 mm or greater.

It has been theorized that larger femoral heads may improve range of motion and stability in total hip arthroplasty by lessening the risk of impingement. In 1975, Amstutz et al. showed that differences in prosthetic designs, specifically the femoral head-neck ratio, caused great differences in range of motion prior to impingement of the femoral neck on the rim of the acetabular implant. Similarly, Chandler et al. showed that increasing head-neck diameter ratios result in increased arc of motion prior to prosthetic impingement. They also found that longer femoral necks improved range of motion as well but are a risk factor for increased prosthetic impingement. Burroughs et al. used an anatomic hip simulator to measure range of motion prior to impingement with either a 28 mm, a 32 mm, a 38 mm, or a 44 mm femoral head articulating with a 61 mm acetabular shell. The results of this investigation showed that femoral head sizes greater than 32 mm provided greater range of motion and almost completely eliminated
impingement between the femoral and acetabular components. They also noted a greater range of motion in flexion before dislocation and a greater displacement needed between the femoral head and acetabulum to produce dislocation with femoral head sizes greater than 32 mm.

While increased head size allows a greater theoretical range of motion prior to component impingement and dislocation, Hammerberg et al. did not find any statistically significant difference in range of motion in patients implanted with femoral heads ranging from 28 mm to 44 mm. However, it should be noted that femoral head size was chosen so that the head-neck ratio was at least 2.0 and the head to cup distance was not greater than 25 mm. Such parameters have been shown to lessen the risk of impingement and instability, and the authors theorize that adhering to these parameters is more important than the absolute size of the femoral head. They also note that reconstruction of appropriate combined acetabular and femoral anteversion as well as the restoration of leg length and offset is important to minimize impingement, and that if impingement is eliminated, then the only restraints to motion would be capsular and muscular compliance.

FEMORAL HEAD SIZE AND HIGHLY CROSS-LINKED POLYETHYLENE

Highly cross-linked polyethylene became available for clinically usage in the late 1990s. Such polyethylene has a greater resistance to oxidation and was introduced to reduce wear rates of polyethylene bearing surfaces in total hip arthroplasty. It has long been known that increased wear rates are linked to osteolysis in total hip arthroplasty and it is generally accepted that linear wear rates less than 0.1 mm per year have a lower chance of producing significant osteolysis around a total hip arthroplasty. Using Charnley low friction arthroplasty as an example, survivorship rates at 25 years are greater than 90% when linear wear rates are less than 0.1 mm per year; however, survivorship rates at 20 years are less than 30% when wear rates are greater than 0.2 mm per year.

Multiple studies evaluating highly cross-linked polyethylene have shown linear wear rates less than 0.1 mm per year in the clinical setting, which, again, is thought to be a critical threshold to minimize osteolysis. Nakahara et al. compared the wear rates of longevity highly cross-linked polyethylene acetabular liners at 8 years follow-up using either a 26 mm or a 32 mm cobalt-chromium head. Linear and volumetric wear rates were evaluated and determined to be negligible over the study period. No difference in wear rates was noted between the two different head sizes. In another study, Thomas et al. used radiostereometric analysis (RSA) to compare the wear rates of conventional ultrahigh molecular weight polyethylene to those of highly cross-linked polyethylene liners. At a minimum of 7 years
postoperative follow-up, the mean steady-state wear rate of highly cross-linked polyethylene was 0.005 mm per year compared with 0.037 mm per year for the conventional ultrahigh molecular weight polyethylene ($p = 0.007$). It is important to note that while no patient in the highly cross-linked polyethylene group had a wear rate greater than 0.1 mm per year, 9% of patients in the conventional ultrahigh molecular weight polyethylene group had wear rates greater than this threshold value. McCalden et al. showed similar findings at a mean of 6.8 years postoperatively in a prospective, randomized controlled study comparing highly cross-linked and conventional polyethylene acetabular liners. They found that the mean femoral head penetration rate was 0.003 mm per year for the highly cross-linked polyethylene group and was 0.051 mm per year for the conventional polyethylene group ($p = 0.006$).

While linear wear rates have been found to be quite low with highly cross-linked polyethylene articular liners and appear to be independent of head size, several studies have shown increased levels of volumetric wear with larger femoral heads. Hammerberg et al. reported their results on 80 hips followed for a mean of 3.6 years with head sizes ranging 28 mm, 32 mm, 38 mm, and 44 mm articulating against highly cross-linked polyethylene with a minimum thickness of 5 mm. Linear wear rates for the 28 mm and 32 mm heads were 0.023 mm per year and were comparable to the linear wear rates of 0.021 mm per year with 38 mm and 44 mm heads. Although these linear wear rates were found to be similar, differences in the volumetric wear rate were noted with the 28 mm and 32 mm heads having volumetric wear rates of 16.7 mm³ per year, while the 38 mm and 44 mm heads had volumetric wear rate of 29.1 mm³ per year. However, the volumetric wear rates for both of these groups were noted to be well below the established osteolysis threshold value for volumetric wear of 80 mm³ per year. In a similar study, Lachiewicz et al. reported on the results for wear rates of highly cross-linked polyethylene articulating against 26 mm, 28 mm, 32 mm, 36 mm and 40 mm femoral heads at a minimum follow-up of 5 years postimplantation. The authors were also unable to find a difference in linear wear rates between the femoral head sizes, but did observe an association between the larger femoral heads and an increased rate of volumetric wear. The authors, therefore, urged caution in using larger femoral heads in younger or more active patients and in those with lower risk factors for instability.

As seen above, increased femoral head size lessens the risk of instability and impingement in total hip arthroplasty. However, increasing femoral head size comes at the expense of polyethylene thickness for a given acetabular shell size in many hip systems. Thin polyethylene is subject to high mechanical stresses, and there have been concerns for rim cracking and catastrophic failure with conventional polyethylene thicknesses less than 5 mm. However, as discussed above, highly cross-linked polyethylene has been shown to have decreased wear
rates compared to conventional polyethylene and has been the impetus for the use of larger femoral heads with thinner articular surfaces. Few studies have evaluated the \textit{in vivo} and \textit{in vitro} wear characteristics of highly cross-linked polyethylene with respect to head size and polyethylene thickness.

Johnson et al. evaluated the short-term wear characteristics of 36 mm heads articulating with thin highly cross-linked polyethylene acetabular liners.\textsuperscript{22} Utilizing a hip wear simulator, the authors tested highly cross-linked polyethylene acetabular inserts with thicknesses of 1.9 mm, 3.9 mm, 5.9 mm, and 7.9 mm articulating with a 36 mm femoral head for 2.4 million cycles. The results of this study showed that mean wear rates decreased with increasing polyethylene thickness. The mean wear rates for the 1.9 mm, 3.9 mm, 5.9 mm, and 7.9 mm liners were $5.0 \pm 0.5 \text{ mm}^3$, $3.2 \pm 0.3 \text{ mm}^3$, $2.5 \pm 1.1 \text{ mm}^3$ and $2.2 \pm 1.3 \text{ mm}^3$ per million cycles ($p < 0.016$). Calculated linear penetration rates, respectively, were $0.015 \text{ mm}$, $0.012 \text{ mm}$, $0.011 \text{ mm}$, and $0.010 \text{ mm}$ per million cycles ($p < 0.016$). No catastrophic failures occurred in any of the samples. The authors conclude that there is a greater rate of wear with thinner highly cross-linked polyethylene; however, such rates remain lower than those commonly reported with conventional polyethylene. The authors call for further \textit{in vivo} studies to validate these findings.

Sayeed et al.\textsuperscript{23} evaluated the clinical and radiographic results of two groups of patients who underwent total hip arthroplasty utilizing the same highly cross-linked polyethylene bearing surface. The bearing thickness in the first group was 3.8 mm and the bearing thickness in the second group was 5.8 mm or greater. There were 53 hips in each group of comparable age and the body mass index (BMI). At a minimum of 2-year clinical and radiographic follow-up, there was no radiographic evidence for malalignment, radiolucency or polyethylene failure in the study group. For the thin polyethylene group, the mean volumetric wear rate was $0.4122 \text{ mm}^3$ per year (range, $0.2311$–$0.7310 \text{ mm}^3$ per year), and the mean linear wear rate was $0.0004 \text{ mm}$ per year (range, $0.0002$–$0.0007 \text{ mm}$ per year). The authors were encouraged with the excellent clinical and radiographic findings at 2 years using thin high cross-linked polyethylene articular bearings and have not seen any catastrophic bearing failure. However, further follow-up of this cohort of patients is necessary to validate these findings on a long-term basis.

\textbf{Head-neck Taper Corrosion as a Mechanism of Failure in Total Hip Arthroplasty}

It has long been known that metal ion levels in serum may be increased following total hip arthroplasty. This has been seen in a wide variety of bearing surface combinations, and is of considerable interest and concern to orthopedic surgeons.\textsuperscript{24–26} In recent years, because of a resurgence in popularity of the metal-on-metal (MOM) bearing surfaces, there has been increasing interest and concern

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regarding the potential adverse reactions, both local and systemic, to elevated metal ions generated from such implants. Multiple studies have reported on adverse local tissue reactions, pseudotumor formation, as well as distant organ and systemic effects attributed to the elevated serum metal ions derived from MOM hip replacements.\textsuperscript{27-30} Other studies have documented an elevation in serum ion levels from nonarticular implants that have caused local as well as systemic reactions.\textsuperscript{31,32}

In 1988, Jacobs et al. described the process of corrosion of metal orthopedic implants.\textsuperscript{33} They believe that corrosion at the femoral head-neck taper in modular total joint arthroplasty is a result of stress and motion at the taper junction as well as the crevice geometry of the taper itself. Normally, the surfaces of metallic implants are protected by an oxidized surface. During normal mechanical loading, these oxidized surfaces are subject to mechanical insult from micromotion between the femoral head and neck. Such mechanical insult may result in abrasion or fracture of the oxidized surfaces exposing the underlying metallic surfaces to acidic local fluids that increases the rate of crevice corrosion. They concluded that the corrosion products from this process may be harmful to biologic tissue.

A recent study of well-functioning metal-on-polyethylene (MOP) total hip arthroplasties shows an elevation in serum cobalt, chromium, and titanium ions at 10 years following total hip arthroplasty.\textsuperscript{34} The authors found that both the cobalt and chromium levels continued to elevate for the majority of the investigational period and titanium levels peaked around year 3 before declining. However, at all time periods, the metal ion levels were greater than the control group which had not received a total hip arthroplasty. The authors of this study theorize that a likely source of these elevated metal ion levels is at the head-femoral neck taper junction rather than from the articular surfaces of the implants. The authors believe that the mechanism for such ion elevation is mechanically assisted crevice corrosion at the modular head-neck junction. Factors that can affect the fretting and corrosion process include femoral neck taper size, femoral neck taper geometry which may affect flexural rigidity of the femoral neck, manufacturing tolerances and assembly forces, surface finishes as well as metallurgy.\textsuperscript{35-37} It is important to note that while the authors of this study have shown an elevation in metal ion levels in well-functioning MOP total hip replacements that the potential effect on local and systemic tissues remains unclear.

Richards et al. examined the influence of the femoral head size on corrosion and fretting at the head-neck taper.\textsuperscript{38} They looked at retrievals of 74 MOP total hip arthroplasty revisions featuring cobalt–chromium alloy femoral heads and stems with a 12/14 taper from two different implant manufacturers. While this study does have limitations including a limited number of 36 mm heads as well as a limited number of femoral stems available for analysis, the authors were able to make conclusions based on the available data. They found that there is a

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relationship between the heads and necks for fretting damage, which the authors attribute to micromotion between the two surfaces. They also found that the use of 36 mm heads creates greater corrosion damage in comparison to 28 mm heads. The results of the study also show a difference between the implants from the two manufacturers with respect to corrosion and fretting damage, particularly along the taper of the head. The authors theorize that such differences between the manufacturers may reflect differences in component manufacturing, surface passivation, design tolerances, and differences in surface finish. They conclude that larger femoral head sizes may cause increased levels of corrosion which in turn generates more metallic ionic debris that can propagate to the surrounding tissues leading to adverse localized tissue reactions also seen with metal-on-metal total hip arthroplasty.

The influence of larger head size and taper corrosion is being implicated in the higher rates of failure of metal-on-metal total hip arthroplasty. The authors of a recent study noted that during revisions for painful metal-on-metal arthroplasty, there was a common finding of significant corrosion products around the femoral head and neck taper junction. The authors of this study theorized that such corrosion is a causative factor of adverse localized tissue reactions. The authors compared failed metal-on-metal hip replacements to failed metal-on-polyethylene hip replacements. Both groups utilized 36 mm heads and a 12/14 cobalt-chromium taper all made from a single manufacturer to minimize variability. They found that the mean corrosion score was higher in the metal-on-metal group, that a higher proportion of femoral heads from the failed metal-on-metal group had corrosion products that extended beyond the taper surfaces, and that the corrosion scores on the retrieved heads were greater in cases revised for adverse local tissue reactions than those performed for other reasons. Interestingly, the authors found that material combination also had a significant effect on corrosion. Although both groups utilized the same femoral head and stem, the corrosion scores for failed MOM cases were greater than such scores for failed MOP revisions. The authors conclude by calling on the manufacturers of orthopedic implants to improve the stability of head-neck tapers.

In another study looking at failed metal-on-metal hip replacements, 114 revisions were performed of large diameter MOM articulations. All of the patients in this study had a previous implantation of a MOM hip from a single manufacturer using the same acetabular, head and head adaptor designs. Three different femoral stems were used. The head sizes ranged from 48 mm to 58 mm. At the time of revision, a black color resembling corrosion was noted on 94% of the head and femoral neck tapers. The authors believed that this indicated instability of the head-neck taper. Significant gross as well as histologic tissue reactions were noted including pseudotumor formation, vasculitis as well as a lymphocytic dominated histomorphology resembling aseptic lymphocytic vasculitis-associated
lesions (ALVAL). The authors measured metal particle levels in the periprosthetic tissues and were unable to make a correlation between head size and local metal particle load. However, elevated levels of titanium and iron were found in the bursa, capsule, and around the proximal femur. These metal particles are not found in the cobalt-chromium head and head adaptors, and were believed to be derived from the taper of the femoral stem. Therefore, the authors theorize that these particles were generated from corrosion at the head and neck taper rather than from wear at the articular surfaces. The authors conclude that instability of the head-neck taper leads to fretting and corrosion with the release of metal ions. The authors conclude that their findings indicate a need for better designed couplings between the femoral head and/or head-adapter and the taper of the femoral stem.

Corrosion has also been found at the head-neck taper of MOM total hip arthroplasties and is also thought to be responsible for adverse local tissue reactions. Cooper et al. have reported on 10 patients diagnosed with failed MOM total hip arthroplasties where visible corrosion at the femoral head and neck junction was found at the time of revision. At surgery, large soft tissue masses and surrounding tissue damage were noted. Pathologic specimens indicated areas of tissue necrosis consistent with failure in MOM hip replacements. A reliable finding preoperatively was elevated serum metal levels with a particularly elevated serum cobalt level relative to the chromium level. The authors of this study emphasize that corrosion is often not thought of in MOM total hip arthroplasty and that there needs to be a high level of clinical suspicion for patients who present with pain or other vague symptoms without other obvious sources of failure. The authors conclude that adverse local tissue reactions can occur in MOM total hip arthroplasties and that serum metal ion levels with a differential elevation of cobalt relative to chromium may help establish the diagnosis.

As corrosion seems to be a clinical problem both with MOM hip replacements as well as potentially with MOP total hip replacements, Kurtz et al. looked to see if such corrosion could also be found with ceramic-on-polyethylene total hip arthroplasty. Ceramic is an electrical insulator and, therefore, may help to minimize or eliminate electrochemical reactions involved in the fretting and corrosion process. The authors matched 96 sets of ceramic head-metal femoral taper pairs to 50 metal head-metal taper pairs that had been submitted to an academic retrieval program. The authors found that fretting initiated crevice corrosion is a complex problem and the severity of such corrosion is dependent upon multiple factors. They found that taper impaction technique, insurance of clean and dry taper junctions prior to engagement, and the use of matching components are very important technical factors that influence taper fretting and corrosion regardless of femoral head material. The authors found that the use of a ceramic head significantly reduces the amount of corrosion at the head and neck taper. However, such corrosion may still take place at the surface of the stem taper.
The authors conclude by suggesting that the use of a ceramic head may significantly mitigate, but not eliminate the risk of corrosion. This fact may influence surgeons’ choices regarding modular components in total hip arthroplasty. The authors call for further focus in ceramic component research to better understand the role ceramics may play in minimizing corrosion of modular components.

CONCLUSION

Larger femoral head sizes may provide greater stability and range of motion in total hip arthroplasty. Historical concerns regarding increased rates of polyethylene wear with larger femoral heads, particularly with thinner polyethylene bearing surfaces, have caused prudence in the orthopedic community with respect to bearing size selection. Highly cross-linked polyethylene appears to have low wear rates, even at very thin dimensions, and may allow for the usage of larger femoral heads in total hip arthroplasty. Concerns, however, remain regarding taper corrosion with larger femoral heads and caution is urged when selecting larger bearing surfaces.

Editor’s Comment

Surgeons have been inclined to use larger femoral heads to reduce the risk of dislocation. The popularity of highly cross-linked polyethylene secondary to positive wear data has increased the trend of using larger diameter femoral heads in total hip arthroplasty. However, the combined effect of liner thickness and head size on volumetric wear is still not fully understood. The decreased mechanical properties of highly cross-linked polyethylene also need to be considered, as the possibility of catastrophic failure of thin liners exists. Furthermore, there is concern regarding modular junction taper corrosion as head size increases. While we await more definitive data, the surgeon should balance the risks and benefits of larger femoral heads prior to universal implementation.

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REFERENCES


Non-arthroplasty Options for Painful Hip in the Young Patient

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ABSTRACT

Hip dysplasia, Femoroacetabular impingement and osteonecrosis of the femoral head account for over 95% of total hip arthroplasty (THA) performed in patients who are less than 55 years of age. If identified early, surgical treatment should aim at joint preservation. This paper will describe the current non-arthroplasty options available for treating the painful hip in young patients.

INTRODUCTION

Hip dysplasia is a structural hip disorder that can lead to degenerative arthritis if left untreated. Hip dysplasia has been well described, although its pathologic features can vary. It is common to see an increasing spectrum of abnormalities ranging from mild forms of dysplasia to severe cases in which the hip is completely dislocated from the acetabulum. Most commonly the changes to the femur are minor and it is the acetabulum that is dysplastic. Contact stresses between the two structures are disproportionate and may lead to symptoms.

Femoral acetabular impingement (FAI) has been suggested to be a preosteoarthritic condition that occurs when the proximal femur abuts the acetabulum with range of motion. Unrecognized and continued FAI can lead to cartilage degeneration and osteoarthritis (OA).

It is more common in patients with abnormal acetabuli (retroverted, coxa profunda, or protrusio), abnormally shaped proximal femurs (pistol grip deformity, post-traumatic deformities, femoral retrotorsion, coxa vara, or femoral head necrosis), or in patients with normal hip anatomy, but with excessive hip motion.

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Reynolds et al.\textsuperscript{3} described another structural abnormality of the hip called retroversion of the acetabulum. Retroversion occurs when the normal anterolateral opening of the acetabulum is pointed more posterolaterally in the sagittal plane. This is a deformity that has been associated with pincer femoroacetabular impingement.

Three types of FAI have been observed: (i) cam, (ii) pincer, and (iii) combined. Currently, it is considered one of the most important causes for hip pain in young adults.\textsuperscript{4,5} Since Ganz et al.\textsuperscript{6} first described FAI, it has become one of the fastest-growing fields in orthopedic surgery.

Avascular necrosis (AVN) of the femoral head is not a specific diagnostic entity (Table 1), but is the end result of a decrease in blood flow that leads to cellular death within the femoral head. This is a debilitating process that typically leads to the destruction of the hip joint and usually affects patients between 20 years and 50 years of age. Unfortunately, diagnosis is usually made at advanced stages of the disorder, when femoral head-conserving surgical treatment is no longer indicated.\textsuperscript{7-9} Accurate staging of disease progression is extremely important because options and outcomes of nonreplacement treatment are predicated on these data. In addition to planning treatments, staging helps provide a basis for counseling the patient and comparing results of surgical intervention.

### PHYSICAL EXAMINATION

When evaluating these patients, it is important to remember that many other conditions can produce symptoms in or around the hip. Differential diagnoses should include an array of pathologies including sacroiliitis, degenerative disk disease, abductor muscle tears and sprains, hip OA, psoas tendinitis, pubic rami fractures, stress fractures of the proximal femur, or trochanteric bursitis.

Most patients with hip dysplasia tend to be young, active, and report groin pain with activity. Patients do not typically complain of loss of motion, but rather increased range of motion. Patients with classic dysplasia report a knife-sharp
Non-arthroplasty Options for Painful Hip in the Young Patient

groin pain and a sensation of catching/locking secondary to tearing of the labrum. Patients with classic dysplasia and increased femoral anteversion may have more internal rotation than external rotation when hips are examined at 90° of flexion or in the prone position.

Clinical examination of the hip should begin with an evaluation of the patients gait, foot progression angle as well as leg lengths. Patients with marked hip dysplasia will exhibit a Trendelenburg gait due to weak abductors. Patients with post slipped capital femoral epiphysis (SCFE) deformities may exhibit an externally rotated extremity with ambulation resulting in an open foot progression angle (>10°). The hip should be carried through a range of motion. Pelvic flexion should be blocked by placing the examiners hand over the iliac crest anteriorly as the leg is brought into flexion. In patients with FAI or retroverted acetabula, it is common to obtain only between 90° and 95° of flexion. Classic dysplastic hips usually have a higher degree of hip flexion. Rotation should then be measured with the hip flexed at 90°. Patients with classic dysplasia and increased femoral anteversion have increased internal rotation. Patients with retroversion and FAI typically have very little internal rotation (<5°), although the female patient with structural abnormality may have normal range of motion as well.

The anterior impingement test has been described for patients with hip dysplasia and commonly used for those with FAI. With the hip at 90° of flexion, maximum internal rotation and adduction are performed. When contact between the anterior-superior acetabular rim and the femoral neck occurs, it can elicit pain. Higher degrees of flexion usually produce more impingement symptoms. Posterior impingement may also be positive and can be tested with the leg externally rotated and in hyperextension. This test can also be positive when global acetabular over coverage is present as can be seen in those with coxa profunda or protrusio or patients with global head-neck offset abnormalities. Posterior impingement test often implies posterior cartilage involvement and is a poor prognostic sign with regards to joint preservation.

Osteonecrosis (ON) can present with any number of clinical manifestations including being clinically silent. It is common for patients to have normal range of motion in the early stages of hip disease. The chief complaint of ON is pain that is typically located in the groin. Physical examination reveals pain with both active and passive range of motion, especially passive internal rotation and progresses in intensity in the late stages.

**RADIOGRAPH EVALUATION**

**Plain Radiographs**

Plain radiographs of the pelvis and hip are commonly used for diagnosis of hip dysplasia, FAI, or ON. However, additional studies might include a false-profile
view, a cross-table lateral, hip abduction views, and magnetic resonance imaging (MRI)-arthrogram of the hip to further evaluate labral pathology. A well-centered anteroposterior (AP) pelvic view is obtained when there is symmetry of the iliac wings and of the obturator foramina, and the coccyx is at a point in the midline with a distance of 0–2 cm above the symphysis pubis.\textsuperscript{11} A well-centered radiograph allows you to evaluate the borders of the acetabulum and assess for the presence of retroversion, coxa profunda, or protrusio (Table 2, Figure 1). The radiographs should be scrutinized for congruency of the femoral head and contour of the femoral head-neck junction. The grade of OA should also be classified according to the criteria described by Tönnis\textsuperscript{1} (Table 3). The lateral center-edge (LCE) angle of Wiberg,\textsuperscript{12} the acetabular index of the weight-
Determining acetabular version on the AP radiograph is critical for management of patients with either classic dysplasia or retroversion. Using a standardized AP pelvic X-ray as described above, the contours of the anterior and posterior wall edges usually meet superior and laterally. Reynolds et al.\textsuperscript{3} described a more distal meeting of the contours of the anterior and posterior wall edges that he called the “crossover sign”. The “crossover sign” is indicative of retroversion (Figure 3). Retroversion has been reported in up to one-sixth of hip dysplasias and must be taken into account at the time of correction.

Conventional and three-dimensional (3D) computed tomography (CT) scanning of the hip have been described for assessing acetabular version and FAI; however, arthro-MRI has gained acceptance for the diagnosis of these conditions as the protocol has been previously described.\textsuperscript{13-18} Axial, coronal oblique, sagittal oblique, and radial sequences should be obtained. The radial sequence is a proton density weighted sequence orthogonal to the femoral head-neck junction and is
a reconstruction of the true axial slice orthogonal to the acetabular plane and the sagittal oblique slice parallel to the acetabular plane. The radial sequence allows the ability to see 360° around the femoral head-neck junction.\(^{17}\) Arthro-MRI is used to diagnose labral pathology, presence of intraosseous ganglion formation, articular cartilage degeneration, and femoral head-neck junction abnormalities. The diagnostic sensitivity for labral tears using MR arthrography is high with reported sensitivity in the 1990s.\(^{16,18-20}\)

Plain radiographs are also the first step in assessment of AVN. Arlet and Ficat\(^{21}\) described four stages in the natural history and progression of the disease and are the most commonly used, although the Steinberg classification is the most complete with six subgroups\(^{22}\) and is the author’s classification system of choice (Table 4). MRI is the most accurate imaging modality used for diagnosis.\(^{23-25}\) Its sensitivity is thought to be between 88% and 100%.\(^{26,27}\) Because of low cost, some

### Table 4: The Steinberg Classification for Staging Osteonecrosis of the Femoral Head

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal radiograph, bone scan, and magnetic resonance imaging</td>
</tr>
<tr>
<td>I</td>
<td>Normal radiograph, abnormal bone scan, and/or magnetic resonance imaging</td>
</tr>
<tr>
<td>II</td>
<td>Abnormal radiograph showing “cystic” and sclerotic changes in the femoral head</td>
</tr>
<tr>
<td>III</td>
<td>Subchondral collapse producing a crescent sign</td>
</tr>
<tr>
<td>IV</td>
<td>Flattening of the femoral head</td>
</tr>
<tr>
<td>V</td>
<td>Joint narrowing with or without acetabular involvement</td>
</tr>
<tr>
<td>VI</td>
<td>Advanced degenerative changes</td>
</tr>
</tbody>
</table>

Note: The extent or grade of involvement should also be indicated as A, mild; B, moderate; or C, severe for stages II through V.

