A Review Paper

Preoperative Templating and Its Intraoperative Applications for Hip Resurfacing Arthroplasty

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Abstract

Hip resurfacing arthroplasty (HRA) is a viable alternative to total hip arthroplasty (THA) in the younger, active adult with degenerative hip disease. However, hip resurfacing has proven to be technically demanding, as accurate component positioning is crucial for success, yet difficult to obtain. Risks of malpositioning of the femoral head include femoral neck notching, varus/valgus malalignment, and femoral neck fracture, while malpositioning of either component may lead to increased edge loading and metal ion levels. A thorough preoperative plan, including a review of clinical findings, radiographic studies, and surgical templating for component size and positioning improves intraoperative accuracy and precision. Key aspects of formulating a methodical preoperative plan for HRA are reviewed. Pertinent aspects of the clinical and radiographic examinations, the technique of preoperative templating, its intraoperative application, clinical outcomes of various preoperative templating systems and intraoperative alignment guides, and the senior author's (EPS) preferred technique are presented.

Metal-on-metal hip resurfacing arthroplasty (MoM-HRA) is a viable alternative to total hip arthroplasty (THA) in select patients with end-stage hip arthritis that has failed conservative management. The goals of hip resurfacing are to alleviate pain and improve function of the arthritic hip while conserving femoral bone stock for potential revision surgery. Data from registries, case series, retrieval analyses, and expert consensus generally agree that ideal candidates for hip resurfacing are young (<65 years), male, and have a large build and osteoarthritis.[1,2] Radiographs should show preserved bone stock and density, minimal bone remodeling, and limited evidence of bone cysts, despite advanced loss of articular cartilage. Patients must also have hip anatomy that accommodates the resurfacing prosthesis, generally meaning nearly normal acetabular and proximal femoral morphology, neutral femoral neck-shaft angle, and equal leg lengths.

After prudent patient selection, successful hip resurfacing relies on technical aspects of the procedure, as accurate sizing and positioning of the components are essential. MoM-HRA has less tolerance for malpositioning than conventional metal-on-polyethylene THA does, as malpositioned MoM-HRA components are particularly vulnerable to impingement, increased bearing wear, and loss of acetabular fixation.[3,4] Furthermore, intraoperative errors and improper femoral component positioning increase the risk for femoral neck fracture, a cause of catastrophic early failure.[3,5,6]

Although the importance of surgeon experience in reliably achieving optimal implant positioning cannot be overemphasized,[6,7] careful preoperative templating should help mitigate many of the technical pitfalls of MoM-HRA implantation and increase a surgeon's ability to deliver consistent, good outcomes. Several authors have reviewed the methodology and merits of preoperative templating for THA.[8-12] To our knowledge, there are no articles reviewing preoperative templating for MoM-HRA. As with preoperative templating for THA, the primary objective of templating for MoM-HRA is reproducibility of results.[8] In addition, the preoperative plan should inform the surgical team of all the necessary components and instrumentation required in the operating room, improve the efficiency and accuracy of the procedure, and help anticipate most intraoperative complications.[8]

History and Physical Examination

Preoperative planning begins with the clinical assessment. Evaluation of eligibility for hip resurfacing starts with a thorough medical history, including patient demographics, preoperative diagnosis, activity level, renal function, and metal hypersensitivity. Younger men are regarded as ideal candidates for MoM-HRA, whereas women in their childbearing years may not be, because metal ions can cross the placenta, and their impact on fetal development is not fully known.[13] Whether female sex is a relative con-

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Figure 1. Anteroposterior pelvis radiograph shows coccyx aligned approximately 18.9 mm directly superior to pubic symphysis.

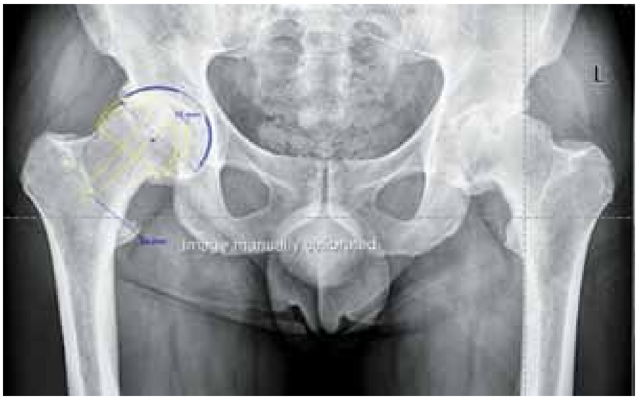

Figure 2. Anteroposterior pelvis radiograph shows digital templating of metal-on-metal hip resurfacing arthroplasty. Distance from fovea to center of articular surface of femoral head was 15 mm, and distance from center of femoral stem to medial aspect of lesser trochanter was 34 mm. Both measurements can be used during surgery to assist in placing alignment guidewire.