Figure 3: A crossover sign is present when the anterior and posterior acetabular walls crossover the femoral head.
surgeons bone scan as an alternative to MRI. A diseased femoral head will likely show a zone of increased activity which represents increased bone turnover.

TREATMENT OPTIONS

Hip Dysplasia

Hip arthroscopy for hip dysplasia accounts for 5% of all hip arthroscopy procedures. The most common indication for arthroscopy in dysplastic hips is treatment of tears of the hypertrophic labrum. However, it is now well understood that isolated treatment of labral pathology without addressing the structural abnormalities could lead to a poor outcome. Patients with moderate dysplasia as defined by evidence of instability, coxa valga with a neck-shaft angle of greater than 140°, a Tönnis angle greater than 10°, and a Wiberg angle less than 17° are not good for hip arthroscopy candidates, unless it is used as adjuvant management to periacetabular osteotomy (PAO).

Periacetabular osteotomy, initially described by Ganz et al., is the preferred pelvic osteotomy in many centers that treat young patients with hip dysplasia. Although there are multiple forms of acetabular osteotomy which are currently used for treatment of symptomatic hip dysplasia, PAO offers several advantages from a surgical standpoint. Those advantages include the ability to perform the osteotomy with a series of straight, reproducible cuts through one incision while preserving the abductors, the ability to permit a wide range of corrections, medially, laterally, and anteriorly while maintaining adequate acetabular version or change the acetabular version if needed, minimal internal fixation, and no external fixation since the posterior column is preserved. One also has the ability to perform a capsulotomy to assess the labrum and check for impingement without compromise to acetabular blood supply. Patient advantages include possible early mobilization and weight bearing since the posterior column is preserved as well as preservation of the pelvic ring and outlet which benefits female patients who plan to become pregnant and deliver vaginally.

The surgical techniques for PAO have been previously described and are beyond the scope of this text. However, it is important for the physician to select the appropriate patient. The ideal candidate for osteotomy is younger than 40 years with little, if any arthritis (Tönnis grade 1), a congruent hip joint with a round acetabulum and round femoral head has a poorly covered femoral head with lateralized hip center of rotation. The results of surgery in this group are predictably good. However, not all patients will fit this description. PAO is contraindicated in patients with complete dislocation and/or high subluxation with the femoral head articulating with a pseudoacetabulum, patients younger than 12 years as injury to the triradiate cartilage could result in acetabular retroversion,
and patients with poor hip range of motion\(^{37}\) (flexion <105° and abduction <30°). Femoral osteotomy is rarely used as sole management for acetabular dysplasia in the adult patient. However, there are indications for concomitant intertrochanteric osteotomy in approximately 10% of patients treated with PAO.

Several studies have reported on the results of PAO and younger age as well preoperative Tönnis grade have been most predictive of successful outcome.\(^{31,35,37,39-42}\)

**Retroversion and Femoral Acetabular Impingement**

*Surgical hip dislocation* is considered by some to be the gold standard for management of FAI. However, the popularity of hip arthroscopy has limited the use of surgical hip dislocation more recently to patients with more severe structural problems. It is now accepted that there are certain patients that would benefit from open surgery over arthroscopic mainly due to the anatomic limitations imposed during arthroscopic surgery. There is a wide range of structural deformity about the hip and each surgeon should be able to decide what they are able to correct with less invasive procedures such as hip arthroscopy.

Typical patients who still undergo surgical hip dislocation in the senior authors practice include cam lesions that wrap over the retinacular vessels. This can be seen on a CT scan or can be inferred on the AP pelvic radiograph when the cam lesion is visible on such view. Coxa profunda is defined as an LCE angle greater than 40°. If pincer impingement is the main structural deformity that is leading to the impingement, then open surgical procedures allow appropriate evaluation of the hip with 270° rim trimming with reattachment of the labrum throughout the circumference of the acetabulum. Those patients without a posterior wall sign indicating severe acetabular retroversion (not candidates for PAO) with severe acetabular retroversion and anterior inferior iliac spine impingement are best treated, in the authors’ hands with open surgical dislocation. With open dislocation, a thorough evaluation of impinging structures can be performed and, most importantly, the hip can be carried through a range of motion arc intraoperatively to determine improvements in range of motion. Anticipated labral reconstruction (using either fascia lata or round ligament) and high riding trochanter (old SCFE or Perthes) since trochanteric advancement and relative neck lengthening can be performed at the same time if necessary.

Surgery is contraindicated for patients with Tönnis grade 3 arthritis or higher OA, uncorrectable deformity and the patient who is older than 60 years of age in whom a total hip arthroplasty would likely be a better option.

*Hip arthroscopy* has been found to be a reliable surgical option for the treatment of FAI in recent years, with radiographic and clinical results comparable to open techniques with fewer complications.\(^{43-45}\) Of all the current indications for hip
Non-arthroplasty Options for Painful Hip in the Young Patient

arthroscopy, the best evidence exists for the arthroscopic management of FAI. Large series have been published on the treatment of FAI with hip arthroscopy with encouraging results in a variety of patient populations. The ideal candidate for arthroscopic treatment of FAI is the patient with intermittent, activity related hip pain, and findings on history and physical examination consistent with FAI who has failed a trial of nonoperative management including activity modification, selective use of physical therapy, and/or intra-articular injections and anti-inflammatory/pain medications. As previously discussed, radiographs should be scrutinized for pathology that may be best treated with an open surgical technique including findings typical of acetabular dysplasia, severe acetabular retroversion with posterior wall deficiency, and protrusio acetabuli.

Central compartment arthroscopy allows for management of labral pathology. Peripheral compartment access allows for treatment of mild to moderate cam lesions of the anterior lateral femoral head and neck junction and can be used to reattach the labrum.

A surgeon must be aware of the limitations of hip arthroscopy. Hip arthroscopy has a long learning curve. The surgeon should have significant experience in hip arthroscopy to treat the acetabular rim pathology using techniques similar to those described in open surgery. Arthroscopy is limited in assessing posterior FAI pathology, difficult to perform in patients with coxa profunda or protrusio, obese patients, and those with significant retroversion.

Periacetabular osteotomy for correction of retroversion in patients with FAI is indicated when there are findings of acetabular rim lesions on arthro-MRI and a positive anterior impingement test. Typically these patients will exhibit the characteristic positive “crossover” sign as well as a “posterior wall” sign which is indicative of poor posterior coverage (Figure 4). A treatment algorithm for acetabular retroversion should use measurements of acetabular coverage

Figure 4: The posterior wall sign is present when the posterior wall is medial to the center of the femoral head.
(LCE angle and the posterior wall sign) and condition of acetabular cartilage to direct treatment of acetabular retroversion. Early clinical results of acetabular reorientation for acetabular retroversion in a limited number of patients have been encouraging.\textsuperscript{35,50,51}

**Avascular Necrosis or Osteonecrosis**

Core decompression was described by Arlet and Ficat in 1964 and was used as part of a diagnostic protocol.\textsuperscript{52} However, patients who underwent this procedure reported lessening pain and it was instituted as a treatment modality. Success rates have varied depending on the stage of disease being treated.\textsuperscript{52-55} Today, bone grafting procedures are used as treatment and have been used alone or in combination with other procedures including core decompression. Vascularized fibular bone grafting has been used to promote vascular ingrowth in the healing bone. It is a technically difficult procedure that requires microvascular anastomosis between vessels from the graft and branches of the femoral artery that provide blood supply to the hip. Decompression of the femoral head and injection of mesenchymal stem cells into the necrotic lesion has also been popularized.\textsuperscript{56}

Osteotomies of the proximal femur have been attempted to offload the affected areas of the femoral head by shifting the major weight-bearing zones of the joint. The effectiveness of this procedure is still under evaluation, but recently mid- to long-term results are favorable when selecting the appropriate patients.\textsuperscript{57} Typically, this is reserved for patients less than 40 years of age and the extent of the disease is less limited (\(<\text{200°}\)) as one might be able to contain or deliver the osteonecrotic lesion.

The authors preferred treatment for early stage ON is to obtain both radiographs and MRI to define the extent of the disease. For stages 0 and I disease, if patients have small lesions and no pain, they are observed. If pain is present and have either stage I or II disease and the lesion is greater than 25% with ON limited to the hips then pluripotent stem cells are used as an adjuvant to decompression of the femoral head.

**CONCLUSION**

The treatment of the young active patient with hip disease is evolving. With our increased understanding of the pathophysiologic mechanisms associated with the development of OA in patients with classic and retroversion dysplasia, FAI or ON, it has become apparent that management should be aimed at preserving the hip joint when possible by recreating normal anatomy with the hopes of improving pain and function.
Non-arthroplasty Options for Painful Hip in the Young Patient

Editor’s Comment

Joint preservation procedures have been some of the most exciting recent developments in hip surgery. An explosion of information has populated the literature and vastly increased our understanding of hip pathology. A variety of treatment options for each condition have been developed and the outcomes of these joint preservation procedures have also been reported. Future research will help us to define which procedures best treat each condition and provide us with direction on appropriate use criteria. Hopefully, these procedures will not only improve short-term outcomes, but also help patients avoid future arthroplasty.

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Minimally Invasive Total Joint Arthroplasty: Myth or Mastery?

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ABSTRACT

The initial reports in the literature of minimally invasive surgery (MIS) techniques for hip and knee arthroplasty date back to the late 1990s. Since then, randomized clinical trials (RCTs) have been published regarding several minimally invasive techniques, but have presented mixed results for the efficacy and safety of these procedures as well as the finding that there are significant learning curves associated with these techniques. There is general agreement that MIS procedures are more difficult to perform than total joint arthroplasties performed through standard incisions, especially in the setting of low-volume joint replacement surgeons. To date, high-volume surgeons or innovators of MIS techniques have performed virtually all RCTs evaluating these procedures.

Several RCTs of MIS total knee arthroplasty have found few significant clinical benefits. From RCTs investigating total hip arthroplasty, benefits of MIS techniques have included a statistically significant shorter hospital stay, less postoperative pain, and less blood loss. The complication rates in these trials have generally been low for both MIS and standard techniques, although some meta-analyses have documented higher complication rates with MIS surgery.

Surgeons who do not perform high numbers of joint arthroplasties may find that their results cannot reproduce the improvements documented by innovators. These surgeons must give patients adequate informed consent regarding the results of experts so that patients do not have overly inflated expectations of their outcomes.

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INTRODUCTION

In recent years, there has been a growing interest toward less invasive surgery in orthopedics and other surgical specialties. In hip and knee total joint arthroplasty (TJA), minimally invasive surgery (MIS) techniques were introduced amidst controversy and enthusiasm. The goal behind this innovation was to minimize the trauma of surgery while maintaining high levels of safety, durability, and efficacy. Proponents of MIS techniques suggest that, if successful, one can expect shorter recovery times, reduced hospital stay, faster rehabilitation, decreased perioperative blood loss, and better cosmetic appearance. Critics report issues such as component malposition, neurovascular damage, wound-healing complications, prolonged operating time, and a steep learning curve as being barriers to widespread implementation of MIS techniques. Over the past decade several studies of varying designs have provided support for and against MIS techniques thus contributing to the controversy. When considering any new medical innovation, detailed analysis of the evidence evaluating both efficacy and safety outcomes must be performed. To critically assess the utility of MIS TJA, the relevant literature will be presented.

HISTORY

In the 1990s, the concept of reducing incision size and the “invasiveness” of joint replacement surgery started to experience growing popularity. The term “minimally invasive” or “mini-incision” surgery is an ambiguous concept based on several broad principles including smaller incisions (<10 cm), decreased dissection of soft tissue, use of a mobile surgical window and the use of modified or new instrumentation. The earliest investigators of MIS total hip arthroplasty (THA) implanted several different prostheses through a limited anterior approach with small secondary incisions for insertion of femoral prostheses. Others focused on modifying traditional hip approaches to limited incisions and less soft-tissue dissection. Since then, the concept of MIS THA has evolved to encompass a family of operations utilizing either one or two small-incision approaches to perform the procedure.

Minimally invasive surgery techniques for total knee arthroplasty (TKA) were first described in the setting of unicompartmental knee replacements. Popularization of the limited surgical approach for partial knee replacements translated to the application of these techniques in TKA. Along with use of a smaller incision, MIS TKA involves avoiding patellar eversion, limiting the extent of cutting into the quadriceps tendon, minimizing dissection in the suprapatellar pouch, performing in situ bone cuts to avoid joint dislocation, flexion, and extension of the lower limb for exposure, symbiotic use of retractors, inferior, and superior patellar capsular releases, using cut bone surfaces as guides and using downsized instrumentation.
The impetus for popularizing MIS techniques focused on its presumed association with reduced recovery times and improved pain control translating into shorter hospital stays and greater patient satisfaction. It is important to note that the introduction of MIS total joint surgery was accompanied by substantial advancements in perioperative anesthetic techniques including multimodal pain management pathways and aggressive rehabilitation protocols.\textsuperscript{14,15} Thus some reported benefits of MIS TKA may actually be due in part to the newly adopted clinical pathways.

**SURGICAL APPROACHES**

Minimally invasive surgery THA can be grouped into two categories: (i) mini-incision approaches and (ii) minimally invasive approaches.\textsuperscript{9} Mini-incision approaches are based on traditional exposures with limited skin incisions and minimal soft-tissue dissection. The mini-posterior and mini-direct lateral (Hardinge) approaches (Figure 1A) are two popular mini-incision techniques because of surgeon familiarity with each approach and the ability to convert each approach to the traditional exposure should unforeseen problems arise. The mini-posterior approach utilizes the same plane of dissection as the conventional posterior approach but minimizes the length of incision, the gluteus maximus split is minimized, the gluteus maximus tendon is no longer divided, and the piriformis tendon attachment is preserved when anatomy allows.\textsuperscript{16} The mini-direct lateral approach involves splitting the gluteus medius and vastus lateralis muscles in various ways to expose the anterior hip capsule through a smaller skin incision while limiting the extent by which each muscle is violated.\textsuperscript{17}

Minimally invasive hip approaches utilize intramuscular or internervous planes to minimize the cutting of muscles and tendons. These include the anterolateral, direct anterior, and two-incision approaches (Figure 1B).\textsuperscript{18-20} The anterior approach uses the internervous plane between the femoral nerve (sartorius and rectus femoris) and superior gluteal nerve (tensor fascia lata and gluteus medius). The anterolateral approach follows the intermuscular plane between gluteus medius and tensor fascia lata as initially described by Watson-Jones. The two-incision technique involves using a 5 cm anterior incision centered over the femoral neck to perform the anterior approach for accessing the acetabulum and performing the femoral neck osteotomy, and a 3 cm posterior incision that utilizes the internervous plane between gluteus medius and piriformis for femoral preparation and implantation. Modified retractors, specialized equipment, fluoroscopy, and modification of techniques (i.e., cutting the femoral neck in situ) are other innovations that contribute to the complexity of MIS THA.

Minimally invasive surgery TKA approaches include the mini-medial parapatellar, the quadriceps-sparing, the mini-subvastus, the mini-midvastus,
and the direct lateral. The most popular MIS TKA approach is the mini-medial parapatellar due to its familiarity and its ability to be extended to a traditional approach at any time. The approach is performed through a midline or slightly medial based incision extending from the superior pole of the patella to the superior portion of the tibial tubercle (Figure 2A). The proximal portion of the medial parapatellar arthrotomy extends into the quadriceps tendon by only 2–4 cm. The quadriceps-sparing approach involves a more limited medial parapatellar exposure wherein the arthrotomy is stopped at the superior pole of the patella (Figure 2B). The skin incision is straight or curved and placed just medial to the patella. Controversy around whether this approach is truly quadriceps-sparing exists because the vastus medialis obliquus (VMO) insertion goes distal to the midpole of the patella and, therefore, is detached from the medial border of the patella.22

The mini-subvastus exposure utilizes a straight midline or medially based incision starting from the superior pole of the patella to the superior portion of the tibial tubercle. After raising a medial full-thickness skin flap, a plane between the undersurface of the VMO and capsule is established and an arthrotomy is made along the inferior border of the VMO extending laterally to the midpole of the patella then turning distally to the medial border of the patellar tendon down to the tibial tubercle (Figure 2C). The mini-midvastus approach utilizes an arthrotomy that starts from just medial to the tibial tubercle and extends proximally to the superomedial corner of the patella, at which point the arthrotomy is turned medially, splitting the VMO in line with its fibers by 2 cm (Figure 2D).21

The direct lateral approach involves an exposure through the iliotibial band to visualize the knee.13 This approach requires navigation and novel instrumentation for preparation of bony surfaces.

Figure 1: Minimally invasive surgery total hip arthroplasty is grouped into two categories: A, mini-incision approaches and B, minimally invasive approaches.
Minimally Invasive Surgery: Total Hip Arthroplasty

Among the various MIS THA approaches, the mini-posterior is the most studied with associated randomized control trial (RCT) evidence. Unfortunately, the majority of literature pertaining to MIS THA is of low-quality based on levels of evidence described by the Oxford Centre for evidence-based medicine and modified by Wright et al. Between 1998 and 2008 only 9 RCTs in the English literature made direct comparisons between an MIS approach (mini-incision posterior or lateral techniques) and the equivalent standard approach, with no RCTs reported on the other MIS THA techniques (minimally invasive procedures). Indeed, during this time period, the majority of studies reported on the posterior approach whereas most case series involved the anterior approach.

Since 2008, there have been four published meta-analysis/systematic review studies assessing short-term clinical outcomes of MIS THA. In 2009, a systematic review of 12 randomized or quasi-randomized control trials totaling 1,205 hips (597 MIS THA and 608 standard THA) assessed operative time, blood loss, length of hospital stay, short-term functional outcome including the Harris hip score (HHS), adverse events, and radiologic outcomes. Operative times showed no significant difference between all MIS THA approaches versus standard approaches. They did find a statistically significant difference in operative time of 4.73 minutes favoring the mini-posterior incision versus the associated standard approach. Additionally, intraoperative blood loss was less in the MIS group compared to the standard group (weighed mean difference = -79.75 mL, range -125.45 mL to -34.04 mL, p = 0.0006). All other outcome measures showed...
no statistically significant difference between either group.\textsuperscript{25} In 2011, a systematic review of published and unpublished literature including all RCTs and non-RCTs comparing clinical and radiologic outcomes of MIS THA and conventional THA (28 studies involving 2,849 hips) found no significant difference in operative times, clinical outcome scores, radiological outcomes, and most complications.\textsuperscript{28} While intraoperative blood loss showed a statistically significant difference favoring MIS THA as compared to the standard group (mean difference = -42.44 mL, range -60.14 mL to -24.73 mL, \( p < 0.0001 \)), there was no statistical difference between groups with respect to drained postoperative blood loss, total blood loss or requirement for blood transfusion (\( p > 0.05 \)). MIS THA patients did report lower pain scores on a visual analog scale (VAS) (mean difference = 0.58 points, \( p = 0.02 \)) and a shorter hospital length of stay (mean difference = 0.59 days, \( p = 0.01 \)). There was a statistically significant difference in respect to iatrogenic nerve palsy (mainly the lateral femoral cutaneous nerve) with a 5 times greater rate of nerve palsy following MIS THA compared to conventional THA (\( p < 0.0001 \)). Two more recent meta-analysis studies have reported similar findings in regards to clinical and radiologic outcomes.\textsuperscript{26,27} It is important to note that many of the studies excluded patients with high body mass indices (BMIs) and were presumably undertaken by surgeons with particular expertise in MIS THA. As such, the authors of each study cautioned whether the reported complication rates and outcome results could be extrapolated to more heterogeneous patient groups and community.

The underlying rationale for using MIS THA to allow for earlier recovery and improved muscle function has been assessed through effects on gait kinematics.\textsuperscript{29} In an RCT of 20 patients randomized to either the MIS Watson-Jones approach or the traditional standard transgluteal Hardinge approach, no significant differences were detected in regards to temporospatial and joint-kinematic parameters at 10 days and 12 weeks postoperatively.\textsuperscript{29} Equivocal effects on postoperative recovery times and gait parameters have been noted in other RCTs as well.\textsuperscript{4,30} The safety of MIS THA has been assessed through several studies looking at component positioning and associated complications. In a consecutive series of 135 primary unilateral hip arthroplasties (50 MIS THA and 85 standard THA) comparing the mini-incision posterior approach to the conventional technique, there was a significantly higher risk of wound complication (\( p = 0.02 \)), higher percentage of acetabular component malposition (\( p = 0.04 \)), and poor fit and fill of femoral components inserted without cement (\( p = 0.0036 \)).\textsuperscript{5} In an RCT of 70 consecutive patients who underwent bilateral simultaneous total hip arthroplasties comparing MIS THA posterior approach with conventional posterior approach, there was actually an increased rate of infection using the MIS technique.\textsuperscript{31} A recent RCT comparing the piriformis-sparing approach with the standard
posterior approach in 100 patients (48 MIS, 52 standard) found the MIS technique to be significantly more difficult than the standard approach as perceived by the surgeons ($p = 0.03$), with significantly less anteversion of acetabular components ($p = 0.005$) and lower mean inclination angle ($p = 0.02$). However, in both groups the mean component positions were within Lewinnek’s safe zone. In contrast, an RCT involving 219 patients undergoing a mini-incision posterior approach or conventional approach by a single surgeon with high-volume experience with mini-incision techniques found no significant difference in component placement or other complications. Additionally, there was no difference noted in functional recovery at 6 weeks. They concluded that MIS TKA via mini-posterior incisions can be safe and reproducible when performed by a high-volume surgeon; however, there is really no significant benefit in the early postoperative period compared with the standard approach. A series looking at 46 revision THAs performed over a 3-year period at a high-volume academic center when infections or re-revisions were excluded identified primary MIS THA as a possible risk factor for early failure of THA. Twelve of fifteen patients having minimal incision (MI) THA required revision within 2 years of primary THA compared with 4 of 31 patients without MI surgery [odds ratio (OR) 26.5, 95% confidence interval (CI), 4.4–160.0].

The direct anterior approach (DAA) for THA has had mixed results in terms of safety particularly when reviewing surgeons inexperienced with the technique. In an observational cohort of 1,152 patients involving nine clinical centers, an acceptable complication profile was noted with a dislocation rate of 0.6% (up to 3 years follow-up). Interestingly, surgeons who had performed less than 100 cases were twofold more likely to have a complication in their patients compared with surgeons with greater experience (20.2% vs. 9.8%, $p = 0.049$). In a recent study of 46 patients who underwent a THA using the DAA by two surgeons with internal education and cadaver training while being supervised and assisted by an experienced orthopedic surgeon with 5 years of experience using the DAA, there was an increased risk of complication (trochanteric fracture, cup migration, and femoral stem subsidence) up to 1 year postoperatively when compared to a matched cohort of patients who underwent THA using the conventional posterior approach. A study focused on short-term results from a community hospital utilizing the DAA technique reviewed 231 consecutive patients (247 hips) who underwent surgery by five community practice surgeons. In this study, the average surgical time (164 minutes) and estimated blood loss (858 mL) were more than double and the major complication rate (9%) was 6 times that reported by the innovator of the procedure. The major complications included 16 femoral shaft or trochanteric fractures, 2 deep infections requiring resection arthroplasties, 2 peroneal nerve injuries, and 3 immediate reoperations for leg length discrepancy (within 24 hours).
Perhaps the most controversial MIS THA approach is the two-incision technique due to its unique and unfamiliar dissection planes resulting in an associated lengthy learning curve and complication rate.\textsuperscript{37} Developers of the technique reported results on 375 hips and found a minor complication rate of 2.1\% and major complication rate of 1.3\%.\textsuperscript{2} This was in stark contrast to several studies that reported relatively higher complication rates including femoral fractures and an unacceptably high rate of component malposition.\textsuperscript{37,38} The two-incision technique also has been purported to spare cutting muscles and tendons despite a cadaveric study of 10 hips refuting this claim.\textsuperscript{39}

**Minimally Invasive Surgery: Total Knee Arthroplasty**

A number of published studies focusing on short-term outcomes of MIS TKA have surfaced. In a recent meta-analysis of 18 RCTs comparing clinical and/or radiologic outcomes of MIS TKA with conventional TKA, 1,582 TKAs were reviewed: 822 MIS TKA versus 760 conventional TKA.\textsuperscript{40} The primary outcome of this study was the Knee Society Score. Secondary outcomes included blood loss, requirement for blood transfusion, length of hospital stay, surgical duration, VAS pain, knee range of motion, quadriceps strength, activity, incidence of radiolucency, difference in the femoral radiologic axis, and valgus/varus implant placement greater than 3 degrees. Complications recorded included nerve palsy, femoral notching, wound healing issues, deep vein thrombosis, deep and superficial infection, and the need for revision surgery to address arthrofibrosis. The quality of studies was judged to have a number of recurrent limitations including lack of concealment of randomization procedures, lack of blinding of patients and/or assessors, failure to demonstrate baseline comparability between study groups, and inadequate follow-up. Nevertheless, this study found no statistically significant difference in clinical or radiologic outcomes between MIS or conventional TKA except for the length of incision (smaller in MIS, \(p = 0.01\)) and the flexion range of motion (greater in MIS, \(p = 0.01\)).\textsuperscript{40} In another review of 23 studies (level one and two evidence) comparing MIS TKA with conventional TKA, no statistically significant difference was noted between perioperative factors, clinical/radiologic outcomes, survivorship, or complications.\textsuperscript{41} The only significant difference observed was in recovery of the quadriceps muscle function (slightly shorter in MIS TKA). The MIS lateral approach was found to have more complications than the other MIS approaches, while the mini-midvastus approach trended toward having the best clinical outcomes at 1 and 3 months compared to the other approaches.

In an RCT of 44 patients (22 men, 22 women) comparing the mini-medial parapatellar approach to the conventional approach, at 4 weeks after TKA, the MIS group had greater hamstrings strength (\(p = 0.02\)) and a trend toward
better quadriceps strength (p = 0.07) compared to the control.\textsuperscript{42} Interestingly, the differences in muscle strength did not translate into differences in function performance (stair climbing test and 6-minute walk test). Additionally, there were no significant differences between the groups in regards to knee pain, active range of motion, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), or Short Form 36. At 12 weeks, the difference in muscle strength between groups was no longer evident. Two other recently published RCTs comparing MIS TKA with conventional TKA also found no significant difference in clinical or radiologic outcomes aside from length of surgical scar and blood loss.\textsuperscript{43,44}

The safety of MIS TKA has been evaluated in a number of studies. Specifically, complications of concern include increased operating room time, component malalignment, longer tourniquet times, a higher rate of intraoperative ligament ruptures, and unanticipated retention of cement.\textsuperscript{45,46} In an RCT of 100 patients undergoing either the mini-midvastus approach or the standard medial parapatellar approach with a mean follow-up of 2 years, the mini-midvastus group was found to have a significantly better functional outcome (as illustrated by the Oxford Knee Score, p = 0.05) up to 9 months after surgery and better flexion at 21 days after surgery (p = 0.04). However, these differences were not observed at final follow-up.\textsuperscript{46} Of concern in this study was a higher rate of technical errors, as 12% of patients in the MIS TKA group demonstrated varus malposition of the tibial component and longer length of surgery. Additionally, 6 of 56 patients randomized to the MIS group had to be converted to a standard approach due to partial patellar tendon avulsion in 2 patients, an inability to displace the patella laterally in 2 patients, and significant soft tissue tightness preventing adequate exposure in the remaining 2 patients.

In a recent meta-analysis of 9 RCTs focused on comparing the incidence of complications between MIS TKA and standard TKA, there were 59 total complications in the MIS group compared with 39 in the standard incision group. When looking specifically at just local surgical complications, there was 95% greater number of complications in the MIS group compared with the standard incision group (41 vs. 21, respectively). This demonstrated a statistically significant increase in complication rates for MIS TKA compared with standard TKA (OR for complications in the MIS TKA group was 1.58, 95% CI, 1.01–2.47; p = 0.04).\textsuperscript{47} There were no significant differences in postoperative alignment or KSS at 3 months between the two groups. Another study actually identified MI TKA as a possible risk factor for early revision due to the associated risk of increased complication.\textsuperscript{48}

The long learning curve associated with MIS TKA is another concern. One study comparing 100 MIS TKAs with 50 conventional TKAs estimated a
learning curve of approximately 50 cases for a high-volume surgeon.\textsuperscript{49} Overall, the MIS TKA took longer to perform than the standard approach (86.4 vs. 78.9 minutes, respectively, $p = 0.01$). The first 25 MIS TKAs had an especially long operative time (mean = 102.5 minutes), significantly less patellar resection accuracy ($p < 0.001$) and more patellar tilt than the last 25 cases ($p = 0.006$).

CONCLUSION

Despite the purported benefits of MIS techniques described by innovators of these procedures, significant concern remains over the safety of these procedures when implemented by low-volume arthroplasty surgeons. Initial studies on MIS techniques have contained conflicting data. When focusing on level one and two studies, few clinically significant benefits have been identified. Statistically significant advantages of MIS THA have included a shorter hospital stay, less postoperative pain, and less perioperative blood loss. However, these statistically significant differences were not clinically important in most instances (e.g., a decrease blood loss of 40–80 mL). Available evidence suggests MIS TKA results in earlier muscle recovery and better early range of motion when compared to conventional TKA. However, these advantages come at the cost of longer time of surgery, steep surgical learning curve, increased technical errors, higher risk of component malposition, neurovascular injury, and a greater risk of early reoperation. Additionally, critics of MIS techniques have suggested that the potential benefits of MIS identified in the literature may be influenced by the recent adoption of more aggressive and innovative anesthetic protocols aimed at early rehabilitation. Another aspect of MIS total joint surgery that has yet to be analyzed is whether the long-term outcomes are equivalent to conventional techniques. Indeed, for MIS techniques to have a role in contemporary total joint surgery, rates of long-term failure and risk of revision must be determined. Long-term durability should not be compromised for limited improvement in short-term outcomes.

Innovators of MIS techniques and high-volume arthroplasty surgeons have performed the majority of studies involving MIS techniques. Surgeons who do not perform high volumes of joint arthroplasties may find they cannot reproduce the benefits documented in the literature. Unfortunately, marketing schemes directed at patients often paint a picture of MIS surgery that is not supported by current literature. As such, patients undergoing MIS total joint surgery must be fully informed regarding the results of experts so that these patients do not have unrealistic expectations of their outcomes.
Editor’s Comment

The outcomes of total hip and total knee arthroplasty have demonstrated a range from good to excellent durability and return to function using traditional approaches. Surgeons are constantly seeking new techniques to improve the outcomes of total joint arthroplasty. Minimally invasive total joint arthroplasty was heralded to improve patient recovery and lessen pain. However, marketing often trumps careful release of newer surgical techniques, and harm can often befall patients. Furthermore, the effects ascribed to the surgical technique may be more related to perioperative pain management, adjustment of patient expectations, and accelerated physical therapy regimes. One must be aware that such techniques are often more technically challenging and subject to significant learning curves.

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Perioperative Pain Management: The Secret Behind Rapid Recovery

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ABSTRACT
Patients undergoing orthopedic surgery experience significant pain. Studies have shown that severe pain occurs in up to 60% of patients, and moderate pain in up to 30% of patients who undergo total knee arthroplasty (TKA).\(^1\)
The importance of pain control extends beyond patient satisfaction. Some of the consequences of severe postoperative pain include prolonged hospital stays, increased hospital readmissions, incomplete physical therapy, increased opioid use and associated side effects, as well as potentially greater cost.\(^2,3\)

INTRODUCTION
Rapid recovery involves optimizing all phases of the perioperative period. This includes patient education, using minimally invasive techniques, controlling postoperative pain with multimodal analgesia, and finally beginning aggressive rehabilitation to improve functional mobility early. One study examined the impact of clinical pathways on length of stay for patients undergoing total hip arthroplasty (THA) or total knee arthroplasty (TKA) in a community hospital. The average length of stay for patients undergoing THA decreased from 4.41 days to 3.24 days, and for patients undergoing TKA the length of stay decreased from 3.92 days to 2.98 days. In addition, implementation of the pathway did not increase complication rates or readmissions.\(^4\)

PREOPERATIVE PHASE
Preoperative patient education and setting realistic goals are key components to rapid recovery. Typical patient education consists of pamphlets that are given to

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the patient before surgery and verbal instructions from the physicians and nurses on the day of surgery. Ideally, preoperative patient education should begin in the surgeon’s office, continue through preadmission testing, and be completed at admission. Psychological preparation of patients undergoing surgery has been shown to shorten hospital stays and to reduce the need for postoperative analgesics.5

A complete history and physical should be taken prior to surgery to identify challenging populations, including opioid-tolerant, elderly, and physically limited patients. It is important to have a plan in place to treat these patients. Opioid-tolerant patients are at risk for high postoperative opioid requirements. It is important to give the patient his or her baseline dose and then additional medication to cover the surgical and breakthrough pain. A multimodal approach involving nonopioid agents and regional anesthesia techniques whenever possible can potentially reduce opioid requirements, as well as their undesirable side effects.

Preemptive analgesia with multimodal therapy is used to control pain in efforts to accelerate rehabilitation. Preemptive analgesia refers to the idea that postoperative pain may be significantly decreased by administering analgesic medications prior to surgical incision in order to prevent the establishment of peripheral and central sensitization. Preemptive analgesia has been shown to be effective in animal models but has had mixed results in humans. Duellman et al. demonstrated a decrease in postoperative opioid requirements and increased rehabilitation participation in patients who received preemptive oxycodone and a selective cyclooxygenase-2 (COX-2) inhibitor compared to postoperative patient-controlled analgesia (PCA). In addition, patients receiving preemptive analgesia had a decreased hospital length of stay and reduced likelihood of discharge to a skilled nursing facility.6 To the contrary, Dahl and Møiniche in 2004 found equivocal evidence that preemptive analgesia decreases postoperative pain or need for supplemental analgesics.7

Multimodal analgesia, whether given preemptively or not, is achieved by combining analgesics with different mechanisms of action at different receptors in the nervous system with the goal of blocking pain signals at several sites. True multimodal therapy typically involves giving two or more nonopioid agents around-the-clock. Guidelines recommend that all patients should receive around-the-clock nonsteroidal anti-inflammatory drugs (NSAIDs), COX-2 inhibitors, or acetaminophen.8 Extensive research has demonstrated the efficacy of multimodal analgesia in reducing postoperative pain. Peters et al. retrospectively compared two cohorts of 50 consecutive total joint arthroplasty (TJA) patients before and after implementing a multimodal protocol of scheduled oral opioids, COX-2 inhibitors, femoral nerve catheters, and periarticular injections. Significant improvements in postoperative pain and walking distance were noted as well as decreased opioid consumption and length of stay in the multimodal cohort.9
Acetaminophen

Acetaminophen has been used as an effective oral analgesic and antipyretic for decades and has been approved for use in the United States as an intravenous formulation since 2010 but available elsewhere in the world for almost a decade. The mechanism of acetaminophen is not completely understood. The main mechanism proposed is the inhibition of COX and recent findings suggest that it is highly selective for COX-2. Other postulated mechanisms include modulation of the serotonergic and opioid systems and inhibition of nitric oxide generation. Acetaminophen lacks the side effect profile associated with NSAIDs in regards to platelet inhibition, renal impairment, and gastric irritation with its most serious side effect being hepatotoxicity. Sinatra et al. demonstrated that patients who received acetaminophen 1 g every 6 hours for 24 hours reported better pain control and satisfaction as well as 33% reduction in morphine consumption (Table 1).

Acetaminophen is well tolerated in all forms by most patients and has few contraindications other than severe hepatic impairment. Care must be taken to avoid unintended dosing with multiple agents containing acetaminophen and exceeding the maximum recommended dose of 4 g per day in adults. Maximal benefit may be seen when acetaminophen is given every 6 hours for a total of 4 g compared to lower doses.

Nonsteroidal Anti-inflammatory Drugs and Cyclooxygenase Inhibitors

Prostaglandins, including prostaglandin E2 (PGE2), are responsible for reducing the pain threshold at the site of injury, which can lead to central sensitization

<table>
<thead>
<tr>
<th>Table 1: Oral Analgesics and Dosing</th>
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<tbody>
<tr>
<td>Preoperative dose (mg)</td>
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<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Ketorolac</td>
</tr>
<tr>
<td>Celecoxib</td>
</tr>
<tr>
<td>Gabapentin</td>
</tr>
<tr>
<td>Pregabalin</td>
</tr>
<tr>
<td>Acetaminophen</td>
</tr>
</tbody>
</table>

*The lower dose is recommended for the elderly and those with impaired renal function.

IV, intravenous; PO, per os.
and a lower pain threshold in the surrounding tissues. Traditional NSAIDs are nonspecific and inhibit both COX-1 and COX-2 enzymes, whereas COX-2 inhibitors are selective for COX-2 isoenzymes and may cause fewer gastrointestinal side effects. COX converts arachidonic acid to prostaglandins and leukotriene. COX-1 is primarily present in the stomach and kidneys and blocking it can result in gastrointestinal and renal side effects. COX-2 is primarily associated with inflammation and is the primary target of NSAIDs. NSAIDs also reduce prostaglandin production associated with the pyrogen interleukin-1, resulting in antipyretic action. Conversely, COX-2 selectivity tends to promote thrombosis. With both COX-2 selective and nonselective NSAIDs, there is a balance between COX-1 and COX-2 effect. For example, ketorolac has more COX-1 activity. Celecoxib is somewhat more COX-2 selective. Rofecoxib (no longer available) is highly COX-2 selective, which accounted for its reported prothrombotic activity. Most other NSAIDs have a moderately equal balance between COX-1 and COX-2.

**Neuropathic Agents**

Gabapentinoids (gabapentin and pregabalin) bind to the alpha subunit of voltage-gated calcium channels in the spinal cord and the brain. Their mechanism of action is via inhibition of the presynaptic voltage-gated calcium channels in the dorsal horn of the spinal cord, thus reducing afferent excitatory signaling. Sedation and confusion are the most common side effects of the gabapentinoids. In a study by Jain et al., patients were randomly assigned to receive either placebo or pregabalin 75 mg twice a day (Table 1). The medication was administered before surgery and continued for 2 days after surgery. Mean morphine consumption was significantly reduced by pregabalin. Postoperative pain was also significantly reduced in the pregabalin group during the first 48 hours after surgery. This group needed fewer rescue analgesics and recorded higher overall patient satisfaction. In a systematic review by Hurley et al., perioperative gabapentin was shown to decrease visual analog scores at 4 and 24 hours postoperatively, concluding that it would make a reasonable addition to a multimodal treatment plan.

**INTRAOPERATIVE MANAGEMENT**

Patients undergoing orthopedic surgery may be offered general or regional anesthesia. The impact of anesthetic technique on perioperative outcomes remains controversial. Spinal anesthesia is most commonly achieved by injecting a local anesthetic with or without opioids into the intrathecal space. Epidural anesthesia typically involves threading a catheter into the epidural space and injecting local anesthetics and/or opioids. An advantage of epidural over spinal anesthesia is that it can be maintained to provide effective analgesia during the
postoperative period. However, the block from an epidural anesthetic is often not as dense as that of a spinal. Consequently, the motor block may be less intense, resulting in less than ideal operating conditions. A recent meta-analysis concluded that neuraxial anesthesia was associated with superior perioperative outcomes, including 30-day mortality, compared to general anesthesia for orthopedic surgery.\(^\text{17}\) Possible benefits of neuraxial anesthesia include decreased incidence of postoperative nausea and vomiting, superior motor block, and decreased surgical blood loss.\(^\text{18}\)

Hu et al. demonstrated that regional anesthesia was associated with a significant reduction in operating time, need for transfusion, nausea and vomiting, and incidence of thromboembolic events, including deep vein thrombosis.\(^\text{19}\) Neuraxial anesthesia attenuates the blood pressure increase with tourniquet inflation, which may lead to a decrease in hypercoagulability.\(^\text{20}\) In a large retrospective review, epidural anesthesia was found to significantly reduce the incidence of proximal thrombosis following total knee replacement (TKR) using a tourniquet.\(^\text{21}\)

**POSTOPERATIVE PERIOD**

Peripheral nerve blocks can be administered as a single-shot injection or a continuous catheter. Paul et al. concluded in a meta-analysis that femoral nerve blocks (FNBs) provided superior analgesia compared to PCA and decreased opioid consumption in patients undergoing TKA. The addition of a continuous FNB or sciatic block failed to show a decrease in pain scores, morphine consumption, or associated side effects. However, few trials in the analysis directly compared single-injection FNB to continuous FNB, and additional studies are needed to make firm conclusions regarding continuous FNB for TKA.\(^\text{22}\)

Effective pain management after TJA can help with rehabilitation and improve outcomes.\(^\text{9}\) TJA patients will likely receive an opioid at some point during their postoperative course. If a patient receives PCA, he or she must be willing to participate and understand how to operate the device. For patients undergoing THA postoperative analgesia can include an epidural, PCA, or a lumbar plexus block (Table 2). Patients undergoing TKA may benefit postoperatively from PCA, an FNB, an epidural, or an intra-articular infusion (Table 2).\(^\text{17}\) Continuing multimodal analgesia in combination with PCA may reduce opioid requirements, resulting in better pain control and fewer side effects.

Despite the advances in postoperative analgesia after TKA, some patients may still develop chronic pain after TKA. In a study by Buvanendran et al., pregabalin was shown to decrease the incidence of chronic neuropathic pain after TKA. Patients given pregabalin consumed less opioid and showed better range of motion during the first 30 days of rehabilitation.\(^\text{23}\)

Oral analgesics and dosing, comparison of postoperative analgesic techniques, and timing of therapy are given in Tables 1–3.
Table 2: Comparison of Postoperative Analgesic Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Spinal opioids</td>
<td>• No indwelling catheter</td>
<td>• Lacks ability to titrate</td>
</tr>
<tr>
<td></td>
<td>• Reduced opioid use</td>
<td>• Limited duration</td>
</tr>
<tr>
<td>Epidural opioids/local anesthetics</td>
<td>• Ability to titrate</td>
<td>• Hypotension</td>
</tr>
<tr>
<td></td>
<td>• Earlier mobilization</td>
<td>• Urinary retention</td>
</tr>
<tr>
<td></td>
<td>• Reduced opioid use</td>
<td>• Unilateral block</td>
</tr>
<tr>
<td></td>
<td>• Anticoagulation issues</td>
<td>• Anticoagulation issues</td>
</tr>
<tr>
<td></td>
<td>• Respiratory depression</td>
<td>• Risk of PDPH</td>
</tr>
<tr>
<td>Single-injection femoral nerve block</td>
<td>• Compatible with anticoagulation</td>
<td>• Equipment issues</td>
</tr>
<tr>
<td></td>
<td>• No hypotension</td>
<td>• Potential for motor blockade</td>
</tr>
<tr>
<td></td>
<td>• No urinary retention</td>
<td></td>
</tr>
<tr>
<td>Continuous femoral nerve block</td>
<td>• Ability to titrate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Earlier mobilization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No hypotension</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No urinary retention</td>
<td></td>
</tr>
<tr>
<td>Adductor canal block</td>
<td>• Compatible with anticoagulation</td>
<td>• Still some potential for quadriceps weakness</td>
</tr>
<tr>
<td></td>
<td>• No hypotension</td>
<td>• Requires experience and specialized training to perform</td>
</tr>
<tr>
<td></td>
<td>• Potentially less quadriceps weakness than a femoral block</td>
<td></td>
</tr>
<tr>
<td>Lumbar plexus block</td>
<td>• Unilateral sympathectomy</td>
<td>• Technically more difficult to perform</td>
</tr>
<tr>
<td></td>
<td>• Significant hypotension is rare</td>
<td>• Increased risk of bleeding compared to other peripheral nerve blocks</td>
</tr>
<tr>
<td>Intra-articular wound infusion</td>
<td>• Compatible with anticoagulation</td>
<td>• Equipment issues</td>
</tr>
<tr>
<td></td>
<td>• Few side effects</td>
<td>• Concern for wound healing</td>
</tr>
<tr>
<td>Patient-controlled analgesia</td>
<td>• Fewer analgesic gaps</td>
<td>• Efficacy not well documented</td>
</tr>
<tr>
<td></td>
<td>• Less use of nursing staff time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Improved patient satisfaction compared to PRN opioids</td>
<td></td>
</tr>
</tbody>
</table>

PDPH, postdural puncture headache; PRN, pro re nata (as needed).
CONCLUSION

Rapid recovery after TJA involves optimizing the entire perioperative period. A team approach involving surgeons, anesthesiologists, nurses, physical therapists, and case management is the most effective strategy. It is imperative to identify special patient populations and have a plan for their perioperative course. By using a combination of around-the-clock multimodal therapy, regional anesthesia and analgesia, as well as opioids, to control their pain, patients can potentially begin rehabilitation earlier and have shorter lengths of stay.

<table>
<thead>
<tr>
<th>Time period</th>
<th>TKA and THA</th>
<th>TKA only</th>
</tr>
</thead>
</table>
| Preoperative | • Acetaminophen  
• Celecoxib  
• Pregabalin  |  |
| Intraoperative | • Spinal  
• CSE  
• General  |  |
| Postoperative | • Epidural  
• Acetaminophen  
• Lumbar plexus block  
• Pregabalin  
• Celecoxib  
• IV PCA  
• PO opioids  | • Adductor canal block  
• FNB  
• Intra-articular wound infusion  |

THA, total hip arthroplasty; TKA, total knee arthroplasty; CSE, combined spinal-epidural; FNB, femoral nerve block; IV PCA, intravenous patient-controlled analgesia; POs, prescription opioids.

Editor’s Comment

Pain is one of the main reasons why patients are reluctant to undergo surgery. Recently, a focus on pain management has appropriately directed better resources and techniques to make the recovery from orthopedic surgery more tolerable. Improved pain management techniques allow for earlier and more aggressive rehabilitation, returning the patient to a productive lifestyle. These techniques also have been shown to reduce hospital stays, increase patient satisfaction, and reduce the need for narcotic medications during the acute postoperative period. A multimodal approach to pain management with a multidisciplinary team may be one of the greatest improvements in the care of orthopedic patients over the last decade.

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Gregg R Klein
REFERENCES


http://e-surg.com
Diagnosis and Treatment of Infected Total Joint Arthroplasty

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ABSTRACT

A comprehensive management plan for identification, treatment, and revision reconstruction is necessary for successful eradication of infection in a total joint. This article reviews all of these important steps and demonstrates an effective two-stage protocol that can be employed in the majority of cases.

INTRODUCTION

Infection following total joint arthroplasty (TJA) remains a difficult problem for patients and the treating surgeon. Fortunately, improved surgical techniques and perioperative care have decreased the rate of deep prosthetic infection. Despite improved care, infection for a percentage of cases remains inevitable. In a review of 124,759 primary total hip arthroplasties (THAs) from the Norwegian Arthroplasty Register, Engesaeter et al. demonstrated an infection rate requiring revision surgery of 0.7%. As the cause of 14.8% of revision THAs, periprosthetic infection was the third leading cause for revision. With an exponential rise in the number of annual TJAs, even with a low infection rate, deep periprosthetic infection will continue to be a common cause of painful and failed TJA.

A commonly performed procedure in the face of early periprosthetic infection remains debridement with retention of components. Concerns remain regarding the efficacy of this intervention. Numerous recent studies demonstrate high failure rates with a narrow window for successful intervention. One recent series
demonstrated only a 60% 2-year survival rate in 99 patients treated with retention of components despite 89% of patients remaining on oral antibiotic suppression. Risk factors for failure in this series include the presence of a sinus tract and duration of symptoms greater than 7 days with 2-year success rates of 39% and 49%, respectively. Only 12.5% of patients with *Staphylococcus aureus* infection were successfully treated with retained components in this series. A similar series demonstrated the window of opportunity for successful debridement with retention of components in the presence of *S. aureus* to be only 2 days, with a relative risk of 4.2 for failure with further delay.

Currently, the “gold standard” for treatment of an infected TJA remains a two-stage revision. During the first stage, resection of the infected prosthesis and soft tissue debridement is performed followed by placement of an antibiotic impregnated cement spacer. The second stage, usually performed 8–12 weeks later, includes redebridement and reimplantation. The successful eradication of infection with two-stage revision averages 80–93%. However, success rates with resistant bacteria have been reported to be as low as 47%. In addition, patients who have failed a previous two-stage procedure with a resistant organism have a success rate of approximately 25%. While earlier studies following two-stage revision focused only on short-term cure rates, a more recent study looking at mid- to long-term follow-up of staged hip reimplantation raised additional concerns. The 10-year survival rates free of infection or mechanical failure were 87.5% and 75.2% respectively following two-stage revision in 169 hips.

Despite being the “gold standard”, two-stage revision results in a significant failure rate, significant patient morbidity, and high costs. For these reasons, two-stage revision is recognized as being far from ideal for the patient, surgeon, hospital, and healthcare system and there is increased interest in the idea of a single-stage exchange for the treatment of deep infection. Jackson and Schmalzried demonstrated an 83% success rate for eradication of infection with a direct exchange in 1,077 infected THAs. Additionally, the Norwegian Arthroplasty Registry demonstrated an 88% 2-year Kaplan–Meier survivorship for a single-stage THA exchange compared to a 92% survivorship for two-stage THA revision. While most studies available in the literature focus on eradication of infection as the sole outcome measure, Wolf et al. looked a quality-adjusted life years in their literature review comparing single- versus two-stage revision. They demonstrated one-stage revision to be superior, when considering both short- and long-term outcome models with both patient and surgeon derived outcomes. Klouche et al. performed a cost analysis and determined two-stage revision to have a 1.7-fold increase in cost compared to single-stage revision for infection. Hence, there is interest in the idea of a one-stage exchange; however, the appropriate selection criteria and surgical techniques are both unclear and unfamiliar to many North American surgeons. For example most one-stage hip revisions are performed with
fully cemented components (which are rarely utilized in North America) and one-stage knee procedures oftentimes have included sacrifice of the collateral ligaments and the use of hinged knee implants with fully cemented stems. Hence, additional study will be required to determine if these techniques will be successful in North American hands or if techniques more familiar to North American surgeons can reproduce European results with a one-stage exchange.

Case Study 1

Infected Bilateral Total Knee Arthroplasty

Chief Complaint: Fever and Bilateral Knee Pain

History of present illness: A 48-year-old male presented to the emergency room with fever and a 2-week history of worsening bilateral pain. The patient underwent simultaneous bilateral total knee arthroplasty (TKA) 4 years prior. The patient was found to be febrile with a leukocytosis and large bilateral knee effusions on presentation in the emergency room. The patient's blood cultures and bilateral knee aspiration demonstrated methicillin-resistant S. aureus (MRSA). The patient has a prior history of MRSA-infected lumbar fusion requiring removal of hardware.

Past medical history: The patient has a psychiatric history of post-traumatic stress disorder and depression following deployment to Afghanistan.

X-rays at presentation: Preoperative bilateral knee X-rays are shown in figure 1.

Diagnosis: Hematogenous Bilateral TKA MRSA Infection

Treatment: Based on the severity (bacteremia and leukocytosis) and chronicity (at least 2-week history of worsening pain) of the infection, we proceeded with aggressive debridement and resection arthroplasty on a semi-urgent basis. Bilateral articulating spacers were utilized to enable mobilization. Two different techniques were employed. On the right, a femoral stem was coated with high-dose antibiotic impregnated cement and a Steinmann pin was placed in an all polyethylene tibial component to improve intramedullary delivery of antibiotics. On the left, cement dowels were utilized to treat the intramedullary canals. Both spacers included a cruciate retaining femoral design and an all polyethylene tibia. Vancomycin (4 g/batch of cement) and tobramycin (4.8 g/batch of cement) were utilized in the cement bilaterally.

Articulating spacer X-rays: Postoperative articulating spacer X-rays are shown in figure 2.

Postoperative care: The patient was treated with 6 weeks of parenteral antibiotics during which time weight bearing and range of motion were allowed as tolerated.
Three weeks following the discontinuation of antibiotic therapy, a C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) were drawn. The lab values both normalized. Bilateral aspirations were performed and demonstrated negative cultures with a nucleated cell count of less than 1,000 nucleated cells/µL. The patient underwent bilateral TKA reimplantation with uncemented stems and
a constrained condylar knee. Trabecular metal tibial cones managed moderate tibial metaphyseal bone loss. The patient remained infection-free at 1-year follow-up. Postoperative X-rays are shown in figure 3.
This article will review the preoperative evaluation, intraoperative, and postoperative care for the infected TJA. Currently, two-stage revision with an articulating spacer is the preferred method of treatment for most periprosthetic infections at our institutions.

Figure 3: Postoperative X-rays.
INDICATIONS AND PREOPERATIVE EVALUATION

Diagnosing the infected TJA is based on history and physical examination, laboratory tests, radiographic evaluation, joint aspiration, and occasionally advanced imaging. Comprehensive guidelines and evidence-based reporting are included in the American Academy of Orthopedic Surgery Clinical Guidelines.\(^{13}\)

History

A thorough history is critical. Attention should be paid to recent fever, wound complication, remote or recent infection, and a history of pain since the index procedure. Risk factors should also be noted. Major risk factors include diabetes mellitus, obesity, inflammatory arthritis, chronic renal insufficiency, malignancy, steroid dependency, malnutrition, immunologic compromise, and psoriasis or skin disorders.

Examination

While physical examination is often not diagnostic, some key elements must be noted. The prior incision should be examined. Drainage or a sinus tract would strongly suggest infection. Additionally, the location of prior incisions and the approach previously utilized should be noted as this will be critical information for revision surgery. In many cases, however, physical examination findings can be more subtle.

Laboratory Tests

In every patient that presents to the office for evaluation of a painful TJA, routine laboratory tests are ordered. These tests include an ESR and a CRP.\(^{14}\) These tests are easily performed, inexpensive, and have high sensitivity. Recently the utility of the serum leukocyte count has come into question and hence is no longer performed routinely in our practices. If the ESR and/or CRP are elevated, or if the clinical history or physical examination is highly suggestive of infection, further evaluated for infection with joint aspiration is routine. While further studies are needed, some early work has suggested that interleukin-6 (IL-6) can play a role in the diagnosis of TJA infection; however, this test is not widely available.\(^{15}\)

Joint Aspiration

In our practice, all patients who present with a painful TJA and have an elevated CRP or ESR, or a clinical history that is suggestive of infection, undergo aspiration
before revision surgery. Routine aspiration, particularly of hips, prior to revision is avoided as false-positive rates have been reported as high as 13%. Synovial fluid obtained is sent for a synovial fluid white blood cell (WBC) count, differential, and culture.

For the diagnosis of chronic infection, the optimal cut-off values for the synovial fluid WBC count are approximately 3,000 WBCs/µL (range 1,600–4,300 WBCs/µL) with 70% polymorphonuclear neutrophils (PMNs) (range 60–80%). In the early postoperative period (within the first 6 weeks), these cut-off values are higher, being approximately 10,000 WBCs/µL and 90% PMNs for the differential. Recent antibiotic use has been shown to affect culture results, and patients should be off of antibiotics for a minimum of 2 weeks prior to aspiration, although longer antibiotic-free intervals may be required to culture more fastidious organisms. Cultures are routinely held for 5 days, but if an atypical organism or fungal infection is suspected, it may be necessary to hold cultures up to 4 weeks.

### Imaging

A close review of an adequate set of radiographs is essential and serial radiographs are oftentimes most helpful. Evidence of early implant loosening (within the first 3–5 years postoperatively) or osteolysis should be assumed to be infectious in etiology until proven otherwise. Identification of the implants in place can be helpful as specific extraction equipment may be helpful or required. Significant bone loss has been proposed as a contraindication to single-stage revision.

In general, nuclear medicine studies have fallen out of favor as diagnostic tests for prosthetic joint infection as they have shown variable accuracy, are costly, and not routinely available at all hospitals. Presently they are performed in our practice only in cases where the suspicion for infection is high and no fluid could be obtained on at least two attempted aspirations. While technetium-99m bone scans have high sensitivity, they are unable to differentiate septic from aseptic failure and hence when performed, indium-111 labeled leukocyte scans are the test of choice, however, they do demonstrate a substantial rate of false-positives and, therefore, may be most helpful in predicting the absence of infection.

### CLASSIFICATION AND TREATMENT OPTIONS FOR PERIPROSTHETIC INFECTION

Several authors have attempted to classify periprosthetic infection in hopes of simplifying and standardized treatment algorithms. Coventry, in 1975, grouped infection into three stages. Stage I is an acute postoperative infection. Stage II, occurring 6 months to 2 years postoperatively, is defined as a delayed infection.
Finally, stage III is a late hematogenous infection. This classification system continues to be utilized today, but is perhaps too simple to guide treatment. Tsukayama, in 1996, proposed another system and provided a guide for selecting treatment (however, not including one-stage revision) as well as a framework for expected outcomes. These categories include positive intraoperative cultures only (during revision THA), early postoperative infection (<4 weeks), late chronic infections (>1 month), and acute hematogenous based infections. With treatment including 6 weeks of parenteral antibiotics, patients with positive intraoperative cultures had a success rate of 90%. Patients with early postoperative infection were treated with debridement and antibiotics demonstrating a success rate of 71%. Patients with chronic infection were treated with two-stage revision and demonstrated a success rate of 85%. Finally, patients with hematogenous infection were successfully treated with debridement 50% of the time.

SURGICAL TECHNIQUE

Articulating versus Static Spacers

It is our preference to employ an articulating spacer in all cases where it is feasible. Contraindications include extensive bone loss, precluding the fixation of an articulating implant; a precarious soft tissue envelope, particularly in the knee, where the soft tissues would benefit from a period of immobilization, and in the case of an associated soft tissue transfer or flap; extensor mechanism deficiency in the knee, or abductor deficiency in the hip, which may limit stability associated with an articulating spacer leading to a higher risk of dislocation.

Preoperative Planning

All revision arthroplasty requires significant preoperative planning. All prior operative notes should be obtained. Attention must be paid to the previous approach, soft tissue management, and implants utilized. The required extraction equipment is based on preoperative X-rays and may include manual revision instruments, flexible osteotomes, trephines, an ultrasonic drive, the Midas-Rex, and the Explant® system. The surgeon must plan for the antibiotic spacer fabrication. The hospital pharmacy should be contacted and the appropriate amount of antibiotic secured. Depending on surgeon preference, the articulating spacer of choice should be readily available.

Approach

Total Hip Arthroplasty

Various surgical approaches can be utilized for revision THA. An extensile approach should be planned for adequate and aggressive debridement as well as
component resection. If the primary surgery was recent, one may consider utilizing the same approach, but the approach must have the ability to become extensile. Based on the preoperative plan, we most frequently use a posterolateral approach and an extended trochanteric osteotomy\textsuperscript{22} if required, or an anterolateral approach and a transverse femoral (Wagner) osteotomy\textsuperscript{23} when required. Extended femoral osteotomy should be considered with a fixed cement mantle, an extensively coated or tapered cementless stem, and proximal femoral deformity that requires correction during revision. In addition, osteotomy may improve femoral canal access for debridement in the face of infection as well as improve acetabular exposure for component removal or reconstruction.

**Total Knee Arthroplasty**

In cases with multiple longitudinal prior incisions, the most lateral and anterior incision is used to preserve the blood supply to the medial aspect of the lateral skin flap. Attempt to maintain a minimum skin bridge of 6 cm between parallel incisions is recommended. Previous transverse incisions that cannot be avoided are crossed at 90° if possible, but certainly at no less than 60°. A medial parapatellar arthrotomy is performed. In most cases, a medial subperiosteal exposure that allows for the tibia to be externally rotated and anteriorly subluxed is usually sufficient for exposure. This is incorporated into a medial release if needed for soft tissue release and balancing. In cases associated with severe stiffness, or a quadriceps snip can be helpful and is performed early to prevent injury to the tibial tubercle and extensor mechanism.\textsuperscript{24} The quadriceps snip is a versatile exposure that is used in the majority of revisions requiring extensile exposure and does not require alteration of the postoperative weight-bearing protocol. When quadriceps snip does not allow adequate exposure, tibial tubercle osteotomy can be considered, particularly if access to the tibial canal is required to facilitate implant and/or cement removal. A long osteotomy as described by Whiteside and Ohl\textsuperscript{25} is particularly useful in patients with marked patellar baja or to assist with removal of long cemented stems and well-fixed ingrowth components.

**Gram Stain, Culture, Frozen Section, Debridement**

It is now clear in the literature that Gram stain provides limited information during revision and should not be performed routinely.\textsuperscript{13,26} Intraoperative frozen section is a useful tool in confirming infection during revision arthroplasty; however, it is subject to sampling error and requires an experienced pathologist. Lonner et al. reported an average of greater than 10 PMNs per high-power field in the five most cellular fields demonstrated a sensitivity of 84% with a specificity of 99%.\textsuperscript{27} More than one specimen for frozen section is frequently sent, especially when the initial specimen conflicts with prior evaluation or clinical suspicion.
During all revision procedures, we send five tissue and/or fluid cultures. These include a specimen from the synovial fluid, femoral component surface, femoral canal, acetabular or tibial component surface, and acetabulum or tibia after component removal. Multiple cultures facilitate culture interpretation; that is, if four of five cultures show the same organism, it is quite likely to be a true positive while one of five cultures showing growth of a nonvirulent organism, such as *S. epidermidis* is likely to be a contaminant. Despite multiple samples, false positives and false negatives will occur. Buchholz et al. reported that 12% of patients with strong clinical evidence for infection had negative cultures.28 Similarly, false-positive results have been reported as high as 30%.19 Ensuring that the patient has not received antibiotics for a period of 14 days prior to surgery and taking multiple samples from multiple sites will improve the reliability of intraoperative culture.19

A systematic approach to debridement is performed. Any tissue appearing infected; including synovium, capsule, muscle, bone, fat, and skin must be mechanically debrided. Curettes, rongeurs, electrocautery, brushes, burs, and high-pressure irrigation systems are utilized. All retained foreign material must be removed including suture, wires, screws, implants, and cement. Irrigation is performed after mechanical debridement and antibiotic solution followed by sterile saline is preferred. A new, sterile surgical field is established and a clean set of sterilized instruments is opened.

**Articulating Spacer**

**Total Hip Arthroplasty**

We utilize a PROSTALAC (Prosthesis with Antibiotic-loaded Acrylic Cement) system for the majority of our two-stage reconstructions. In most cases, the longer length stems are required, particularly if an osteotomy was required (Figure 3). These can be assembled in the clamshell molds provided. Sterile mineral oil facilitates removal from the mold. The cemented all-poly shell is then implanted and the articulation snap-fits together in a semiconstrained manner, improving stability. The femoral osteotomy is then secured with 16-gauge wires with a figure-of-eight around the greater trochanter. If the proximal bone is limited, a collar of extra cement can be added to the stem to improve resistance to rotation and subsidence (Figure 4).

**Total Knee Arthroplasty**

Following careful debridement of all surfaces and canals, dowels are made using a cement gun. Again sterile mineral oil facilitates their removal from the gun tubing. A small disk of cement attached to the end of the dowel prevents subsidence
Nett et al

down the canal following insertion. Trial femoral and tibial components are then used to establish appropriate soft tissue stability. An acorn tip bur is then used to place divots in the underside of the chosen polyethylene component. A new femoral component is cemented on first, followed by either an all polyethylene tibial component, or a constrained condylar polyethylene (Figure 5).
POSTRESECTION CARE

Following resection arthroplasty, all patients are treated with 6 weeks of parenteral antibiotics. We favor the use of a peripherally inserted central catheter line due to its ease of insertion and low complication rate. The choice of antibiotic and the duration of treatment are directed by an infectious disease specialist. Once the 6-week course of antibiotics is finished, the patient is observed for 2 weeks off of antibiotics and the ESR and CRP are repeated; if the labs trend toward normal, reimplantation is performed the following week. In our experience, the ESR and CRP will show significant decreases from prior to the first stage explantation, but may not always normalize even if the infection has been successfully eradicated.\textsuperscript{29,30} If the ESR or CRP increase following antibiotic cessation or if the patient experience increased pain off of antibiotics, an aspiration is performed for cell count and culture. When an aspiration is performed, the optimum cut-off for the nucleated cell count is 3,500 WBCs/µL for hips and 3,000 WBCs/µL for knees.\textsuperscript{29,30} Intraoperatively, frozen section is sent with a cut-off of 10 polymorphonuclear cells per high-power field. The reliability of intraoperative frozen section varies significantly with the experience of the pathology department and therefore should not be relied on exclusively.

FINAL RECONSTRUCTION

Total Hip Arthroplasty

Hip reconstruction following two-stage revision is largely dependent on bone quality and bone loss. On the femoral side, one may consider reconstruction with a cemented stem with antibiotic-loaded cement. During single-stage revision, the use of antibiotic-impregnated cement seems important. Single-stage revision of infected THAs with plain cement has been successful in 60% (40 of 67) compared to 83% (1,352 of 1,630) of infected hips reconstructed with the use of antibiotic-impregnated cement.\textsuperscript{1} However, the disadvantages of a cemented femoral stem must be considered. These include nonbiologic fixation and the possible need for cement removal in the event that the infection recurs. We favor uncemented femoral and acetabular reconstruction. With an intact proximal femur, we prefer to implant a single plane, mediolateral tapered wedge design. With proximal femoral metaphyseal bone loss or compromise, a fully porous-coated cylindrical stem is implanted. Finally, in the presence of significant proximal bone loss or following an osteotomy, a modular taper fluted design is used.

Total Knee Arthroplasty

The basic principle of revision knee arthroplasty involves creating a kinematically stable arthroplasty that is well-fixed and well-aligned. The key is to create equal
flexion and extension gaps. Adjustments made on the femoral side can affect the knee in either flexion or extension, whereas any adjustments on the tibial side will affect both. The reconstruction is approached using a three step method: (i) recreate the tibial platform; (ii) recreate the femur and rebuild the flexion space; and (iii) rebuild the extension space. We choose to reconstruct the vast majority of our revision total knees with implants that are cemented in the metaphysis and use diaphyseal engaging uncemented stems; porous metal cones and augments may be required in cases of more severe bone loss. In the patient with multiple prior incisions, previously irradiated tissue, or densely adherent skin, a preoperative plastic surgery consultation may be critical to wound closure and healing. Our practice will utilize tissue expanders prior to reimplantation in severe cases.

CONCLUSION

In the vast majority of cases, infection can be either ruled in or out using a serum ESR and CRP followed by selective aspiration of the joint, sending the synovial fluid obtained for a synovial fluid WBC count, differential, and culture. Early postoperative infection and acute hematogenous based infections with a low virulence pathogen can be treated successfully by early intervention, debridement, and component retention. In the face of delayed intervention for an acute infection, chronic infection, a poor host, compromised soft tissue, a sinus tract, or a resistant or polymicrobial infection attempted implant retention will meet with an unacceptably high rate of failure. While treatment for chronic infections in North America is still dominated by a preference for a two-stage exchange protocol, interest is increasing in the use of a one-stage exchange.
REFERENCES


Partial Knee Arthroplasty: When Not to Go All the Way

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ABSTRACT

Contemporary experience with unicompartmental knee arthroplasty (UKA) has gained renewed interest over the past few decades. This revival is partly due to interest in minimally invasive procedures, quicker recovery, improved function, and patient satisfaction. Newer techniques and instruments have also been developed, focusing on ease of operation and consistency of surgical technique. Indications for UKA have continued to evolve as long-term data is reported. As we continue to explore these issues and outcomes of surgery, we will have a better understanding of why UKA can be an excellent option in patients with unicompartmental arthritis.

INTRODUCTION

The expected goals in any arthroplasty are to alleviate pain, provide stability, and function with predictable result. While total knee arthroplasty (TKA) is one of the most successful procedures performed in medicine, unicompartmental knee arthroplasty (UKA) has also shown excellent mid- to long-term results.1-12 In our clinical experience, at least 35% or more of patients present with isolated anteromedial arthritis and a ligamentous normal knee that corrects to neutral. In these patients, UKA and preservation of remaining normal one-third of the knee would sensibly be the best surgical option. The decision to perform UKA or TKA is largely based on physical examination, radiologic and intraoperative findings. Other factors influencing surgical preference include physician experience and training. Newer techniques and changes in implant design have been developed to mitigate surgical variability and enhance reproducibility yet continued controversy remains.
DIAGNOSIS

Indications for the treatment of unicompartmental arthritis with UKA vary. Traditional indications described a diagnosis of unicompartmental osteoarthritis or osteonecrosis in either the medial or lateral compartment; age greater than 60 years with a low demand for activity, weight less than 82 kg (181 lb); minimal pain at rest; range of motion (ROM) arc greater than 90° with less than 5° flexion contracture; and an angular deformity less than 15° that is passively correctable to neutral. Traditional contraindications to UKA are a diagnosis of inflammatory arthritis; patient age less than 60 years; high patient activity level; pain at rest (which may indicate an inflammatory component to the arthropathy); and patellofemoral pain or exposed bone in the patellofemoral joint or opposite compartment.13

The evolution and expansion of these criteria have been somewhat controversial with more recent indications being centered on anterior cruciate ligament (ACL) status, age, weight, and the patellofemoral arthritis. We prefer to use the following inclusion and exclusion criteria for partial knee arthroplasty (Table 1).

The premise of a patient treated with UKA of the medical compartment is isolated anteromedial arthritis. There should be no deficiency or wear of the posteromedial tibial plateau. Evidence of posteromedial wear of the tibia is diagnostic for ACL deficiency. Biomechanical and in vivo studies have examined the proposed loads placed on the ACL deficient knee in UKA.14-16 These studies suggest the potential for instability, adjacent compartment wear, and altered

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<th>Table 1: Indications for Medial UKA and Contraindications to UKA</th>
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<tr>
<td><strong>Indications for medial UKA</strong></td>
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<tr>
<td>• Anteromedial disease pattern</td>
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<tr>
<td>• Secondary avascular necrosis</td>
</tr>
<tr>
<td>• Intact anterior cruciate ligament</td>
</tr>
<tr>
<td>• A deformity that corrects to neutral</td>
</tr>
<tr>
<td>• Intact medial collateral ligament</td>
</tr>
<tr>
<td>• Arch of motion &gt;90°</td>
</tr>
<tr>
<td>• Flexion contracture &lt;5°</td>
</tr>
<tr>
<td>• Angular deformity &lt;15°</td>
</tr>
<tr>
<td><strong>Contraindications to UKA</strong></td>
</tr>
<tr>
<td>• Inflammatory arthritis</td>
</tr>
<tr>
<td>• Ligamentously unstable knee (anterior cruciate ligament, medial collateral ligament)</td>
</tr>
<tr>
<td>• Large central lesion of the opposite compartment</td>
</tr>
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UKA, unicompartmental knee arthroplasty.
mechanics potentially accelerating polyethylene wear or dislocation in mobile-bearing implants. Other authors have reported equivalent results in the ACL deficient knee when compared to the ACL intact knee.\textsuperscript{16-18}

Age and weight indications continue to evolve with mixed results. Several studies have suggested that weight, body mass index (BMI), or age should be a contraindication to UKA.\textsuperscript{2,5,11,12,16,19,20} Berend et al. examined early outcomes of unicompartmental medial knee arthroplasty in obese, young patients. They concluded that weight and BMI were not predictive of survivorship or clinical outcome. Also noted was no increased risk of early failure in patients younger than age 50 or 60 years old. However, they did notice, slightly lower clinical scores in younger patients.\textsuperscript{21} Although the authors of many studies may suggest weight not be considered as a contraindication to UKA, additional studies have suggested otherwise. Berend et al. found a BMI greater than 32 was predictive of failure and associated with reduction in survivorship in fixed-bearing UKA.\textsuperscript{22} Murray et al. examined failure rates in patients with increased BMI and also did not associate increased BMI with increased failure. They reported the most common cause of failure in obese patients to be polyethylene wear.\textsuperscript{23}

Perhaps the contraindication that sparks the most discussion is the preoperative status of the patellofemoral joint. Traditional indications suggest that involvement of a second compartment should preclude UKA. Reports in certain fixed-bearing designs have indicated progression of arthritis of the patellofemoral joint as a mode of late failure.\textsuperscript{24-26} Data reported by the Oxford group and the use of a mobile-bearing design has been excellent and without clinical failure secondary to progression patellofemoral arthritis.\textsuperscript{10,27-30}

We currently do not consider age, weight, or patellofemoral arthritis—a contraindication to UKA—in patients who meet inclusion criteria. As we continue to see more data with long-term follow-up, we will have a better understanding of the impact on patient selection and criteria have on UKA outcomes.

**PREOPERATIVE ASSESSMENT**

**History**

History and physical examination along with radiographic imaging of the knee are equally important parts of the preoperative assessment. Any patient who is a candidate for UKA typically gives a history of isolated medial or lateral-sided pain on the knee with activity. Any history of global knee pain may be indicative of more than unicompartmental arthritis. History of previous arthroscopic surgery and recent images may be of assistance in determining the involvement of other compartments. Also helpful in the patient’s history may be that of
inflammatory arthritis. If there is a history of inflammatory arthropathy then UKA should not be considered in these patients as the risk of later involvement of the rest of the knee would necessitate further surgical intervention.

Physical Examination

The examination of the patient should include palpation of the knee for crepitance, ROM, load in both varus and valgus stress, assessment of correctability, stability, and examination for competence of the ACL.

Radiographs

Standard anteroposterior (AP), lateral, and sunrise views should be obtained for the knee. We also prefer to obtain a posteroanterior (PA) flexed view as well as varus or valgus stress view. While the frontal views allow for assessment of joint space narrowing, the lateral view allows for visualization of the wear pattern. It is important to make sure the pattern is that of anteromedial disease and that preservation of the posterior tibial plateau remains (Figure 1). The necessity of the stress views allows for radiographic assessment of collapse of the opposite compartment, and ability to discern correction to neutral alignment. The stress view is taken with the knee in approximately 15° of flexion while the technologist applies a stress to the distal femur and an opposite force to the distal tibia (Figure 2).

Figure 1: The disease pattern of anteromedial arthritis is present with preservation of the posteromedial tibial plateau. This pattern of wear suggests that there is preservation of the anterior cruciate ligament and partial knee arthroplasty would be a good surgical option.
TREATMENT

Once the decision to proceed with UKA has been made, the next option should be consideration of the design of implant which you choose to use. Implant design has evolved over the past few decades with instrumentation design becoming more user-friendly allowing for more reproducible results.

The main difference between implants available today is the design of a fixed-bearing nature or that of a mobile bearing (Figure 3). Several studies have examined outcomes with these two different implant designs. In a retrospective study, Emerson et al. reported a survival rate of 99% in the mobile-bearing group and 95% in the bearing group.31 Other studies have shown better survivorship in fixed-bearing implants than with mobile bearing.32 Parratte et al. found no
difference in survivorship between these two groups at mean 17.2 years follow-up. Whittaker et al. also found no difference between the two groups at mean 6.9 years follow-up. Confalonieri et al. in a prospective randomized controlled studies that have compared the two different implant designs and at mean 5.7-year follow-up, there was no statistically significant difference between the groups in terms of clinical outcome scores or revision rates.

The authors use a mobile-bearing design and have reported excellent result with 96% survivorship in their first 1,000 UKA. However, it appears both bearing designs demonstrate excellent pain relief and restoration of function with durable implant survival.

RECOVERY

The recovery after TKA or UKA can be quite intensive. Pain control and rehabilitation can be challenging for patients as they recover. The institution of rapid rehabilitation programs and utilization of minimally invasive surgical techniques has helped mitigate many of these challenges. Lombardi et al. matched 115 UKA and TKA patients utilizing a rapid rehabilitation protocol and found patients who underwent a UKA had better ROM at discharge and shorter hospital stay than those who had a TKA. Morris et al. also reported a low rate of mortality and serious postoperative complications in 1,000 UKA. Another multicenter study found an increased risk of postoperative morbidity in TKA versus UKA.

OUTCOMES

Many studies have been published, reporting good mid- to long-term survival for UKA (Table 2). In a randomized controlled trial, Newman et al. reported 89.8% survivorship at 15 years compared to 78.7% in the TKA group. Pandit et al. reviewed outcome of their first 1,000 MB knees and had a 10-year survival of 96% including all revisions.

<table>
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<tr>
<th>Study</th>
<th>Bearing type</th>
<th>Results</th>
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<tr>
<td>Tabor et al. (1998)</td>
<td>Fixed-bearing Marmor-style non-metal-backed</td>
<td>Survivorship: 91% at 5 years, 84% at 10 years, 79% at 15 years</td>
</tr>
<tr>
<td>Squire et al. (1999)</td>
<td>Fixed-bearing Marmor fixed-bearing design</td>
<td>Survivorship at minimum 15-year follow-up 89.8%</td>
</tr>
<tr>
<td>Argenson et al. (2002)</td>
<td>Fixed-bearing metal-backed Miller-Galante prostheses</td>
<td>Three to 10-year follow-up Kaplan-Meier analysis, 10-year survival rate was 94% ± 3%</td>
</tr>
<tr>
<td>Price et al. (2011)</td>
<td>Oxford mobile-bearing</td>
<td>Survivorship at 20-year follow-up 91%</td>
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</table>
Berend et al. reported excellent early survivorship with UKA for lateral compartment arthritis. In a retrospective review of 100 lateral UKA, they reported a revision rate of 1\%\textsuperscript{48}.

**FAILURE MODE**

Adjacent compartment disease either the patellofemoral or tibiofemoral has been described as a cause for revision of a UKA (Figure 4).\textsuperscript{49} Studies examining preexisting patellofemoral disease as a cause of failure have been somewhat mixed. In two separate studies using the Oxford mobile-bearing implant, Beard and Kuipers were unable to find a correlation between preexisting patellofemoral disease and progression as a mode of failure.\textsuperscript{50,51} The authors currently do not consider preexisting patellofemoral arthritis—a contraindication to UKA. In contrast, Argenson et al. examined results using Miller-Galante fixed-bearing implant. In their series, revisions for patellofemoral arthritis were found to be associated with preexisting disease in the same compartment. The authors of this study considered advanced arthritis in the patellofemoral compartment to be a

![Figure 4: A, A radiograph of the left knee showing a lateral fixed-bearing unicompartmental knee arthroplasty. B, Five years later, the patient presented with medial knee pain. Adjacent compartment arthritis is visualized in the medial joint space. C, The patient underwent conversion to a primary total knee arthroplasty.](image-url)
contraindication to UKA. Berger et al. followed 59 Miller-Galante UKA and at average 13 years had two revisions both for patellofemoral arthritis. The authors noted that neither of the patients had patellofemoral arthritis at the time of UKA. Patellofemoral impingement may also represent a clinical cause of failure after UKA. Careful attention to appropriate sizing and position of components can help prevent this occurrence. Current Oxford instrumentation addresses this concern with removal of excess anterosuperior bone around the femoral implant (Figure 5).

Ackroyd in a long-term follow-up of 409 medial UKA reported 9 failures due to adjacent compartment disease, 8 in the lateral compartment and 1 in the patellofemoral compartment. Several studies have reported similar results of progressive failure of the opposite tibiofemoral joint space. Sagittal plane over correction is thought to be the cause for this mode of failure.

Other modes of failure include aseptic loosening, bearing dislocation tibial subsidence, and tibial fracture. Emerson et al., when comparing mobile-bearing design versus fixed-bearing UKA, concluded the major reason for failure in the fixed-bearing group to be aseptic tibial loosening versus lateral progression in the mobile-bearing group. Familiarity with instrumentation and careful attention to surgical technique can help minimize these modes of failure.

The complexity of conversion of UKA to TKA has been shown to be largely dependent on the implant design and failure mode. Several studies have shown conversion of UKA to TKA to be less complex than conversion of primary TKA to revision TKA with long-term results comparable to that of primary TKA.

**Figure 5:** A, Instrumentation in use to address the issue of impingement. B, Note the area just superior to the femoral implant is devoid of cartilage which prevents impingement in extension.
CONCLUSION

Unicompartmental knee arthroplasty results in less postoperative pain, shorter hospitalization, faster recovery, lower rates of thromboembolic disease, and better ROM compared with TKA. UKA continues to evolve, and studies support UKA having excellent long-term outcomes. Although selection criteria may vary and continue to evolve, adherence to strict surgical indications and appropriate patient selection, along with meticulous surgical technique may help further optimize these positive outcomes.

Editor’s Comment

Partial knee arthroplasty has been a viable option for appropriately selected patients for many years. Excellent survivorship and long-term outcomes have been published. A consistent source of debate has been the definition of an appropriate candidate for partial knee arthroplasty. Meticulous attention to surgical technique and maintenance of an appropriate surgical volume appear to be key to the success of the operation. Additional data on outcomes, as related to preoperative patient characteristics, will be useful in further refining patient selection criteria.

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Gregg R Klein

REFERENCES


Customized Total Knee Replacement: Simple Fad or New Standard of Care?

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ABSTRACT

Customized knee replacement is an exciting innovation in the field of orthopedic surgery. This novel technology allows for the fabrication of surgeon-approved, patient-specific instruments from advanced preoperative imaging which can be used to make precise and reproducible bony cuts for primary total knee arthroplasty (TKA). There are several different implant companies that design and manufacture customized knee replacement systems. Each company tends to have proprietary software to design individualized cutting guides with or without custom implant components but the overall development steps are similar. Potential advantages of this technique include more accurate postoperative mechanical alignment with decreased number of outliers, quicker overall operating times, better operating room efficiency, and potential superior patient outcomes. Alternatively, the high-economic cost, the surgeon’s indirect costs, and potential errors of new technology have led to opposition to its widespread use. With such conflicting views and limited data, custom knee replacement technology has become a contemporary controversy with potential to become either a simple fad or, perhaps, a new standard of care. Further well-designed, prospective, and randomized research is necessary before routine use of this technology in primary TKA can be routinely recommended.

INTRODUCTION

Total knee arthroplasty (TKA) is a proven treatment to relieve pain and improve quality of life for patients with advanced knee osteoarthritis.¹ The annual volume of
primary TKA procedures continues to increase with projections of 673% growth or 3.48 million procedures by the year 2030.2 Given that substantial healthcare costs related to TKA will also increase dramatically, there remains a strong interest in developing new technologies that increase efficiency while continually improving overall patient outcomes. Customized knee replacement, or individualized cutting guides or components, represents such a technology that has provoked both opposition and enthusiasm within the orthopedic surgery community.

The success of TKA is largely dependent upon accurate and reproducible surgical techniques.3 The overall goal during surgery is to restore knee alignment to within $+3^\circ$ of neutral mechanical axis of the limb which classically has been thought to be an important factor in preventing implant loosening, instability, or wear.4,5 Standard surgical technique requires careful preoperative planning from plain radiographs and conventional instrumentation to perform the procedure. With the development of computer-assisted TKA (an image-free intraoperative navigation system), improved accuracy has been demonstrated in several studies as compared to standard instrumentation.6-8 There was a significant utilization of this technique after this technology was initially made available. However, only a minority of TKA procedures are currently performed with computer navigation likely due to the increased operative time, steep learning curve, fractures reported from pins placed to register bony landmarks, and high additional hospital costs per procedure.9,10

Customized knee replacement is a relatively new and novel technology where preoperative imaging is used to manufacture custom, disposable (single use) cutting blocks that eventually fit and guide bony cuts relative to the patient’s specific knee anatomy and alignment. The advantages of this technique are considered to be optimized implant position and alignment, improved operating room (OR) efficiency (reduced instrument inventory), and potentially superior patient outcomes.10 Disadvantages may include higher direct costs to the patient and healthcare system, the indirect costs to the surgeon, and potential errors related to this technology. Customized knee replacement is an exciting development in total joint arthroplasty but the obvious question remains: will this technology become the new standard of care or just a simple fad?

HISTORY AND TECHNIQUE OF CUSTOM KNEE REPLACEMENT

This technology was initially made available when the OtisMed (Hayward, CA) system was developed in 2004 and custom tibia and femoral cutting guides were fabricated from a preoperative magnetic resonance imaging (MRI) scan of the arthritic knee.11 The initial intraoperative experience of 48 custom instrumentation used was encouraging with no adverse events, minimal repeated
femur or tibia cuts, and only three sets of improperly fitting cutting guides. A subsequent study was published illustrating that the same OtisMed custom cutting blocks recommended alignment greater than or equal to 3° off of the mechanical axis leading to misalignment in 4 patients. Despite the mixed early results and uncertain future outcomes, the attractiveness of this technology to all stakeholders (innovators, patients, and surgeons) continues to fuel its research and development. Currently, customized instruments based on preoperative imaging are manufactured and offered by seven different orthopedic implant companies (Table 1).

Each customized knee replacement system has its own software that allows the surgeon to modify the surgical plan but the overall development steps are similar (Table 2). First, MRI or computed tomography (CT) imaging of the patient’s operative knee must be obtained. The type of preoperative imaging required varies according to each implant company with specific imaging protocols and patient positioning to minimize errors in manufacturing and fit of the instrumentation. In general, a surgical plan is created from the advanced imaging with desired bone resections and approximate position of components (Figure 1). The surgical template is then sent to the surgeon who modifies the plan based upon clinical factors as desired (fixed deformity, flexion contracture, ligament insufficiency)

<table>
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<th>Table 1: Customized Knee Replacement Instrumentation Systems</th>
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<tr>
<td><strong>Instrumentation system</strong></td>
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<tr>
<td>Patient-Specific Instruments®</td>
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<tr>
<td>Signature™ Personalized Patient care</td>
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<tr>
<td>Visionaire™ Patient Matched Technology</td>
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<tr>
<td>TruMatch™ Personalized Solutions</td>
</tr>
<tr>
<td>Prophecy Pre-operative Navigation Guides®</td>
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<tr>
<td>ShapeMatch® *</td>
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<tr>
<td>iTotal® CR</td>
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MRI, magnetic resonance imaging; CT, computed tomography.
*Recalled by Food and Drug Administration (FDA).

<table>
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<th>Table 2: Implementation Process for Patient Specific Instrumentation</th>
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<tr>
<td><strong>Process of customized knee replacement instruments</strong></td>
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<tr>
<td>- Obtain advanced preoperative imaging (CT, MRI, or choice)—modality and protocol are manufacturer specific</td>
</tr>
<tr>
<td>- Review of surgical plan with specific modifications and approval made by surgeon</td>
</tr>
<tr>
<td>- Fabrication of customized instruments, sterilized, and shipped ready for immediate operative use</td>
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CT, computed tomography; MRI, magnetic resonance imaging.
that can affect the resection levels. Finally, femoral and tibial cutting blocks or pin guides are manufactured, sterilized, shipped to the hospital, and immediately available for use. The interval time for OR-ready custom total knee equipment is currently estimated to be 3–6 weeks from surgeon approval of the template.

The intraoperative technique of the specific instrument packs also slightly differ. Many guides are fabricated to fit directly on the patient’s arthritic knee anatomy and can serve as a direct guide to bone resections through cutting slots, or, alternatively, provide a guide for pin placement into the femur and tibia (Figure 2). In the latter, bony resections are made only after removal of the guide and standard cutting jigs are placed into the pin holes. The majority of implant companies simply use “off-the-shelf” components after the individualized resections; however, one company does supply both custom guides and custom knee components. It is important to understand that this technology does not perform necessary ligament balancing, patellar preparation, component rotation (although several systems do allow for femoral and tibial component rotation planning), or implant fixation and these techniques must be completed conventionally.

**ADVANTAGES (STANDARD OF CARE?)**

There are both objective and theoretic advantages that individualized instruments provide compared to conventional instrumentation for primary TKA. First and foremost, custom knee replacement technology allows for simple and optimized
implant alignment and does so without violation of the intramedullary canal. Noble et al. recently introduced the first randomized study comparing radiographic postoperative mechanical alignment of standard knee arthroplasty instrumentation to the custom knee Visionaire™. The patient-specific instrumentation (PSI) group demonstrated significantly closer neutral alignment (1.7° vs. 2.8°, p = 0.3) concluding that custom knee instrumentation provides repeatable improvements in surgical accuracy. Similarly, Ng et al. performed the largest retrospective review of 569 custom Signature™ knees compared with 155 conventionally instrumented knees and found the overall mean hip-knee-ankle angle for PSI guides were similar

![Image](image1.png)
to manual instrumentation with significantly fewer “outliers” in the custom cutting guide cohort (9% vs. 22% defined by +3° of the mechanical axis, p = 0.018). These authors’ often cited conclusion is that patient-specific guides successfully achieve the desired neutral mechanical axis as well as conventional instrumentation while also reducing the number of misaligned outliers. Conversely, other comparative reports have demonstrated no significant difference in the outlier component position when comparing customized guides to and standard instrumentation, although, also showed similar to superior mean hip-knee angles. While current data appears to suggest moderate gains in improving postoperative mechanical alignment with utilizing with custom guides, additional studies will be needed to determine whether this technology improves clinical function and implant survival.

An attractive advantage of customized knee replacement is the potential value the technology provides to simplify and improve OR efficiency. The most obvious improvement is the reduction of overall operative time provided by easily guided cuts and preoperative component sizing. Current literature estimates a reduction of 6.7–13 minutes, which could provide surgeons the opportunity to perform extra-arthroplasty per day. The OR logistics also play an important role when considering implementing new technology during the procedure. Custom knee guides provide a significant reduction in the amount of surgical instrument trays needed to perform TKA compared to conventional instruments and cutting jigs (Figure 3). Barrack et al. analyzed instrument tray processing between the two groups and found significantly shorter postoperative processing times with cost savings of $31 per tray. Combined with an 11-minute decreased operative time with PSI, their institution calculated a net savings of $628 per case. These

Figure 3: A, Standard instrumentation operative set-up. B, Patient-specific instrumentation operative set-up with reduced (usually 1–2) trays.
savings unfortunately failed to offset the extra costs associated with preoperative MRI and manufacturing of the specific cutting guides. Conceivably, a separate and less described advantage may be a potential improvement in OR atmosphere and personnel attitude (circulating nurses and surgical technicians) with less tray set-up, breakdown, and predictable equipment.

The most critical advantage that customized TKA must prove is its ability to reduce complications and significantly improve clinical patient outcomes. Currently, there is a paucity of data that exists to date with use of patient-specific technology. Noble et al. provided encouraging results with statistically significant decreases in incision length and hospital length-of-stay with comparable intraoperative blood loss between a customized technique and standard instrument cohorts. While difficult to clinically assess, avoiding femoral intramedullary canal violation with conventional guides theoretically reduces risks of systemic embolic phenomenon. Further clinical studies must be performed in order to properly evaluate if customized knee replacement can provide improved patient outcomes, satisfaction, function, and implant survival.

**DISADVANTAGES (NEW FAD?)**

Disadvantages with the advent of any new technology are inherent and custom knee replacements are no exception. Perhaps of highest concern is the high-economic cost to both the patient and the overall healthcare system which must be weighed against potential cost savings (OR efficiency, decreased failure, or revision rates). As described previously, all customized techniques require additional and more costly imaging that can incur more costs if radiologists at imaging facilities submit professional charges for reading the CT or MRI. Additionally, manufacturing single-use guides for individual patients is certainly more costly than the cost associated per case with utilization of standardized instrumentation that is used repetitively. Multiple studies have attempted to evaluate procedure-related cost comparisons and potential cost-effectiveness of custom total knee replacements. Specifically, two such studies estimate cost savings from decreased OR time and fewer trays to be $322–$391 which fail to offset the costs associated with preoperative imaging and instrument fabrication. Slover et al. recently performed a cost-effective analysis comparing custom cutting blocks to traditional instrumentation for TKA. In order to prove a cost-effective tradeoff, a Markov decision model found that the 20-year revision rate from use of customized techniques would need to decrease by 50% relative to conventional instrumentation.

The indirect costs endured by the surgeon may be difficult to measure but cannot be understated. The foremost concern would be working through the intraoperative learning curve necessary for utilizing the new technology. Although customized
Customized Total Knee Replacement: Simple Fad or New Standard of Care?

Instruments are intended to reduce technical inefficiencies, early studies described frequently abandoning instrumentation due to poor fit or perceived misguided resections.\textsuperscript{12,13} Stronach et al., in one of the larger series of 66 patients, reported an average of 2.4 intraoperative changes per knee were required (poor custom guide fit requiring intramedullary instrumentation, alignment changes, and use of different implant size than what was predicted by PSI).\textsuperscript{21} Another apparent indirect cost to surgeon is the uncompensated time and effort needed to modify and approve each individual preoperative plan from engineers. Furthermore, coordinating each patient’s advanced imaging and following up with manufacturers to ensure timely fabrication and delivery of products would likely increase present clinical staff responsibilities or even require obtaining additional employees.

Additional disadvantages are the limitations and potential errors of custom knee technology. Any pre-existing metal plates or screws within 10 cm produce radiographic artifact on CT or MRI distorting images needed to develop the instruments. Unfortunately, the most difficult primary total knee population standing to benefit from this technology often consists of post-traumatic osteoarthritis or severe deformity patients with prior hardware in place limiting the utilization for some systems. Also, the individualized instrumentation does not replace critical arthroplasty skills required for successful operation—ligament balancing, soft-tissue releases, implant rotation, and idealized fixation technique. Potential errors and complications will unavoidsbly and inadvertently happen with this technique as with many other new technologies, especially during its early use.\textsuperscript{12,21} Surgeons need to be aware of the failings of this technology as well. Recently, one system was recalled (ShapeMatch\textsuperscript{®}, Stryker, Mahwah, NJ) because the cutting guides may have been manufactured outside the required preoperative planning ranges. An ethical argument can be made that patients possibly suffer inversely proportional to the amount of trial and error of new technology. For this reason, a true informed consent must be obtained only after a forthright discussion occurs with the patient highlighting surgical experience, results, complications, and expectations of custom total knee replacement.

Advantages and disadvantages of customized knee replacement are given in Table 3.

PEARLS AND PITFALLS

- Select appropriate patients with understanding of contraindications (retained hardware, inability of patient to undergo imaging)
- Perform careful and comprehensive review of surgical plan prior to approval
- Practice techniques and use of each manufacturer’s customized instrumentation
- Maintain a constant awareness of possible inappropriate alignment and component positioning intraoperatively (do not blindly use the guides)
Table 3: Advantages and Disadvantages of Customized Knee Replacement

<table>
<thead>
<tr>
<th>Advantages</th>
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<tbody>
<tr>
<td>• Potential optimized implant position and alignment compared to standard</td>
<td>improved operative efficiency (shortened operative time, less</td>
</tr>
<tr>
<td>instrumentation</td>
<td>instrumentation, accurate preoperative implant sizing, quicker</td>
</tr>
<tr>
<td>• Improved operative efficiency (shortened operative time, less</td>
<td>turnover)</td>
</tr>
<tr>
<td>instrumentation, accurate preoperative implant sizing, quicker</td>
<td>turnover)</td>
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<td>turnover)</td>
<td></td>
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<tr>
<td>• Possible improved implant survivorship and patient outcomes</td>
<td></td>
</tr>
<tr>
<td>• Theoretical advantages associated with lack of violation of the</td>
<td>femoral canal (blood loss, embolic phenomena, etc.)</td>
</tr>
<tr>
<td>femoral canal (blood loss, embolic phenomena, etc.)</td>
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<table>
<thead>
<tr>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>• Increased direct cost to patient and/or healthcare system and indirect</td>
<td>increased indirect cost to the surgeon and support staff</td>
</tr>
<tr>
<td>cost to the surgeon and support staff</td>
<td></td>
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<tr>
<td>• Variability in reliability and accuracy of intraoperative instrumentation</td>
<td></td>
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<tr>
<td>• Efficacy for cases with retained hardware or significant deformity</td>
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</table>

- Rely on fundamental surgical principles (sterility, flexion/extension gap balancing, cement technique)
- Continuous review of case outcomes with critical review for improvement and appropriate adoption of the technique.

CONCLUSION

Customized total knee replacement represents some of the newest and most innovative technology which allows creation of patient-specific instruments from advanced preoperative imaging. The goal of these guides is to allow for precise and individualized femoral and tibial cuts without the use of bulky jigs or intramedullary guides. Early studies reviewing utilization of this technology have shown a moderate improvement in accuracy of mechanical alignment with decreased number of outliers, quicker overall operative times, and better OR efficiency. There has been limited to no data demonstrating decreased complications, revisions, and improved patient outcomes, which would certainly enhance its attractiveness. Conversely, drawbacks of custom knee replacements include the high expense of imaging and manufacturing, the indirect cost to the surgeon and his or her practice, and the inevitable errors of new technology.

Orthopedic innovation is necessary and permits great advancement of the surgical discipline. However, surgeons must balance the pressure to implement new technologies with being responsible in choosing that which actually improves patient care and outcomes. Furthermore, adoption of new technologies should be considered if repeatable improvements in healthcare efficiency and a return on investment can be confirmed.22 Customized knee replacement as described here certainly has the potential to be a practice-changing innovation but
Customized Total Knee Replacement: Simple Fad or New Standard of Care?

Editor’s Comment

Customized knee replacement has gained popularity in recent years. Customized cutting guides are fabricated from advanced imaging modalities to theoretically make more precise and accurate cuts during total knee arthroplasty. Many of the implant manufacturers have embraced and invested heavily into this technology. Advantages of this technology include: improved alignment, component position, improved operating room efficiency, and shorter operations. The use of advanced imaging can help precisely place implants in relationship to key anatomic landmarks. Limitations of this technology include the increased financial cost, and potential inaccuracies. Future prospective randomized studies are necessary to effectively evaluate this technology.

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REFERENCES

Gender-specific Total Knee Arthroplasty:
Facts for the Female Patient

William J Long MD FRCSC, Chris D Bryce MD

ABSTRACT

Gender differences in knee anatomy were first recognized during early anatomic studies performed in the 1970s. With more widespread use of knee arthroplasties, surgeons have sought to better distinguish these differences, modify techniques based on them, and critically examine and improve outcomes resulting from the observed differences. This has spurred debate into the more global aspects of gender and implications on outcomes in total knee arthroplasty (TKA) which do demonstrate significant clinical differences between the sexes.

INTRODUCTION

There are a number of aspects to total knee arthroplasty (TKA) that differentiate women from men. The gender debate significantly increased, as did studies into discrepancies between women and men, following the introduction of a “gender-specific” femoral component for TKA. Though prosthetic differences have not resulted in significantly improved outcomes, the ensuing research has highlighted differences in preoperative function, expectations, and outcomes all demonstrating significant differences between genders. As there are two distinct topics in the gender debate, we will review the rationale associated with the development of a modified femoral design and outcomes in one section and the clinical differences associated with indications, outcomes, and gender in another.

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PROSTHESSES

Gender-specific total knee prostheses were introduced in 2007 with significant direct to consumer marketing. As this technology has become available worldwide there has been much debate regarding the utility of a female-specific total knee design. Under consideration has been the question of whether the additional cost of these implants is justified by differences in anatomy of the female knee and more importantly whether they improve outcomes.

A majority of TKAs are performed in women. TKAs performed in females account for approximately 60% of all TKAs. Conventional implants are designed based on the average size and shape of both male and female anatomy. As total knee design has evolved, knee replacement has become one of the most successful procedures available. Hoping to further improve outcomes, designers have targeted differences in male and female anatomy as a basis to refine the shape of total knee prostheses. While the durability of TKA for women with a conventional prosthesis has already matched or exceeded that of men satisfaction and clinical scores for women have lagged.

Designers have focused on differences in the anatomy of the distal femur between men and women. Morphologic measurements were first performed in 1975 and highlighted anatomic differences between the genders. The most accepted difference in anatomy is that women tend to have a narrower femur than men. The measure of narrowness of the distal femur is often expressed as the aspect ratio, or the ratio of medial-lateral to anterior-posterior dimensions of the distal femur which is generally less in women than men. However, there is also variability within gender with shape being dependent on both body morphotype and ethnicity. For example, in both men and women, endomorphs (wide body type) have wider knees and ectomorphs (narrow body type) have narrower knees. Among different populations, Chinese and Japanese women have been shown to have more narrow femurs than Caucasian women.

While it is generally accepted that female knees are narrower than male knees, the clinical significance of this in relation to outcome has not been shown. In knee replacement, the anterior to posterior dimension of the femur is important for flexion-extension gap affecting the flexion gap. The anterior to posterior dimension also influences quadriceps tension and patellofemoral tracking. The medial to lateral dimension of the femoral prosthesis affects coverage and may cause overhang resulting in soft tissue impingement.

The anterior portion of the gender-specific femoral component has also been designed with an increased trochlear groove angle, as well as a thinner anterior condyle (Figure 1). Women are generally shorter than men and on average have greater Q angles compared to men. With a greater Q angle, the patella tracks at a wider angle over the distal femur. Gender-specific knee prostheses have addressed this issue by increasing the trochlear groove angle. However, it has also
been shown that Q-angle magnitudes are not necessarily a function of gender. When corrected for height, women and men have similar Q angles. Shorter people have greater Q angles than taller people.22 A recent study showed that gender-specific prostheses implanted in both males and females have a significant decrease in the need for lateral retinacular release.23

The thinner anterior condyle of the gender-specific femoral component was designed to address the medial and lateral anterior condylar height of the distal femur that is slightly smaller in women than men.10 However, similar to the Q angle, when corrected for size, anterior condylar height is similar between men and women.24

This technology is relatively new and there are unanswered questions regarding their utility. Opponents of this technology question whether stated differences in anatomy are real or have any clinical relevance.25,26 We did demonstrate a significant reduction in lateral patellar release rates and the use of larger femoral prostheses with a narrower femoral component in women,27 but early follow-up has shown no significant differences in clinical outcome or satisfaction with this modification.28-33 Heavy marketing by industry to patients and physicians accompanied the introduction of this technology. While these implants were marketed as a gender-specific knee made for females, the design features of being narrower, an increased trochlear groove angle, and a thinner anterior condyle do not match anatomy of all females and also apply to the anatomy of some males. Thus gender does not exclusively determine knee shape as body morphotype and ethnicity also play a role.
It seems unlikely that we will have a definitive answer regarding whether there is an advantage of this technology during the short-term follow-up period. Long-term outcomes of more conventional implants are favorable and our current measurement tools to assess outcomes are likely not precise enough to detect differences in this refinement in design. The gender-specific knees offer more options for matching patient morphology and are not restricted for use in females. Orthopedic surgeons should understand the design and options for sizing of the system they are using.

EXPECTATIONS AND OUTCOMES

National joint registries demonstrate better survivorship for TKA in women than men (Australian Joint Registry\textsuperscript{34} and New Zealand Joint Registry\textsuperscript{35}), but clearly that does not describe the full picture. A number of authors have noted a lower rate of satisfaction following knee arthroplasty in women\textsuperscript{36,37} and a higher rate of moderate to severe pain at mid-term follow-up after TKA.\textsuperscript{38} Earlier improvements in Western Ontario and McMaster Osteoarthritis scores have been noted in women, but this discrepancy was not seen at 1 year.\textsuperscript{39} In a 2008 study on patient reported activity levels following TKA by Dahm et al., men had significantly higher functional scores, and higher self-assessment of activity level versus their peers, than women.\textsuperscript{6} Interestingly satisfaction appears to be primarily determined by patients’ expectations rather than the absolute level of function achieved with their TKA.\textsuperscript{40} Also, women tend to choose to undergo TKA at a later stage, approximately 3 years older, and with lower preoperative functional scores, which then persist following TKA.\textsuperscript{41} Thus, though survivorship is better in women than men, they choose to undergo TKA at a later stage, with more functional deficits, resulting in more residual pain, and lower functional scores following TKA.

CONCLUSION

At this point, the facts that can be provided to female patients regarding TKA are that women undergo the procedure at a later stage, with more functional deficits. Despite significant attention to design modifications toward a narrower more anatomic femoral component for women, we do not see any functional benefits. Outcomes in women are more durable, but with poorer clinical scores, perhaps as a result of delayed intervention. Gender distinctions in TKA are one aspect to a larger debate regarding a more personalized and customized approach to TKA. Two converging trends will continue to expand this debate: (i) the tremendous increase in utilization of the procedure globally and (ii) the move beyond durability to patient-derived outcomes and satisfaction with TKA.
Editor’s Comment

Approximately 60% of total knee replacements are for female patients. Previous studies have shown anatomic differences between the male and female knee. Women generally have a narrower medial-lateral dimension for a given anteroposterior dimension. In addition, women have an increased Q angle. Implant manufacturers have developed better gender-specific implants to match this morphology. To date, scientific studies have failed to show a difference between the standard and these gender-specific implants. Although studies have been unable to show a significant difference at this time, this technology and research has forced both the implant manufacturers and surgeons to re-evaluate current surgical techniques and implants. In addition, this debate has also motivated further studies into the differences between men and women.

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 Gregg R Klein

REFERENCES

Robotically Assisted Unicompartmental Knee Arthroplasty

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ABSTRACT

This article will review the currently available robotic systems in use for unicompartmental knee arthroplasty (UKA), the rationale for radiographic results of robotic technologies for UKA. This information can be synthesized by the reader so that they can make a determination regarding whether this innovative, novel, and “disruptive technology” may be worth pursuing in their own clinical practices.

INTRODUCTION

Robotic technology is becoming increasingly more utilized and impactful in society. Ninety-nine percent of farm workers have been replaced by automation and it is anticipated that by the end of this century, 70% of today’s occupations—manufacturing, assembly, transport, warehousing, military, inventory, healthcare—will likewise be replaced by automated technologies.\(^1\) While the emergence of medical robotics has lagged compared to other industries, by the year 2018 the global medical robotics market is expected to reach $1.53 billion.\(^2\) In the United States alone, roughly 85% of prostatectomies performed in 2012 employed robotic technology. While the emergence of robotics in knee and hip arthroplasty has been gradual, the penetration of semiautonomous robotic technology for unicompartmental knee arthroplasty (UKA) in 2013 accounted for 15% of the UKA market in the United States. Enhanced precision and optimized outcomes have raised substantially the interest in robotics in UKA, but the challenge facing the robotics sector is to produce technologies that are also efficient and economically feasible.

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RATIONAL FOR ROBOTIC ASSISTANCE FOR UNICOMPARTMENTAL KNEE ARTHROPLASTY

Currently approximately 10% of patients who undergo knee arthroplasty for arthritis receive UKA. That number may increase to 20% or more, as patients continue to present for treatment of their arthritis at an earlier stage than patients typically did in the past, particularly if combined with patellofemoral arthroplasty (PFA). Patients and surgeons are increasingly pursuing and providing early intervention strategies, which tend to be more conservative and leave a more “normal” feeling knee than total knee arthroplasty (TKA). UKA is also a particularly relevant option when considering that our knee replacement patients today tend to be more active, younger, and often present with an earlier stage of arthritis than in years past, with an interest in and/or need for rapid recovery and return to work.

The results and durability of UKA are impacted by a variety of factors, including the pattern of arthritis, deformity and pain location, as well as prosthesis design, polyethylene quality, and implant alignment and fixation. It has been shown that excessive posterior tibial slope or varus alignment of the tibial component and/or mechanical axis of the limb may predispose the prosthesis to early failure. However, achieving consistently accurate component alignment of the tibial component in UKA using conventional approaches is difficult. Outliers beyond 2° of the desired alignment may occur in as many as 40–60% of cases using conventional methods, and the range of component alignment varies considerably, even in the hands of skilled knee surgeons. The problem is compounded when using minimally invasive surgical approaches, which is how most contemporary UKAs are likely performed. One study analyzing the results of 221 consecutive UKAs performed through a minimally invasive approach found a large range of tibial component alignment, with a mean of 6° (SD ± 4°) and a range from 18° varus to 6° valgus.

Computer navigation was introduced in an effort to reduce the number of outliers and improve the accuracy of UKA. However, even with computer navigation, the number of outliers (beyond 2° of the preoperatively planned implant position) may approach 15% since there remains an element of imprecision with the use of standard cutting guides and conventional methods of bone preparation. Robotic guidance has subsequently been advanced to further refine and enhance the accuracy of bone preparation and soft tissue balancing, even with minimally invasive techniques, by better interfacing and integrating the planning and process of bone preparation.

ROBOTIC SYSTEMS DESCRIPTION

A key distinction in robotic applications in knee arthroplasty deals with whether the system is autonomous or semiautonomous. Autonomous robotic systems
involve preprogramming the system with parameters that define the amount and orientation of bone to be removed and then the system moves independent of the surgeon. In other words, the surgeon does not control the system after programming, other than having access to a “shutdown” switch. Semiautonomous systems involve the mapping of condylar landmarks and determination of alignment indices which also define the volume and orientation of bone which is to be removed, but while the system removes bone and cartilage within the parameters, the robotic tool is controlled and manipulated by the surgeon. These semiautonomous systems also provide real-time quantification of soft tissue balancing which contribute to the reported successful clinical and functional outcomes with semiautonomous systems.

The predicate early generation autonomous robotic system (Robodoc, Curexco Technology Corporation, Fremont, CA) has been used for total hip and knee arthroplasty, although it is only approved by the US Food and Drug Administration (FDA) for use in total hip arthroplasty (THA). While some published results have been complementary,19,21 market penetration of autonomous robotic systems has been limited and results in both hip and knee have raised concerns regarding its safety.23,24 Semiautonomous systems, on the other hand, are gaining market share due to their proven accuracy and absence of soft tissue complications that have been observed with autonomous systems.

At the time of this writing, in the United States two robotic systems are approved by the US FDA for UKA; and are being used clinically:

- Robotic Arm Interactive Orthopedic System (RIO)™ (MAKO Surgical Inc., Ft. Lauderdale, FL)—FDA approved in December 2008 [earlier generation system (Tactile Guidance System (TGS)™ approved in November 2005] (Figure 1)
- Navio Precision Freehand Sculptor (Navio PFS)™ (Blue Belt Technologies, Plymouth, MN)—FDA approved December 2012 (Figure 2).

**RIO™ System Overview**

The RIO™ is a robotic arm attached to a consul that uses preoperative computed tomography (CT) images of the patient’s lower extremity to allow accurate preoperative planning, intraoperative navigation, and robotic assistance to prepare bone for implantation of UKA components. While beyond the scope of this article, it is also in use for patellofemoral and THA surgery. The RIO™ system provides a stereotactic (haptic) interface which constrains the burr tip to within a predefined resection volume.

For the UKA application, a preoperative CT scan is performed of the patient’s hip, knee, and ankle to gather the patient-specific data on limb alignment (mechanical axis) and anatomic features. The RIO™ software converts the CT scan data into segmented slices which create a patient-specific three-dimensional (3D)
bone model from which the operative plan—including implant position, size, alignment, and corresponding volume and orientation of bone resection—is determined (Figure 3).

Bicortical partially threaded pins are drilled percutaneously into the proximal tibia and distal femur and optical tracking arrays are clamped to the respective pins, approximately 1–2 cm above the skin surface. After making the arthrotomy, surface landmarks—including the medial and lateral malleoli, medial and lateral epicondyles, and numerous discrete points along the articular cartilage of the knee
and periarticular surfaces of the distal femur, and proximal tibia—are identified and registered using optical probes.

Osteophytes are excised and the soft tissues on the surgical side of the knee tensioned as the knee is brought through a range of motion. A graphic representation of flexion and extension gap spacing (laxity and tightness) is displayed at each captured flexion angle. Adjustments in implant position and slope can then be made on the computer before bone preparation begins to achieve the desired ligament tension and gap balance.

The robotic arm is steriley draped and brought into the surgical field. Bone preparation is performed with a 6 mm burr attached to the “hand” of the robotic arm, also called the end effector (Figure 4). Bone resection is performed with the robotic arm, which applies stereotactic boundaries to the cutting burr. With trial components in place, an assessment of range of motion and stability is made. If necessary, additional bone can be removed by making adjustments to slope or depth of resection in the surgical plan on the computer, and then resculpting the bone surfaces.

**Navio PFS™ System Overview**

The Navio PFS™ represents the next generation of robotic technology for UKA, as well as emerging applications for PFA and femoroacetabular impingement (FAI). This handheld, light weight robotic tool combines image-free intraoperative registration, planning, and navigation with precise bone preparation. As a semiautonomous system, it augments the surgeon’s movements, with safeguards...
in place to optimize both accuracy and safety. The system continuously tracks the position of the patients’ lower limb, as well as the handheld burr, so that the limb position and degree of knee flexion can be changed constantly during the surgical procedure to gain exposure to different parts of the knee during registration and bone preparation through a minimally invasive approach.

After percutaneous insertion of bicortical partially threaded pins into the proximal tibia and distal femur and attachment of optical tracking arrays, mechanical and rotational axes of the limb are determined intraoperatively by establishing the hip and knee centers and the center of ankle. Either the kinematic, anteroposterior (Whiteside), or transepicondylar axes of the knee are identified and selected as the basis for the rotational position of the femoral component (Figure 5). The condylar anatomy is mapped out by “painting” the surfaces with the optical probes. In this way, image-free intraoperative surface mapping supplants a preoperative CT scan that is required in the Mako procedure (Figure 6). A virtual model of the knee is created and implant size, position, and orientation are established (Figure 7).

Osteophytes are excised and a dynamic soft-tissue balancing algorithm is initiated. With an applied valgus stress to tension the medial collateral ligament (for medial UKA) or a varus stress to tension the lateral structures (for lateral UKA), the 3D positions of the femur and the tibia are captured throughout a passive range of knee motion. A graphic representation of gap spacing through an entire range of flexion is created, and determination is made regarding whether the planned position of the femoral and tibial components is adequate or adjustments can be made to achieve the desired soft tissue balance (Figure 8). By adjusting the
implant positions—including tibial slope, depth of resection, and anteriorization or distalization of the femoral component—virtual dynamic soft tissue balance can be achieved.

**Figure 5:** With the Navio PFS™ the knee is flexed through a full range of motion showing varus alignment. Additionally, at this step the kinematic rotational axis is determined as the basis for establishing the eventual rotational position of the femoral component. Alternatively, the anteroposterior or transepicondylar axes can be used.

**Figure 6:** Condylar anatomy is mapped out by “painting” the surfaces of the femoral component with optical probes (Navio PFS™).
Figure 8: After osteophyte excision, a dynamic soft-tissue balancing algorithm is initiated. In the case of a medial unicompartmental knee arthroplasty, a valgus stress is applied to tension the medial collateral ligament and other medially based soft tissues. A virtual graphic representation of flexion and extension gap spacing is provided and an assessment can be made regarding the planned position of the femoral and tibial components through a full range of motion. Adjustments in implant position can be made accordingly (Navio PFS™).

Figure 7: After a virtual model of the femoral condyle and tibial hemiplateau is created, femoral and tibial component sizes, alignment and position are determined (Navio PFS™).
A 5 or 6 mm handheld sculpting burr is utilized to prepare the bone on the condylar surfaces. Unlike its predecessors, Navio PFS™ does not rely on “haptic” feedback. Rather, it provides protective control against inadvertent bone removal by modulating the exposure and/or speed of the motorized burr. In “exposure control” mode, the Navio PFS™ system modulates the exposure distance of the burr tip beyond the protective sheath. This position data is continuously updated in real time, resulting in fluid adjustments in position of the burr tip (Figure 9). In “speed control” mode, the passive exposure guard is removed from the Navio PFS™ handpiece, and the system modulates the rotational speed of the burr based on proximity to the target surface. This allows the burr to spin and remove the intended bone, but slows and stops the burr when the tip has reached the final preparation position. Speed control mode is ideal for preparing the lug holes, as the algorithms inherently allow the user to find the correct plunge trajectory, prevent cutting bone beyond the walls of a post-hole—and stop the burr from cutting bone at the bottom of the post-hole.

After bone preparation, the surfaces are assessed and trial components impacted into place for assessment of range of motion and stability (Figure 10). Limb alignment, range of motion, implant position, and gap balance can be quantified and compared to the preoperative plan by the system (Figure 11). If necessary, additional bone can be removed by making adjustments to slope or depth of resection in the surgical plan on the computer, and then resculpting the bone surfaces. Once the knee is considered adequately aligned and balanced, the final components are cemented into place (Figures 12 and 13).

**Results—RIO™ System**

Lonner et al. compared the radiographic alignment of the tibial component in 31 consecutive UKAs performed with robotic arm-assisted bone preparation to a sequential series of 27 consecutive UKAs in which bone preparation was performed.
Figure 10: Intraoperative view of prepared femoral and tibial surfaces show precisely prepared surfaces (Navio PFS™).

Figure 11: With trials in place, limb alignment and soft tissue are reconfirmed. In this case, final limb alignment in full extension is 1° varus (Navio PFS™).

using conventional manual instrumentation. The root mean square (RMS) error of the tibial slope was 3.1° with the conventional manual technique compared with 1.9° robotically. In addition, the variance using manual instruments was 2.6 times greater (p = 0.02) than the robotic arm-guided bone preparation method.
In the coronal plane, the average error of tibial alignment was $2.7^\circ \pm 2.1^\circ$ more varus using manual instruments compared with $0.2^\circ \pm 1.8^\circ$ when bone preparation was performed with robotic arm assistance ($p < 0.0001$), and the varus/valgus RMS error was $3.4^\circ$ manually compared with $1.8^\circ$ robotically.\textsuperscript{15}

Dunbar et al. compared 3D preoperative and postoperative CT scans in 20 knees to quantify the differences between planned and actual positions of the femoral and tibial components. The implant positioning errors in this study are summarized in Table 1 and compared to the data observed with other semiautonomous systems (Acrobot\textsuperscript{™} and Navio PFS\textsuperscript{™}) as well as conventional methods of bone preparation. Average RMS errors were within 1.6 mm and 3.0° in all directions of planned implant positions for both the tibial and femoral components.\textsuperscript{17}

An unpublished multicenter series looking at minimum 2-year survivorship of 750 robotically assisted UKA using with a metal backed fixed bearing UKA found a cumulative revision rate of 0.5%, compared to 2-year rates of revision published in international registries that range between 4.0% and 6.1% (Lonner, American Academy of Orthopaedic Surgeons) Instructional Course Lecture 2013, unpublished\textsuperscript{.25-29}

**Results—Navio PFS\textsuperscript{™} System**

In an initial feasibility study of Navio PFS\textsuperscript{™}, Smith et al. assessed the accuracy of bone preparation in 20 synthetic lower extremities (10 right and 10 left) and found RMS errors across all angular orientations (flexion-extension, varus-valgus and rotation) ranging from $1.05^\circ$ to $1.52^\circ$ for the femoral implant and $0.66^\circ$ to $1.32^\circ$ for...
the tibial implant. RMS translational errors averaged 0.61 mm, with a maximum of 1.18 mm. Mean surface overcut or undercut was 0.14 mm and 0.21 mm for the femoral and tibial surfaces, respectively.\textsuperscript{18,20}

A follow-up study by Lonner et al. evaluated the precision of bone preparation using Navio PFS\textsuperscript{TM} in 25 cadaveric specimens. Intraoperative surface mapping

\textbf{Figure 13:} Standing anteroposterior, lateral, sunrise radiographs showing isolated anteromedial osteoarthritis in a 67-year-old woman. Standing postoperative anteroposterior and lateral radiographs after medial unicompartmental knee arthroplasty with Navio PFS\textsuperscript{TM}. 
was performed and virtual selection of implant size and position was completed. The “planned” and “actual” angular, translational and rotational positions of the components were compared. The RMS angular errors were 1.42–2.34° for the three directions for the femoral implant and 1.95–2.60° for the three directions of the tibial implant. The RMS translational errors were 0.92–1.61 mm for the femoral implant and 0.97–1.67 mm for the tibial implant. The results are further summarized in Table 1, with comparison made to other series reviewing implant position with robotic and conventional technologies.

## SAFETY

Typical complications after UKA, in general, can also occur with robotic arm assistance, including loosening of the prostheses, polyethylene wear, progressive osteoarthritis of the unresurfaced compartments of the knee, infection, stiffness, instability, thromboembolic complications, and others.

Surgical complications resulting from robotically assisted UKA are identical to those encountered with surgical navigation, in general. The pin sites create a stress riser in the cortical bone which poses a risk for fracture. Inadvertent pin placement could theoretically cause neurovascular laceration. Most concerning, however, is the risk of inadvertent soft tissue complications during bone preparation with the robotic tool. A study by Chun et al. reported the need to abandon 22% of cases using an autonomous robotic-assisted technology (Robodoc, Curexo Technology Corp., Fremont, CA). Five percent were due to patellar tendon disruption; the remainder were due to technical or mechanical glitches of various sorts. On the other hand, the need to abandon the procedure with the two semiautonomous, surgeon driven technologies now used in the United States has been less than 0.5%. In an unpublished series by this author, of 937 consecutive UKA cases performed with either MAKO RIO™ or Navio PFS™ there were four recorded robotic system failures (0.4%) resulting in manual implantation of a UKA. These resulted from a blown fuse (n = 2), overheated motor (n = 1) and moved array

| Table 1: Summary of Positioning—Robotic Techniques versus Conventional |
|-----------------------------|-----------------|-------------------|-----------------|-----------------|
| RMS error                  | MAKO RIO™¹⁷     | Acrobat¹²         | Navio PFS™²²    | Conventional¹² |
| Flex/Ext (°)               | 2.1             | 2.1               | 1.8             | 6.0             |
| Varus/Valgus (°)           | 2.1             | 1.7               | 2.5             | 4.1             |
| Int/Ext (°)                | 3.0             | 3.1               | 1.7             | 6.3             |
| Prox/Dist (mm)             | 1.0             | 1.0               | 1.3             | 2.8             |
| Ant/Post (mm)              | 1.6             | 1.8               | 1.3             | 2.4             |
| Med/Lat (mm)               | 1.0             | 0.6               | 1.0             | 1.6             |

RMS, root mean square.
Robotically Assisted Unicompartmental Knee Arthroplasty

There were no aborted cases related to safety issues or concerns and no soft tissue complications caused by bone preparation.

CONCLUSION

The utilization of robotics is increasing in UKA, now accounting for 15% of UKAs performed in the United States. Additionally, applications for robotic assistance are expanding to areas, such as PFA, THA, and FAI. Robotic assistance in UKA significantly improves the accuracy of bone preparation, component position, and soft tissue balance which likely contribute to excellent early functional results and durability. The safety profile and absence of inadvertent soft tissue complications are important considerations that further distinguish the two commercially available semiautonomous (surgeon controlled) robotic systems from an autonomous robotic system.

The newer generation of image-free robotic technology offers a key blend of precision and safety, with improvements in affordability and convenience. This leads to an increase of the role of robotic technology in ambulatory surgery centers, which is where many UKAs are being performed at the current time.

Editor’s Comment

Unicompartmental knee arthroplasty has good documented results in the appropriately indicated patient. There has been increased interest in the use of robotics and automation when performing these procedures. Over time there has been an increased interest in automation and this is now penetrating the arthroplasty world. The use of robotics may increase the accuracy of component alignment and position. There is an increased cost of the use of this technology. Long-term prospective studies are necessary to truly evaluate this technology.

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REFERENCES


Cementless Total Knee Arthroplasty: Do We Need Cement Anymore?

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ABSTRACT

Total knee arthroplasty (TKA) continues to be one of the most successful orthopedic procedures aimed at treating end-stage degenerative joint disease of the knee. The evolution of surgical technique and implant design has yielded significant progress in relieving pain and restoring a more normal function. In the United States, cemented TKA remains the gold standard for patients with degenerative or inflammatory arthritis of the knee. Failure after a TKA has been extensively studied. The usual mechanisms of failure include periprosthetic joint infection, aseptic loosening, polyethylene wear, and osteolysis.1-3 Not surprisingly, revision surgery portends a worse functional outcome, not only because of the severity of osteolysis and resultant poor bone quality, but also because of the type of implant needed to confer stability to the revised knee.

INTRODUCTION

Cemented implants are susceptible to aseptic loosening in the medium and long term. Therefore surgeons have been reluctant to use these devices on young, active patients, even with severe osteoarthritis. In the past, surgeons have turned toward joint preservation procedures including high tibial osteotomies, distal femoral osteotomies, and aggressive persistent use of nonoperative measures, such as unloader braces to delay arthroplasty surgery as long as possible. This reluctance is reflective of the concern for failure of the primary total knee arthroplasty (TKA)

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from either aseptic loosening or wear of the polyethylene over time. It is clear that the results of revision TKA are suboptimal in comparison to a primary TKA secondary to the poor bone stock and associated ligamentous issues. The major contributor to loosening of a cemented implant is the nature of the bone-cement interface. Methyl methacrylate, the commonly used cement, is brittle and thus prone to fatigue fracture. It is inherently toxic to cells and, cement polymerization, an exothermic process, leads to thermal necrosis of bone. This thermal injury promotes the growth of a fibrous tissue layer that separates the bone-cement interface. In the long term, the stress on the bone-cement interface results in an increasing incidence of failure via aseptic loosening, prompting consideration for revision surgery. Loosening can compromise bone stock to such an extent that revision surgery usually requires use of stems to provide meta-diaphyseal support.

Therefore, TKA has historically been reserved for older, less active individuals. These less active patients theoretically place less functional demand on the implant, and thus increase implant longevity. However, there has been a recent trend in performing TKA in younger, more active patients. In a 2010 study, the demand for TKA in patients aged 45–54 years increased 300%. Younger patients are more likely to be active, thus placing more functional demand on the implant, a factor that highlights the importance of prolonged implant survivorship. It is not unreasonable for a young patient to expect their implant to last multiple decades. Thus, there has been a renewed interest in cementless knee technology to allow for a total knee prosthesis that has the same robust longevity as a cementless total hip arthroplasty in a young patient.

**DEVELOPMENT OF CEMENTLESS TOTAL KNEE ARTHROPLASTY**

Cementless TKAs were a part of a series of technological advances, including intramedullary alignment, and metal-backed tibial and patellar components, all of which sought to improve implant function and durability. Two important determinants for implant longevity are component durability and the quality of fixation. A successful implant is one that minimizes stress shielding, resists osteolysis, and one that withstands compression, torque, and shear forces. A cementless fixation relies on surface coatings and/or porous metals to promote osseointegration, a biologic bond between bone and implant (Figure 1). Without a bone-cement interface, the potential for the development of a fibrous tissue layer and osteolysis secondary to aseptic loosening is potentially eliminated.

Unfortunately, early cementless implants were engineered without acknowledging earlier lessons gleaned from tibial fixation of a cemented TKA. Micromotion at the bone-implant surface of the tibial component is a result of
varus/valgus malalignment, and the sliding or rollback of the femoral component. Micromotion in excess of 150 µm will compromise osseointegration. The type of material used to make the implant is paramount to reduce micromotion. Materials with lower modulus of elasticity may bend, thus increasing micromotion. Conversely, an increase in an implant’s modulus will result in stress shielding, yielding brittle bone that is likely to fracture.

Furthermore, fixation of the tibial component can be difficult due to the inadequate nature of the cancellous bone of the upper tibia. This bone is oftentimes unable to support the tibial component unless broad surface contact is achieved and this interface is protected with a central stem. Many early uncemented implants were designed without central stems and as a result, reports on the survivorship of uncemented TKAs are less than favorable. Between 1985 and 1994, the Swedish Arthroplasty Register found the risk ratio for any reason was 1.5 times higher in uncemented tibial group than the cemented tibial group.

However, recent advances in porous metal technology, and the success of porous metals in primary and revision total hip arthroplasty with massive bone loss has reignited interest in uncemented fixation in TKA. Porous metal uncemented fixation potentially offers several advantages to young or high-demand patients requiring TKA, including preservation of bone stock, larger volumes of osseointegration, which confers greater implant stability, and reduced stress shielding. First described in the 1970s, cementless fixation is not a novel concept. The ability to yield encouraging clinical results in various pathologies has propelled cementless fixation back into the forefront of TKA.
ADVANTAGES

Cementless knee implants have documented success with stability, as well as short- and medium-term longevity. In a prospective review of 105 uncemented TKAs, Helm et al. found equivalent results to cemented prostheses. At 3 years, no implant demonstrated radiolucent lines under the tibial component and there were only four patellar resurfacings and one revision for persistent pain in a patient who fell 2 months after the initial procedure. The uncemented prosthesis demonstrated statistically significant improvement in the patients’ postoperative Oxford Knee Score.⁹

Kamath et al. reported the results of a prospective 5-year follow-up on 100 patients younger than 55 years who received uncemented TKA. This cohort was compared to a retrospective control group of 312 patients who received cemented TKAs. Their data did not find any statistical difference in complication rate or operative times between the two groups. The clinical outcomes were also similar in both groups, with rates of revision being equal. Five cemented implants were revised. Three uncemented implants needed revision, but none due to failure of fixation: one was due to arthrofibrosis, one was revised for a periprosthetic supracondylar fracture after fall, and another was revised for midflexion instability.¹⁰

In a study that followed patients for 20 years, Eriksen et al. reported an 84.4% survival rate for all components in 102 patients who underwent uncemented TKA. The majority of revisions were due to early tibial and late patellar implant failure.¹¹

In 2010, Ritter and Meneghini reported similar results. Survival rate for implants, excluding the metal-backed patellar implant, was 96.8% at a 20-year follow-up.¹² Cross and Parish reported on the outcome of cementless fixation in 1,000 TKAs. Their failure rate was 0.5%, primarily due to periprosthetic infection.¹³

Henricson et al. used roentgen stereophotogrammetric analysis (RSA) to observe migration patterns of uncemented tibial components and compared them with a cemented cruciate-retaining tibial component in patients younger than 60 years. At 3 months, all uncemented implants were considered stable in all planes except external rotation, which stabilized at 12 months. Cemented implants in this study performed similarly to uncemented ones.¹⁴ To further support this result, Dunbar et al. found that uncemented implants were significantly less likely to be at risk for aseptic loosening, based on RSA analysis of micromotion of the tibial component. Although uncemented implants demonstrated greater initial migration, this migration stabilized at 12 months, after which, none of the 28 uncemented implants demonstrated signs of aseptic loosening, while 4 out of 21 cemented implants demonstrated early aseptic loosening.¹⁵

Cementless implants have also been shown to be successful in younger patients. Excluding infection, Tai and Cross reported a 97.5% survival for cementless TKAs in patients younger than 55 years at 12-year follow-up.¹⁶ This was confirmed in
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_a study by Hofmann et al., which reported the outcomes of cementless TKA in patients younger than 50 years. There were no cases of loosening; the only reason for reoperation was infection._17

_Lastly, it has been proposed that cementless fixation facilitates an easier revision surgery than a cemented implant, should a revision be required. For cementless implants demonstrating aseptic loosening, the lack of cement allows for implant removal without the bone loss associated with cement removal. Furthermore, a reduced operative time may also be advantageous, as there would be no need for cement mixing and waiting for cement polymerization._10

DISADVANTAGES

_Despite the advantages of cementless fixation outlined above, there are certain disadvantages that must be addressed. The studies references above demonstrate generally equivalent results for cemented and uncemented knee implants. However, there are several studies that demonstrate the inferiority of cementless fixation. Duffy et al. prospectively studied a group of 55 uncemented TKAs and compared them to a matched group of 51 cemented TKAs. They found the survival rate to revision for either aseptic failure or radiographic loosening was 72% in the uncemented group, while the survival in the cemented group was 92% at 10 years._18

_Although bony ingrowth is the desired outcome of an uncemented TKA, osseointegration may not always occur. In an 11-year follow-up of 131 uncemented implants, Berger et al. found that 80% of all tibial implants did not demonstrate bony ingrowth of the tibial component.19 Even if osseointegration is achieved, this excellent fixation between bone and implant may complicate revision surgery.20,21 Revision surgery in a joint where a cementless implant has been used requires the use of an oscillating saw to cut the bone-implant interface. During this process, those implants that employ metaphyseal pegs for additional stability must have their pegs cut, creating significant metal debris. This metal debris may potentially lead to adverse soft tissue reactions and creates the difficult task for the surgeon to ensure that all metal debris has been removed from the operative site._

_Initial implant stability and fixation are important determinants of implant survival. Several studies have suggested that cementless implants are at high risk for initial migration and potential deformation under physiologic stresses._14,15 _Low-modulus uncemented implants demonstrate significant subsidence and deformation under biomechanical loads. Henricson et al. compared implant migration between an uncemented cruciate-retaining monoblock porous tantalum tibial component to a cemented cruciate-retaining tibial component using RSA.14 In their cohort, they found cementless implants had significantly more rotation around the axes of the knee than did the cemented implants. Furthermore,
subsidence was also significantly more pronounced in the cementless group. Both cemented and cementless implants showed similar patterns of migration, with most migration occurring within the first 6 weeks to 3 months of implantation. Thereafter, most implants seemed to stabilize with no further migration, with the exception of internal-external rotation, which did not stabilize until 12 months postoperatively. This migration may be a consequence of uncemented implants not possessing the immediate filling property of cement. Therefore, migration and subsidence will continue until the underlying bone is healthy enough to accommodate osseointegration. In a similar study, Dunbar et al. compared an uncemented posterior-stabilized monoblock porous tantalum tibial component with a cemented posterior stabilized tibial component. They demonstrated migration of the uncemented implant to be significantly higher than that of the cemented component, with increased subsidence, posterior tilt, and more internal rotation. Despite this migration, the components remained stable for the duration of the study.

To address rotational and coronal plane stability of the implant, manufacturers devised implants with dual pegs on the inferior surface of the tibial implant. However, 5-year follow-up with a dual-peg design has resulted in an unforeseen consequence. There is a risk of peg penetration of the lateral cortex, especially if the tibia is overresected. O’Keefe et al. studied 125 TKAs for a duration of 5 years. In their series, a total of three implants demonstrated lateral cortex penetration. The clinical significance of this complication is not yet understood.

Monoblock tibial implants were designed to directly compression mold the polyethylene onto the trabecular metal (Figure 2). Advantages to such a design

![Figure 2: Monoblock tibial component with trabecular metal ingrowth surface and dual-peg fixation. Courtesy: Zimmer Orthopedics (Warsaw, IN).](image)
include elimination of backside wear, a low modulus of elasticity, and a relatively flexible component that avoid stress shielding. However, the monoblock design has led to increased difficulty in implantation due to the inability to balance soft tissues with polyethylene thickness after tibial component implantation. Fewer options for polyethylene thickness may prove to increase postoperative instability or, conversely, tightness resulting in poor range of motion.

Lastly, many of the disadvantages of cementless fixation are a consequence of the patella and difficulties related to fixation and patellar bone stock at the time of surgery. Most cementless TKA procedures incorporate a cementless femoral and tibial component fixation coupled with cemented polyethylene patellar buttons. Some implants employ a metal-backed component that is either fixed to the polyethylene articular surface or permits rotation of a polyethylene bearing that is snap-fit onto a metal prosthesis. The disadvantage to this design is that the polyethylene is thinner, thus making the implant more susceptible to wear. Chronically this wear-through of the polyethylene causes eventual metal-on-metal wear of the femoral and patellar components. Ries et al. retrospectively reviewed a group of 18 knees with patellar bone deficiency at primary TKAs (2 knees) and revision TKA (16 knees). Ten of eleven implants that had at least 50% host bone contact remained stable, with no evidence of migration or loosening. Conversely, none of the seven patellas that had no bone host contact, remained stable at 12-month follow-up. These results were comparable to a study by Tigani et al. Similarly, Berger et al. reported on the long-term follow with an uncemented design and found the revision rate for the patellar implant was 48%. When replacing the patella during a TKA, it is also important to assess the viability of the patella in order to achieve a successful osseointegration. Blood supply to the patella is vital; should the need arise for a lateral release, the use of an uncemented patellar implant should be considered a contraindication. Some may point to the decreased operative time of a cementless TKA as a potential advantage, but with the use of cemented patellar components in the setting of a cementless femur and cementless tibia, there is only a limited improvement in tourniquet time, and therefore, trivial benefit in relation to potential for infection, etc.

Some of the key disadvantages related to cementless TKA are more practical than truly scientific in this current era. Anywhere from 2% to 20% of patients who undergo TKA of any type may continue to have some level of pain following surgery that leaves them somewhat dissatisfied with the results of the operation. This often leads to them seeking further opinions for diagnosis and management of their discomfort. Following cementless TKA there may be no signs of osseointegration, but no signs of component failure or subsidence that leaves the question of whether the patients’ pain is related to component
loosening/failure of ingrowth. Some arthroplasty surgeons will argue that cementless TKA leads to yet another variable that is difficult to fully assess and may lead to increased revision surgery in this patient population, whether or not the components obtain ingrowth or not. Additionally, in this current era of heightened concern for periprosthetic joint infection and higher risk patients undergoing total joint arthroplasty surgery, there is significant data from the arthroplasty registries indicating a reduced risk of failure with antibiotic-loaded bone cement used prophylactically in TKA. Bone cement allows the introduction of an antibiotic that elutes slowly from the cement over a period of time in the early stages after the TKA. The recently released consensus statement on periprosthetic joint infection does also support the use of antibiotics in bone cement prophylactically in TKA. As another practicality one may argue that early failure (<3–5 years) with cemented TKA due to aseptic loosening is rather uncommon with the modern generation of TKA and that cementless TKA brings with it a risk of an increased incidence of early failure. Early failure is without a doubt a difficult pill for a patient and the surgeon to swallow and this increased early risk may be, in fact, avoided with cemented TKA.

CONCLUSION

Revision surgery remains a feared complication of TKA. Cementless knee replacements have several proposed advantages: improved implant longevity, potentially shorter operative time, potentially easier revision surgery, and equivalent outcomes to cemented knee arthroplasties. These cementless total knee replacements have demonstrated similar results to their cemented counterparts. However, this success must be weighed against the documented complications associated with this type of implant. Most reports indicate that cementless knee arthroplasties fail early. Those that did achieve early success went on to achieve favorable long-term clinical results. At the present time, younger, high-demand patients with good bone stock can achieve excellent results with cemented TKA without the potential for early failure. Additionally, the added benefit of prophylactic antibiotic in the bone cement as well as the more clearly defined component fixation in the postoperative follow-up period lead to clear advantages of cemented TKA.

As our understanding of knee biomechanics, implant geometry, and biomaterials has refined, so has the engineer’s ability to develop implants that increase longevity and decrease failure. However, cleverly designed an implant may seem, there is absolutely no substitute for evidence-based decision-making when the time comes for an orthopedic surgeon to choose an implant for TKA.
Editor's Comment

Today, cemented total knee arthroplasty remains the gold standard for knee arthroplasty in the United States. Excellent long-term outcomes have been reported. However, failures such as aseptic loosening do occur especially in certain patient populations. As the patient population becomes younger and more active, the concern for aseptic loosening in this population increases. There has been a renewed interest in cementless technology. Unfortunately, early generations of cementless implants have not had great success. Recently, the use of porous metals has been used to improve the results of cementless total knee arthroplasty.

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What Is New in Total Joint Arthroplasty: Europe

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ABSTRACT

This article covers the following topics related to total joint arthroplasty in Europe: (i) the history of total joint arthroplasty; (ii) diagnosis; (iii) biomaterials; (iv) design; (v) technique; (vi) surgical approach; and (vii) total ankle arthroplasty.

INTRODUCTION—HISTORY OF TOTAL JOINT ARTHROPLASTY AND NATIONAL REGISTERS

The first hip prosthesis models introduced in the first decades of the 21st century did not reach satisfactory results in most of the patients due to problems related to biomaterials, design, and surgical techniques.

The revolutionary approach introduced in 1959 in the United Kingdom by Charnley obtained extraordinary results, thanks to the introduction of newly designed prostheses, the use of metal-on-polyethylene bearing, the use of cement, and both the posterolateral and the transtrochanteric approach. Afterward, the research in the orthopedic world applied to improving the three aspects of materials, design, and surgical techniques and reached outstanding outcomes, so that total hip arthroplasty is now considered one of the most successful of all surgical treatments, as reported in the review: “The operation of the century: total

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hip replacement” published by Learmonth et al. in Lancet in 2007. The number of total hip and total knee replacement (TKR) has constantly increased over the past decades.

In the year 2012, a total of 700,000 hip replacements were performed in Europe: 250,000 in Germany; 130,000 in France; 100,000 in Italy; and 90,000 in the United Kingdom.

The National Arthroplasty Registers, as they represent the most ample databases available, are now important benchmarks for the study of the survivorship rate of arthroplasty and their revision, and help reduce failure rate by identifying poorly performing implants, procedures and hospitals. The Swedish Knee Arthroplasty Register, developed in 1975, was the first of the National Arthroplasty Registers developed, followed by the Swedish Hip Arthroplasty Register (1979). The other Scandinavian countries followed shortly afterward: Finland (1980), Norway (1987), and Denmark (Hip 1995, Knee 1997). Many other countries have tried to adopt the Scandinavian system, facing political and practical challenges that in some cases led to a failure of the Registry; nowadays, the Scandinavian registers and the New Zealand Joint Register are the most widely known and used registers in long-term survivorship studies.

Based on these registers, European revision rates can be affordably estimated as: 1.29 revisions per 100 arthroplasty per year after hip and knee replacement, 1.53 after medial unicompartmental knee replacement and 3.29 after total ankle replacement. Infection rates are around 1% for hip and 0.7% for knee replacement.

The analysis of the national registers shows also an increase of around 5% in the number of hip and knee replacements every year.

**DIAGNOSIS—RULING OUT ARTHRITIS AND INFECTION**

Osteoarthritis is the most common underlying condition for total joint arthroplasty (TJA). Other conditions include inflammatory arthritis, fracture, and tumors. No great findings have been introduced in the recent years for diagnosis of articular conditions, but it is mandatory to respect the correct collection of patient’s data including history, physical examination, and imaging. Risk factors for primary arthritis include genetics, female sex, past trauma, anatomical paramorphisms such as femoroacetabular impingement, advanced age, and obesity. The diagnosis is suspected on a history of joint pain worsened by movement, which can lead to disability in daily living. The physical examination and X-ray can provide objective evidence of the disease. Blood rheumatoid markers monitoring is required when an inflammatory disease is suspected. In some cases, articular aspiration can be performed. In primary osteoarthritis, the white blood cell (WBC) count is usually less than 500 cells per mm² (0.5 × 10⁹ per L) and is composed predominantly of mononuclear cells.
In inflammatory aspirates, the WBC count is usually greater than 2,000 cells per mm$^2$ ($2.0 \times 10^9$ per L), and the predominant cell type is usually the neutrophils. Magnetic resonance imaging (MRI), computed tomography (CT), and bone scans are useful when a neoplastic etiology is suspected. Prosthetic infection must be ruled out in case of persistent wound leakage or an acute onset of fever, pain, swelling, effusion and erythema at the implant site. Late infections may present more insidiously with worsening joint pain. Routine blood tests may suggest a diagnosis of infection [for example, a raised C-reactive protein (CRP) or white cell count], but these are unhelpful in the early postoperative phase as they will be raised for around 14 days after surgery. The radionuclide-based technique most widely used is combined leukocyte/marrow imaging, with a reported accuracy of 88–98%. Intraoperative cultures have been reported to be not affordable owing to high percentages of false-negative and false-positive cases. This evidence has been modified by the recent introduction of sophisticated detecting technologies such as sonication and polymerase chain reaction (PCR) analyses: thanks to multiplex PCR of sonication fluid and the PCR-based electron spray ionization time-of-flight mass spectrometry (ESI-TOF-MS), many of the revision arthroplasty cases that have previously been considered to be purely aseptic after microbiological and histological examinations, may now reveal a component of unrecognized, subclinical infection. Concerns on the high number of false positives with the use of these techniques still exist, especially concerning amplification of DNA of dead bacteria.

**BIOMATERIALS—METAL-ON-METAL HIP ARTHROPLASTY**

Metal-on-metal (MOM) THA was introduced in 1970 by Weber. MOM has been employed for a long time showing early promising results and some advantages compared to other types of bearing: a reduced risk of fracture if compared to ceramics, less volumetric wear compared to conventional polyethylene, and reduction of dislocation risk and increase of range of movement related to use of larger head size. Nevertheless, the high rate of wear and corrosion of metal may lead to a release and accumulation of ions locally and systemically. Chromium, cobalt, aluminum and nickel ions release occur both from MOM and polyethylene-on-metal (POM) bearings, and may result in local adverse reactions to metal debris. Furthermore these particles penetrate cell plasma membrane through lymph and systemic vascular system, regulate cytokine expression, and can cause oxidative DNA damage perhaps combined with inhibition of DNA repair. Many concerns still remain regarding the effects of prolonged exposure to increased metal ion levels. Eventful pregnancies in young patients cannot be considered evidence in favor of MOM and the increased risk of cancer is
still unknown, as the length of follow-up of patients receiving new-generation prosthesis is too short.\textsuperscript{15} Hypothyroidism, polyneuropathy, impairment of cranial nerves II and VIII, and cardiomyopathy may be caused by high blood ions concentrations.\textsuperscript{16} Penny et al.\textsuperscript{17} described that circulating T lymphocyte levels may decline after MOM hip resurfacing and total hip replacement (THR), regardless of implant type. Treatment of symptomatic metallosis consists of the removal of the prosthesis: it has been reported that in patients with a normal kidney function, metal ion levels fall to almost normal levels shortly after removal of the implant.\textsuperscript{18}

More recently, systemic metal ion levels have become popular in the workup of a metal on metal hip arthroplasty. There is controversy about what value for these tests is predictive for local or systemic pathology. However, elevated blood metal ion levels should be considered as a warning of undetectable and ongoing periprosthetic osteolysis in asymptomatic patients.\textsuperscript{19} Hart et al. demonstrated that blood metal ions had good sensitivity (63\%) and specificity (86\%) to discriminate failed from well-functioning hip replacements using the cut-off level of 4.97 parts per billion (ppb) for cobalt and chromium.\textsuperscript{20}

Prosthesis design and positioning also plays a fundamental role in originating metal debris. Multiple studies on resurfacing MOM THA showed high serum levels of metallic ions and soft tissue complications, especially with smaller size, female patients, and low coverage arc, focusing the attention on design and orientation of the components.\textsuperscript{21} Hart et al. underlined that the effect of an acetabular inclination angle of greater than 50° was connected to higher metal ions level, similar to what happened in early metal-on-polyethylene bearing.\textsuperscript{22} Multiple studies support the advantages of MOM THA compared to MOM resurfacing, but the data in the literature report contrasting opinions: Savarino et al. in a long-term follow-up study, found higher chromium and cobalt release in MOM resurfacing than in MOM THA, while Valcu et al. did not show any long-term clinical difference in MOM resurfacing and MOM THA.\textsuperscript{23,24}

Furthermore, recent studies report high failure rates for MOM replacement. Smith et al. reported a high failure rate for MOM THR, from the National Joint Registry of England and Wales. Failure at 5 years was related to head size, with larger heads failing earlier (3.2\% for 28 mm and 5.1\% for 52 mm head). On the contrary, for ceramic-on-ceramic bearings larger head sizes were associated with improved survival (3.3\% for 28 mm and 2.0\% for 40 mm head).\textsuperscript{25} In the international orthopedic community, a very controversial discussion was started on the affordability of MOM bearing and the need for follow-up of implants, but evidence-based data are still lacking.

The use of modular prosthesis design improved flexibility in matching the anatomic characteristics of each patient during THR, but also introduced the risk of metal ion release at the interfaces. In particular, taper junction corrosion
and ion diffusion are described in all THA modular design types and severity might be associated with the number of metallic junctions. It has been suggested that the main cause of taper junction corrosion is the increased lever arm acting on this structure, particularly in varus stems, in large-diameter head MOM hip replacements. Some authors report that even the addition of a modular sleeve can cause an increased cobalt release and recommend modification or rejection of modularity in TJA.²⁶,²⁷

The “European multidisciplinary consensus statement on the use and monitoring of MOM bearings for THR and hip resurfacing” was founded in 2013 to define a common behavior in European orthopedic society. The consensus described benefits, local and systemic risks, and follow-up recommendations related to MOM bearings. The most interesting recommendation was to adopt a strong follow-up for large head (≥36 mm) MOM and resurfacing THA, consisting of X-rays and cobalt metal ion rate measurement. Critical cobalt values for clinical concern are expected to be within the range of 2–7 µg/L, while levels less than 2 µg/L are not alarming. In case of clinical or radiographic suspicion as well as elevated ion levels, ultrasound, CT scan, and MRI were recommended to better understand the implant conditions.²⁸

**DESIGN—PROSTHESES DESIGN AND HIGH-FLEXION TOTAL KNEE ARTHROPLASTY**

At the beginning, total knee arthroplasty (TKA) was introduced as a pain reliever in osteoarthritic patients, as an alternative to arthrodesis. In the late 1970s, the goal of restoring normal knee function gained in importance. Many design patterns have been proposed, and some concerns still remain regarding posterior cruciate ligament (PCL) sacrifice or retention, fixed or mobile-bearing polyethylene inlay, and design of the inlay (traditional versus high flex).

Some recent papers have investigated patient preference regarding the type of TKA implant. Between posterior stabilized (PS), anterior cruciate retaining (CR), mobile bearing, anterior and posterior cruciate (bicruciate) retaining, and medial pivot total knee implants, the designs that obtained better patient satisfaction were the medial-pivot designs and bicruciate-retaining, which were introduced in Europe in the late 1990s.²⁹,³⁰

Nowadays, range of movement is commonly used as an indicator of functional outcomes, and accounts for the definition of a well performing TKA as much as pain scoring. Because of this, specific rehabilitation protocols and new prosthesis designs have been proposed to improve flexion (i.e., “high-flex” prosthesis design). Many studies examine knee function after arthroplasty in high-flexion activities of daily living, such as rising from a chair, ascending stairs, and normal walking.³¹,³² The result is that the best functional results are achieved when knee flexion is
allowed to 130°. It is important to note that a better functional outcome does not always result in a greater patient satisfaction. Little is known about patient perception and normal life improvement after high-flexion TKA. A recent study reveals no significant difference in perceived outcomes by the patient. In 2012, Nutton et al. compared the normal and the high-flexion design of the same knee replacement demonstrating a greater flexion for the high-flex one. However, the motion that was gained with the high flex component is not considered necessary for normal daily activities. Furthermore, the pain score after surgery was significantly higher in the high-flex group. Thomsen et al. also compared normal and high-flexion designs with a 1-year follow-up: the result was that there was no significant difference in clinical outcome and knee function between the two groups, even in the flexion rate. High-flexion TKRs also require thicker posterior femoral cuts.

TECHNIQUE—NAVIGATION AND PATIENT-SPECIFIC ALIGNMENT TOOLS FOR TOTAL KNEE ARTHROPLASTY

The different techniques today available for component alignment can be divided into conventional, navigational, and patient-specific (custom made). In traditional techniques, an intramedullary rod is commonly required. The use of this method introduces some potential complications: increased blood loss, embolization of medullary content, and difficult positioning of the intramedullary rod due to deformity, retained hardware, long hip stems, or pathological bone disease. Mason et al. in 2007 demonstrated that with the traditional technique a malalignment of more than 3° occurs in 1 out of 3 patients, while in navigated implants it occurs in only one out of ten cases. On the other hand, navigation requires longer surgical time, higher cost, increasing complication and a long learning curve. To avoid these problems, recently, patient-specific guides have been developed; with these hardware, the use of an intramedullary rod is not required and the technique should eliminate almost all the complications of navigation.

Patient-specific approaches to TKA utilize preoperative MR or CT imaging data to manufacture custom cutting jigs specific to a single patient’s bony anatomy. Nunley et al. evaluated the cost by quantifying the savings from decreased operative time and instrument processing costs compared to the additional cost of imaging and guide. The result was that, while the cutting guides reduced costs through decreased operative time and instrument processing time, the estimated savings was undercut by the additional cost of the imaging exam and the cost of the cutting guide itself. The few published papers and subjective clinical practice results on this topic showed that customized patient instrumentation technology have comparable or better implant alignment than traditional technique. It has
also been observed an increased efficiency is surgical time and a decrease in
the number of surgical instruments needed. However, patients’ satisfaction and
improved clinical results has not been shown yet and more studies are required to
address this question.41

**TECHNIQUE—MANAGEMENT OF PATELLA
IN TOTAL KNEE ARTHROPLASTY**

The treatment of the patella during TKR continues to be debated. Patella
resurfacing or nonresurfacing remains controversial. Many papers showed that
maintaining the native patella grants a better tracking and a better clinical
function, minimizing complications, such as fractures, avascular necrosis,
patellar maltracking, polyethylene debridement, patellar clunk and component
infection.42,43 Other authors have shown better results in patients with resurfaced
patella in terms of satisfaction and anterior knee pain, and decreased remission
rates.44

In later studies, no differences were reported in terms of clinical outcome
between resurfacing patella or not, even in the same patient, so the last thought
is that is not correct to concentrate the attention only on the “bony part” of the
problem, but we need to consider many other structures and factors that may
influence patellar tracking and correlated pain.45 Component rotation, patella
height, ligament balancing, component design, and ROM are key points to
consider whether the patella is resurfaced or not.46

Interestingly, a lot of emphasis has been placed on soft tissue releases in medial
and lateral compartments for achieving a balanced TKA. The patellofemoral
compartment approached differently, as it has historically been addressed only by
the geometrical design of the trochlear groove and the medial-lateral positioning
of the patella component.

In some recent papers, a new approach has been attempted, emphasizing the
role of soft tissues around the patella for medial-lateral mechanical stability and
tracking, and thus proposing a staged lateral release to correct patellar tracking.
The most recent research (led by Amis, in the United Kingdom) has also
highlighted that the geometrical features that correlate most with anterior knee
pain are patellar thickness and rotation of the femoral component, while the
improved design of patella component and femoral groove have not obtained
enhanced results.47-49

In light of these findings, the correct approach to patella management should
be decided by developing a decision algorithm that should be as much as possible
“patient specific” and consider all the aforementioned aspects, in order to minimize
invasiveness and improve outcomes.
SURGICAL APPROACH—MINIMALLY INVASIVE SURGERY TOTAL JOINT ARTHROPLASTY

One of the most fascinating innovations in hip and knee replacement in the 1990s was minimally invasive surgery (MIS). This concept, firstly introduced in general surgery, was based on the purpose of minimizing surgical damage to the patient by using a shorter and less tissue-damaging approach for joint replacement. The rush for smaller incisions and less invasive technique has led to extreme solutions and showed little benefit with an unacceptable increase in certain complications. The three major concerns about MIS have always been: (i) cosmesis, (ii) efficacy, and (iii) complications. The concept of MIS was generally mistaken for a way to reduce only skin incision, and went through attempts and failures that led to the introduction of the term tissue-sparing surgery (TSS) that better represents its original purpose.

Pipino introduced TSS in 2006 describing a decalogue of rules to perform a TJA in full respect of anatomy and function. The decalogue not includes advice on the choice of the surgical approach, but also on the instrumentation, bone integration, and use of computer assistance.50,51

In knee surgery, the search for a smaller, less tissue-damaging approach aimed at three principles: (i) short skin incision, (ii) absence of patella eversion, and (iii) integrity of the suprapatellar pouch. The most used MIS approach is the mini subvastus. Historically, the standard subvastus approach was not used in obese or muscular patients in order to avoid damage to the vastus medialis obliquus and retinacular tissues surrounding patella. In addition, it was difficult to evert the patella. In the mini-subvastus approach, patella eversion is not required and can be just subluxated. For this reason, this approach is applicable to almost all patients. This MIS approach is reported to allow faster rehabilitation with a better clinical outcome. Almost all authors agree that clinical outcome at short term is better in “quad-saving” mini approaches than with a standard approach, causing less damage to the quadriceps mechanism.52,53 All authors report that the downside of MIS techniques is that they can be more difficult, leading to prolonged surgical time, and expose the patient to a higher risk of implant malpositioning due to a reduced view of anatomical landmarks. For some authors the future is the use of the navigation system: this should avoid the problems of malalignment and prolonged surgical time.54,55 Biasca et al. in 2009 compared computer-assisted MIS and conventional navigated one: they observed a better outcome in the first group only in the first 6 months. The authors concluded that MIS TKA leads to a better short-term outcome with increased risks if performed by an inexpert surgeon; these risks can be reduced if performed with a computer-assisted technique.56
TOTAL ANKLE ARTHROPLASTY

Supported by the success of THA, surgeons attempted to reconstruct all joints with contrasting results. Total ankle arthroplasty (TAA) was first performed in the 1970s with unsatisfactory results and was, at the time, considered inferior to ankle fusion. This view started to change in the late 1980s, when new, more anatomical designs were proposed and there was a good improvement of clinical outcomes. Nevertheless today the controversy still exists on ankle arthrosis treatment: whether to perform an arthroplasty or arthrodesis.57

The improvements in TAA outcomes result from a combination of different factors: better patient selection, more precise knowledge and replication of ankle biomechanics, less constrained designs with minimum bone resection, no need for cementation and greater attention to soft tissue balancing for component alignment.58 The complexity of TAA depends on ankle biomechanics, involving three articular components: (i) tibiotalar, (ii) fibulotalar, and (iii) tibiofibular. The first implants were formed by a concave polyethylene component and a convex metal part or other designs with a constrained movement. The result was catastrophic for both designs due to instability or loosening. In the 1990s, new implants were introduced that use a three-part mobile bearing system. Nowadays, the indications for a TAA are aged patients of more than 50 years with severe arthrosis, low body mass index, and low demands.59 Even if some authors consider acceptable to perform a TAA on younger patients with post-traumatic arthrosis it is reasonable to give attention to weight and activity level.60 Ankle fusion normally transmits abnormal overloads to contiguous joints accelerating arthrosis progression and leading to progressive arthrosis of the hindfoot, an incidence of hindfoot arthrosis of 100% at 22 years after tibiotalar fusion has been documented.61 In case of preexisting arthrosis of neighboring joints, it is possible to perform a TAA associated to subtalar and hindfoot arthrodesis, even in a two-stage approach. Some authors proved TAA efficacy as conversion from a painful fusion, but only in highly selected patients.62,63 In our opinion, according to the reported findings, TAA has to be considered a more helpful procedure than how it is regarded today in the orthopedic world.

CONCLUSION

European research has supplemented and added to the vast knowledge base of worldwide literature. Studies from various parts of Europe have resulted in multiple points of view on current popular topics in joint arthroplasty.
Editor’s Comment

Total joint arthroplasty is performed worldwide. There have been geographic differences in philosophy of implants, surgical techniques, and perioperative management. These differences have led to significant discussion and growth internationally. Current hot topics are discussed.

Matthew S Austin
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REFERENCES


What Is New in Total Joint Arthroplasty: Asia

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ABSTRACT
This article covers recent total joint arthroplasty from Asian publications. Topics included are: ligament balancing, the use of tranexamic acid, bilateral simultaneous procedures, and deep vein thrombosis and pulmonary embolisms in total joint arthroplasty.

INTRODUCTION
The number of total joint arthroplasties (TJAs) performed has been growing explosively in both Western countries and Asia. For example, in Japan, the number of total knee arthroplasty (TKA) performed annually increased from 33,700 in 2001 to 70,800 in 2011, while that of total hip arthroplasty (THA) increased from 25,300 to 44,100. The number of TJA performed in Japan for relative population is still small compared to that in the United States, but the total number doubled over a decade, and the same tendency has been observed in other Asian countries.

Owing to the increasing demand for these procedures, many Asian orthopedic surgeons have specialized in TJA, and it is suggested that they have become active in both the clinical and research fields. Rahman et al. reported that Japan's share of articles in orthopedics (not limited to TJA) from 1991 to 2000 was 8.3% in top seven orthopedic journals, and its contribution was third among top 20 countries [the first being the United States (50.3%) and the second being the United Kingdom (UK) (11.2%)]. In other Asian countries, China was the 12th (1.0%) and India was the 14th (0.8%). The proportion of Japan’s share (8.3%) was much higher in orthopedics than in basic medical science (3.1%) or general clinical science (0.7%).

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RECENT TOTAL JOINT ARTHROPLASTY PUBLICATIONS FROM ASIA (TABLE 1)

Original scientific papers were searched in MEDLINE using “total hip” or “total knee” as key words in four widely circulated orthopedic journals for TJA (J Bone Joint Surg Am, J Bone Joint Surg Br, Clin Orthop Relat Res, and J Arthroplasty).

Table 1: Recent Total Joint Arthroplasty Publications from Asia

<table>
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<tr>
<th>Region</th>
<th>Country</th>
<th>Subject</th>
<th>Total</th>
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<td></td>
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<tr>
<td></td>
<td>New Zealand</td>
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<tr>
<td></td>
<td>Subtotal</td>
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<td>4.9</td>
</tr>
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<td>Others</td>
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</table>

TJA, total joint arthroplasty; THA, total hip arthroplasty; TKA, total knee arthroplasty.
I divided the total of 1,928 papers related to TJA that were published from January 2010 to June 2013 into three groups: (i) specific to THA (906 papers), (ii) specific to TKA (786 papers), and (iii) general to TJA (236 papers). The papers were also classified by the first author’s country. Eight hundred and eighty-eight papers published were from the United States (45.7%), while 192 papers published were from the UK (10.0%). Of the Asian countries, 131 (6.8%) published were from Japan, 121 (6.3%) Korea, 45 (2.3%) China, 20 (1.0%) Taiwan, and 20 (1.0%) India. It is not possible to simply compare these results to those published by Rahman et al.;¹ however, it is notable that Asian countries other than Japan have made a much greater contribution to the recent body of TJA publications than they had in the past. The total share of Asia was 18.2%, comparable to that of Europe (24.5%).

The subjects discussed in recent TJA papers were essentially universal worldwide, but there are some specific topics addressed by papers originating in Asian countries, including those that might arise from the nature of race, lifestyle, social and economic environment, and surgeon attitude. In this paper, four specific topics were selected as follows: (i) ligament balancing in TKA, (ii) the use of tranexamic acid in TKA, (iii) bilateral simultaneous TKA, and (iv) deep vein thrombosis (DVT) and pulmonary embolism (PE) in TJA.

**LIGAMENT BALANCING IN TOTAL KNEE ARTHROPLASTY**

The original models of the current condylar total knee prostheses and the surgical techniques were developed in the 1970s by a number of creative innovators³ using two different design approaches: (i) a functional approach and (ii) a strictly anatomical approach. In the former, the articulating surface had relatively high conformity and the posterior cruciate ligament (PCL) was sacrificed using the gap balancing technique, which later led to posterior-stabilized (PS) TKA. In the latter, the prostheses had less conforming surfaces and the PCL was retained using the measured resection technique, which led to cruciate-retaining (CR) TKA. The idea of the original gap balancing technique was developed by Michel Freeman and John Insall in the early 1970s in the UK, and Insall then brought it to the United States. However, when Insall developed the IB II (the modified total condylar TKA), he discontinued using the gap technique and instead integrated the functional approach and the measured resection technique in the United States. The reason for this shift was probably due to the clinical situation in the United States. The gap technique required additional surgical instruments and was more time consuming and complicated for surgeons; therefore, it was not accepted widely in the United States.

At the end of the 1990s and in the early 2000s, the use of deep flexion after TKA was highlighted, especially in Asian countries. To achieve better range of
motion during flexion, it is believed that the gap at flexion should be equal to that at extension, and an appropriate balance should be maintained between the medial and lateral sides during flexion. Some enthusiastic Japanese surgeons have developed their original tensioning devices to obtain a balanced flexion gap and then examined the gaps between the femoral and tibial components throughout the range of motion in a patella reduced position.\textsuperscript{4,5} As mentioned previously, the number of TKA procedures performed for population in Japan was small. Even in an arthroplasty center, surgeons usually performed only two or three TKA a day. In such circumstance at the operating theater, dedicated surgeons were allowed to perform a complicated procedure and measurement within a time limit using a tourniquet.

Matsumoto and Muratsu developed their own off-set type tensor and intraoperatively measured soft tissue balance within a reduced patellofemoral joint. They compared the soft tissue tension of CR and PS TKA measured at 0°, 10°, 45°, 90°, and 135° of flexion with the patella both everted and reduced in 40 patients with osteoarthritis and concluded that soft tissue tension patterns differed between everted and reduced patellae as well as that between PS and CR TKA.\textsuperscript{6} They also examined the influence of preoperative deformities on intraoperative soft tissue balance and found that the degree of such varus deformities had no influence. They concluded that even in preoperative severe varus deformed knees, gap balancing can be adjusted during PS TKA.\textsuperscript{7} Furthermore, they correlated the intraoperative values of soft tissue tension with the postoperative values assessed by stress radiographs during extension and flexion at a minimum 5-year follow-up, and elucidated that the intraoperative condition of the soft tissue balance reflected the postoperative values, especially in CR TKA, even at a 5-year midterm follow-up.\textsuperscript{8}

The development of sophisticated measuring and gap-making devices has enabled surgeons to conduct precise examinations of intraoperative ligament tension and create well-balanced joint gaps. The benefit of a balanced gap technique has been reported to provide superior coronal plane stability as measured by assessment of the incidence and magnitude of femoral condylar lift-off,\textsuperscript{9} and a more normal kinematics pattern during stair ascent was achieved using gap balancing techniques.\textsuperscript{10} However, it has not been examined whether the gap technique provides better clinical outcomes in terms of range of motion, function, and patient satisfaction. Further controlled studies and detailed examinations are required to elucidate its effects.

**THE USE OF TRANEXAMIC ACID IN TOTAL JOINT ARTHROPLASTY**

Tranexamic acid, a synthetic derivative of the amino acid lysine that exerts its antifibrinolytic effect by reversibly blocking the lysine-binding sites on plasminogen
molecules, has recently gained attention as a hemostatic agent for TJA in the United States. Tranexamic acid is an old and inexpensive drug. Developed by Professor S Okamot in the early 1960s in Japan, it has been widely used to treat or prevent excessive blood loss during surgery. It was introduced in Scandinavia and Japan in the late 1990s and many Asian studies have published about its efficacy.

Yang et al. performed a meta-analysis to assess the effectiveness and safety of tranexamic acid use in TKA. Randomized controlled trials published before May 2011 were retrieved, and 15 studies met the inclusion criteria of the present study. The results indicated that the tranexamic acid group had less blood loss and required significantly fewer blood transfusions than the placebo group. Additionally, no significant differences were detected in prothrombin time, activated partial thromboplastin time, DVT, or PEs between the groups.

Onodera et al. conducted a randomized prospective study to clarify the effectiveness and risks of topical use of tranexamic acid and carbazochrome sodium sulfonate hydrate associated with a drain-clamping method after 100 TKA procedures. Although the bleeding volume was significantly lower in the tranexamic acid group, the risk of asymptomatic deep venous thrombosis detected by ultrasonography was comparable between the groups.

Imai et al. evaluated the hemostatic effects of tranexamic acid by examining the timing of its administration during THA. A total of 107 patients undergoing THA were randomly divided into five groups according to tranexamic acid administration timing. The intraoperative blood loss, postoperative blood loss, and hemoglobin levels of these patients were monitored. Intraoperative blood loss in the preoperative tranexamic acid administration groups was significantly lower than those of the control and postoperative tranexamic acid administration groups. Furthermore, 1 g tranexamic acid administered 10 minutes before surgery and 6 hours after the first administration was most effective for reducing blood loss during THA.

Tranexamic acid reduces perioperative blood loss in TJA. However, its effect does not last long due to its very short half-life in the blood (several hours). Even with the use of tranexamic acid, these surgical sites (especially knees) remain swollen for weeks after operation, which negatively affect patients’ perioperative quality of life. Thus, the creation of additional hemostatic and anti-inflammatory measures after TJA is required.

**BILATERAL SIMULTANEOUS TOTAL KNEE ARTHROPLASTY**

As mentioned previously, the contribution of Korea to the publication in TJA has become greater in recent years. Especially in the field of TKA, 71 papers were
published from Korea which were 9% of the total papers from the world and 2nd in the world (Table 1).

Professor Kim is the leading person in the field of TKA in Korea, who published 10 of the 71 TKA papers during the survey period in this paper, and in the 8 of the 10 papers he employed bilateral simultaneous TKA as a randomized trial. He and his colleagues compared a standard and a gender-specific posterior cruciate-substituting high-flexion TKA, standard and gender-specific posterior-cruciate-retaining high-flexion TKA, the low contact stress and press fit condylar rotating-platform mobile-bearing TKA, long-term outcomes in a cemented and cementless TKA using an identical design, fixed-bearing and mobile-bearing TKA in patients younger than 51 years of age with osteoarthritis in longer follow-up, standard and high-flexion TKA after a minimum of 10 years of follow-up, computer-navigated and conventional TKA, and TKA with oxidized zirconium and cobalt-chromium femoral components. They used Knee Society scores, Western Ontario and McMaster Universities osteoarthritis index, and plain radiographs as standard measures to detect the differences, but they were not able to discover any differences in all above comparison. In other words, such examination procedures were not enough sensitive to detect the latent differences, and more detailed evaluation, for example kinematic analysis and wear particle study, are required.

DEEP VEIN THROMBOSIS AND PULMONARY EMBOLISM IN TOTAL JOINT ARTHROPLASTY

In Western countries, venous thromboembolism (VTE) is relatively common after THA, and many surgeons recommend routine pharmacologic thromboprophylaxis. However, VTE has traditionally been thought to be rare in Asian populations. There is some evidence to suggest that genetic differences partially explain the lower risk of VTE in Asian patients.

Yokote et al. reported a randomized controlled trial performed to evaluate whether the incidence of postoperative VTE was reduced by using pharmacological anticoagulation with either fondaparinux or enoxaparin in addition to the mechanical prophylaxis. They examined 255 Japanese primary unilateral cementless THA patients, and found that the rate of VTE was 7.2% with the placebo, 7.1% with fondaparinux, and 6.0% with enoxaparin detected by ultrasonography, no differences between groups. They confirmed the effectiveness of mechanical thromboprophylaxis without the use of anticoagulant drugs after THA in Japanese patients.

Lee et al. conducted a meta-analysis to determine the overall incidence of DVT and PE without chemoprophylaxis after TKA in the Asian population. A total of 1,947 patients from 18 studies were reviewed, and the incidence of
symptomatic PE was 0.01%. The incidences of overall DVT, proximal DVT, and symptomatic DVT were 40.4%, 5.8%, and 1.9%, respectively. They found that the incidence of symptomatic PE and DVT after TKA without prophylaxis is low in Asian countries and has not changed over time, despite Westernizing lifestyles and an aging populace.

Thus, routine chemoprophylaxis following Western protocols after TKA is still debatable in Asian populations, and further investigation with large randomized studies is needed to confirm these results and identify the risk factors that can lead to PE and DVT.

**CONCLUSION**

The recent publication trends in Asian articles related to TJA were searched by MEDLINE in major orthopedic journals. In the total of 1,928 papers, 131 (6.8%) published were from Japan, 121 (6.3%) Korea, 45 (2.3%) China, 20 (1.0%) Taiwan, and 20 (1.0%) India. Asian countries other than Japan have made a much greater contribution to the recent body of TJA publications than they had in the past. The total share of Asia was 18.2%, comparable to that of Europe (24.5%). The subjects discussed in recent TJA papers were essentially universal worldwide, but there are some specific topics in Asian countries, and it is important to discuss the differences between Asia and Western countries to elucidate the nature of TJA.

**Editor’s Comment**

*Total joint arthroplasty is popular throughout the world. There are generally many similarities in techniques and approaches to joint replacement. However, differences among different populations do exist. Differences in the Asian population are highlighted. Scientific articles that originated from Asian countries are reviewed.*

_Matthew S Austin
Gregg R Klein_

**REFERENCES**


What Is New in Revision Total Joint Arthroplasty

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ABSTRACT

The purpose of this article is to review (i) new strategies to achieving fixation in the hip; (ii) new strategies and controversies in achieving fixation in the knee; and (iii) new devices to optimizing hip stability during revision total joint arthroplasty.

INTRODUCTION

With an aging population and expanding indications for joint replacement surgery, the number of primary and revision hip and knee replacements is projected to significantly increase.1,2 Despite improvements in surgical technique, materials, and prosthetic design, failures resulting from infections, wear, fractures, and instability persists.3-5 The goals of revision joint replacement surgery include achieving stable implant fixation; restoring length, offset, and alignment; and minimizing instability. Over the years, there have been significant innovations in materials and prosthesis design aimed at making revision surgery more reliable and reproducible.

FIXATION DURING REVISION TOTAL HIP ARTHROPLASTY

Acetabular Reconstruction

Acetabular reconstruction during revision total hip arthroplasty (THA) can present significant challenges to the orthopedic surgery. Often, bone loss associated
with wear and osteolysis are underestimated by plain radiographs (Figure 1) and therefore, one must be prepared to address larger than anticipated bone lesions at the time of revision. If the acetabular component is well fixed, removal of a well fixed cup can also lead to fracture and additional bone loss. While the goal of bone preservation during acetabular component removal has remained constant over decades, commercially available, curved explant osteotomes designed to match the outer diameter of the cup allow the surgeon to remove even the well ingrown cup with minimal bone loss (Figure 2). These devices work by using a matching femoral ball head in conjunction with either an existing liner (without screws) or a trial liner (following screw removal) to center a diameter matched curved

**Figure 1:** Often, bone loss associated with wear and osteolysis are underestimated by plain radiographs.

**Figure 2:** Commercially available, curved explant osteotomes designed to match the outer diameter of the cup allow the surgeon to remove even the well ingrown cup with minimal bone loss.
What Is New in Revision Total Joint Arthroplasty

osteotome around the acetabular shell; thus minimizing the risk of fracture or unnecessary bone loss.6

Once the acetabular component is removed, reconstruction follows standard principles. Re-establishment of height and hip center of rotation is essential to a long-lasting hip prosthesis.7 For most acetabular revisions, a standard, large hemispherical cup is sufficient to achieve stable implant fixation and bone ingrowth.8 Grafting of cavitary defects can help restore bone stock and in addition provide a stable platform for the socket.7 Furthermore, the use of porous metals has allowed surgeons to achieve stable, long term, biologic fixation even when host bone contact is significantly reduced. Sternheim et al. compared the outcomes of a group of patients undergoing revision THA with less than 50% acetabular bleeding host bone contact to patients with host contact greater than 50% using trabecular metal acetabular components. At a mean of follow-up of 72 months, the authors reported only 7.5% failure rate in patients with significant bone deficiencies and cup to host bone contact less than 50%.9 Consequently, the use of porous metal revision acetabular shells allow for use of uncemented hemispherical cups even in the setting of significant bone loss.

Challenges arise when pelvic deficiencies prevent reconstruction with standard devices. Over the years, many techniques have been described for management of these defects and include the use of bulk allograft, custom double bubble implants and antiprotrusio cages.10 While bulk allografts have been shown to be effective in aiding the reconstruction of segmental pelvic deficiencies, the long-term survivorship of these grafts remains in question.11 Today, most revision systems have options for augments of various shapes and sizes aimed to address these issues. Made from porous metals, these augments allow for intraoperative customization and provide a buttress for increased component stability (Figure 3). Studies using these augments have shown good intermediate results for the reconstruction of these large defects.12,13 Van Klunen et al. reported on a series of 97 acetabular revisions with Paprosky IIA or greater pelvic defects and at a mean follow-up

Figure 3: These augments allow for intraoperative customization and provide a buttress for increased component stability.
of 45 months, showed that the use of trabecular metal acetabular shells with or without modular augments can be used to effectively revise failed acetabular components with substantial pelvic bone loss.\(^\text{12}\) More recently, Del Gaizo et al. reported on a series of 37 hips with Paprosky IIIA pelvic defects treated with porous metal cup and augments. At a mean follow-up of 26 months, only one hip required re-revision for cup loosening.\(^\text{14}\) Consequently, today, the multiple augment shapes and options are available to help manage pelvic defects of various shapes and sizes during revision THA.

In recent years, recognition and appropriate management of pelvic bone loss with associated pelvic discontinuity has improved the results of reconstruction in these cases. The use of additional imaging, such as CT scans, and careful intraoperative assessment are critical in the recognition of these special circumstances. These large, pelvic defects have historically been managed with antiprotrusio cages; however, concerns about the lack of long-term fixation and hardware failure have led to development of alternative techniques and devices. One technique that has been currently employed in the management of pelvic discontinuities in revision THA is the use of a cup/cage construct. The theory behind this technique is that the cage serves as a protective agent for the cup and thereby allowing for potential biologic ingrowth in case of failure. Rogers et al. compared complex reconstructions using ilioischial cages compared to cup-cage reconstructions and reported an 8-year survivorship of 86.3% of cup-cage constructs compared to a 29% failure of the ilioischial cages.\(^\text{15}\) Others have reported management of these massive defects using custom, individual triflange components (Figure 4). Tauton et al. reported on a series of 57 patients with pelvic discontinuity treated

![Figure 4: Others have reported management of these massive defects using custom, individual triflange components.](image)
with custom triflange components. At a mean follow-up of 65 months, 95% were free of revision. Consequently, appropriate management of pelvic discontinuity requires use of either pelvic plating, antiprotrusio cages, cup-cage constructs, or custom triflange devices.

**Femoral Reconstruction**

Fixation on the femoral side during revision THA is dependent on the degree of bone loss and the size, shape, and length of the previously implanted femoral component. Historically, options for revision femoral components include long-cemented revision stems and uncemented monolithic femoral components. Femoral reconstruction using long-cemented stems have had inconsistent track records, and therefore the work horse for femoral revisions in the United States has been the use of extensively coated femoral components. While these uncemented implants have been shown to provide reliable and durable fixation, disadvantages of these devices include (i) inconsistent prosthesis seating; (ii) inability to adjust version; and (iii) need for an intact femoral isthmus. In recent years, manufacturers have shifted their focus toward long-tapered modular stems in order to improve the consistency of femoral instrumentation. These devices can obtain stable fixation with 2–4 cm of fit compared to the 4–8 cm of isthmic fixation; allows for adjustments in body height and version; and for independent preparation of the distal segment which allows for more consistent seating of the prosthesis (Figure 5). Results using these modular components

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**Figure 5:** These devices can obtain stable fixation with 2–4 cm of fit compared to the 4–8 cm of isthmic fixation.
have been encouraging. Palumbo et al. reported a series of 18 tapered, modular
titanium stems implanted for Paprosky III and IV femurs. At a mean follow-up of
4.5 years, 94% survivorship achieved, with one revision required for infection and
subsidence. Disadvantages of these stems can include subsidence, breakages, and
potentially corrosion of the modular junction. However, improvements in taper
tolerance and modular junction designs have decreased the incidence of failures.
Therefore, despite potential failures at the modular junctions, improved materials
and designs have made these femoral components more reliable and thus have led
to an increase in revision stem options which have helped make revisions of failed
femoral components simpler and more reproducible.

IMPROVING HIP STABILITY

Instability remains a significant cause of failure following both primary THA and
revision hip replacement surgery. Historically, dislocation rates following revision
surgery have been reported to be as high as 50%. Maximizing hip stability depends
largely on acetabular component position and achieving appropriate soft tissue
tension. Furthermore, while maximizing head size can improve the arc of motion
and minimize impingement, there are some limitations to the size of ball heads
that can be used before concerns about polyethylene thickness and more recently,
concerns with trunnion wear become an issue. In recent years, increasing
popularity of offset, face changing liners, and dual mobility acetabular components
into the United States have added another tool to the armamentarium to minimizing
postoperative hip instability. Offset, face changing polyethylene liners allow for fine
tuning of acetabular component position by altering abduction, version, and increase
soft tissue tension through an eccentric polyethylene liner (Figure 6). While these
components can theoretically improve component position, allow for increased ball
head sizes, and minimize impingement, these implants cannot overcome poorly
positioned acetabular components. In extreme cases, spontaneous dissociations from
the underlying acetabular shell have been reported.

The concept of dual mobility is not new, and has been used in Europe with
good, long-term results. The basic construct relies on either a metal or ceramic
small ball head placed into a larger all-polyethylene ball head (Figure 7). This,
in turn, articulates into the acetabular component with a metal inner shell. This
construct allows for maximizing head size while reducing issues associated with
volumetric wear. Combes et al. reported on a series of 2,480 consecutive primary
THA performed using a dual mobility cup and at a mean of 7 years follow-up,
their rate of dislocation was 0.88%. However, while there was no evidence of cup
loosening, the authors reported a 6% incidence of osteolysis particularly in the
younger patients (<50 years). Consequently, the use of dual mobility cups should
be done on a selective basis and with caution. In certain instances, interprosthetic
dislocations between the inner and outer heads of these articulations have been reported.29

ACHIEVING FIXATION: THE KNEE

Similar to hip revision surgery, the principal goal of revision total knee arthroplasty (TKA) includes (i) achieving stable fixation; (ii) proper alignment; and
(iii) a balanced knee in both flexion and extension. Unfortunately, as the number of primary TKAs continues to increase, the revision burden is also projected to rise.\textsuperscript{1,5} Currently, the top reasons for revision knee surgery include instability, infection, and loosening.\textsuperscript{2,3,5} Consequently, in recent years, there has been a focus toward solving problems related to implant sizing, achieving diaphyseal and metaphyseal fixation, and improved wear profiles of revision implants.

During revision TKA, stem extensions are often utilized in order to improve and augment implant fixation. These stems can be cemented or they can be press fit into the medullary canal. Today, controversy remains on which type of stem fixation is preferable. Advantages of cemented stems include (i) ability to deliver antibiotics to the medullary canal; (ii) ability to implant the components independent of host anatomy; and (iii) no end of stem pain. Difficulties in component and cement removal if additional surgery is required and limited stem diameters and lengths to achieve rigid fixation in large capacious canals are potential disadvantages of revision TKA using cemented stems. In contrast, advantages of uncemented press fit stems include (i) ability to use the host medullary canal to restore alignment; (ii) ability to engage the diaphysis for added rotational and axial stability; and (iii) improved ease of removal. In the literature, long-term successful revisions using cemented and press fit stems have been reported.\textsuperscript{30,31} The critical point is that the success of press fit, uncemented stems hinges on appropriate sizing and diaphyseal engagement of the stem.\textsuperscript{32,33} Disadvantages of press fit stems include end of stem pain and component malposition secondary to femoral and tibial bowing. Current revision systems allow for both uses of cemented and uncemented stems depending on the bone deficiency and on the preference of the treating surgeon.

Restoration of the joint line and achieving metaphyseal fixation and implant stability is another goal of revision TKA. Recently, various forms of metaphyseal augmentation have become incorporated into various manufacturers’ revision portfolio (Figure 8). These augments allow the surgeon to address large, meta-

\begin{figure}[h]
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\includegraphics[width=0.5\textwidth]{figure8}
\caption{Recently, various forms of metaphyseal augmentation have become incorporated into various manufacturers’ revision portfolio.}
\end{figure}
What Is New in Revision Total Joint Arthroplasty

physeal defects (AORI type II and type III) and allow re-establishment of a stable proximal tibial and distal femoral platform.34 (Figure 9). The early clinical results using these augments have been encouraging. Long and Scuderi reported on a series of 16 revision TKA with severe bone loss treated with porous metal metaphyseal augments. At a mean 31-month follow-up, there were no mechanical failures or loosening.35 More recently, Lachiewicz et al. reported on a series of 33 tantalum cones used in 27 revision TKA. At a mean of 3.3 years follow-up, only one femoral cone was revised for loosening.36 Consequently, use of metaphyseal cone or sleeve augments can improve implant axial and rotational stability and facilitate joint line restoration in cases with severe bone loss.

Finally, improving polyethylene wear characteristics remain a goal for manufacturers in TKA. In recent years, the use of highly cross-linked polyethylene (HXPE) has permeated into the total knee market. However, concerns with HXPE include increased brittleness and resulting concerns about post wear.37 Stoller et al. evaluated the in vitro performance of HXPE compared to conventional polyethylene (CPE) in TKA and reported reductions in wear rates and improved tibial post-durability.38 Clinically, Hodrick et al. compared a group of TKA implanted with HXPE and CPE and reported no increased rates of loosening, osteolysis, or complications with the use of HXPE in TKA.39

Other manufacturers have looked toward mobile bearings to improve wear and minimize osteolysis. Advantages of mobile bearings include reduction of forces transmitted to the tibial component and potential reduction in post-wear.40 While there have been a number of basic science studies demonstrating the benefits of mobile bearings in TKA, there have not been clinical confirmatory studies showing clear superiority of this type of TKA design.41 Consequently, despite of improved
wear characteristics through materials and design, there are no studies to date demonstrating clear clinical superiority of either HXPE or mobile bearings in revision TKA compared to CPE.

CONCLUSION

Recent advances and innovations in materials and prosthetic designs have improved the reliability and reproducibility of revision hip and knee arthroplasty. These improvements have facilitated our abilities to obtain prosthesis fixation, and maximize implant stability. However, it is important to remember that while these implants can be somewhat more forgiving, the fundamentals of meticulous surgical technique and proper component position and rotation remain the keys to successful joint reconstruction.

Editor's Comment

The long-term results of hip and knee replacement have been well documented. However, failures do occur. As the number of arthroplasties increases and the population becomes younger, the number of revision procedures will increase dramatically. The key to successful revisions is multifactorial. Precise preoperative planning, meticulous surgical techniques, and appropriate implants are necessary. There has been an evolution of implants that have helped improve long-term outcomes of revisions. Specifically the use of porous metals results in improved fixation of implants.

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REFERENCES


WORLD CLINICS
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The streams of medicine and surgery are evolving constantly at a rapid pace, creating a need for the healthcare professionals to continuously update their knowledge base and skills. This is necessary to offer their patients the best ‘real world’ treatment options based on current concepts, status, and trends, reflecting the achievements of evidence-based medicine. This pace of advances in medicine is a compelling reason for the physicians and surgeons to seek information through multiple resources, such as journals, workshops and conferences.

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