traindication to MoM-HRA is debatable. Smaller femoral head size, rather than sex, may be better correlated with implant failure.[14,15] Likewise, advanced age may be related only indirectly, if at all, to decreased MoM-HRA survivorship.[16]

The preoperative diagnosis provides prognostic information regarding implant longevity. For example, data from the Australian registry show that revision rates are lower for patients with a diagnosis of osteoarthritis and higher for those with developmental dysplasia.[17] Patients with osteoarthritis, posttraumatic arthritis, osteonecrosis of the femoral head, and mild to moderate developmental dysplasia (Crowe type I or II) may be candidates for MoM-HRA. Patients with slipped capital femoral epiphysis (SCFE), Legg-Calvé-Perthes (LCP) disease, advanced osteonecrosis of the femoral head, and more severe types of dysplasia (Crowe type III or IV) typically have inadequate bone stock and morphology for the MoM-HRA prosthesis.[18] Placement of MoM-HRA in these patients may require sacrifices in technique that threaten the durability of the implant.[19] Patients with LCP disease often have wide femoral necks, which require placement of oversized femoral components to avoid notching, and posterior-medial rotation of the femoral head relative to the femoral neck in patients with SCFE may result in femoral implants unsupported by bone, if femoral head alignment is corrected.

Patients who go into surgery expecting to return to their high levels of preoperative activity are typical candidates for MoM-HRA. In contrast to THA surgeons,[20] resurfacing surgeons often do not discourage patients from engaging in high-impact activities, such as running.[21] However, patients should be counseled that higher levels of activity increase the risk for implant failure.[22]

MoM-HRA should be avoided in patients with impaired renal function and history of metal allergy. The incidence of metal sensitivity is higher in patients with metal-on-metal prostheses than in the general population.[23] Factors known to increase blood levels of metal ions, such as renal disease and malfunctioning prostheses, increase the risk for developing metal sensitivity, aseptic lymphocytic vasculitis-associated lesions, and pseudotumor.[24-26]

Physical examination begins with assessing the patient's general appearance. Patients of large stature have anatomy that accommodates larger femoral head sizes (>48 mm), which demonstrate improved implant longevity.[14] Obesity, as indicated by body mass index (BMI) higher than 35, may complicate accurate implant positioning, risk femoral notching, and increase the risk for femoral neck fracture.[6,27] However, Le Duff and colleagues[28] found a statistically significant implant survival advantage in heavier patients (BMI ≥30), possibly related to decreased levels of activity and larger component sizes.

Next, the surgeon should assess the patient's gait, hip range of motion, and fixed or functional deformities. In general, MoM-HRA is reserved for patients with preserved joint mechanics, as the prosthesis has limited capacity to correct alterations in hip center and limb length. THA should be considered when there are significant differences in limb length and alterations of hip joint mechanics.

Radiographic Examination

Templating begins with obtaining appropriate films, including anteroposterior (AP) radiograph of the pelvis and AP and cross-table lateral radiographs of the affected hip. Templating accuracy relies on obtaining radiographs with standardized patient positioning and image magnification. The tip of the coccyx should be centered 1 to 2 cm over the pubic symphysis on AP pelvis radiographs (Figure 1). The hips are internally rotated 10° to 15° to improve visualization of the femoral head and to account for natural femoral anteversion.[29] Femoral malrotation and hip flexion contribute to erroneous radiographic measurements.[30-32] Kay and colleagues[31] found that 7° of external rotation of the femur can cause more than 10° of change in apparent femoral neck-shaft angle, and Olsen and colleagues[32] showed that femoral flexion of more than 40° can lead to clinically significant errors in neck-shaft angle measurements. Magnification is verified with a radiographic marker of known size (Figure 2) and should be reflected in the implant templates.[33]

Radiographs confirm the diagnosis and suitability of MoM-HRA for a patient's hip geometry. MoM-HRA is contraindicated in patients with inadequate bone stock in the femoral head, neck, or acetabulum, defined by osteoporosis, large (>1 cm) cysts in the femoral head or neck, and osteonecrosis resulting in significant head collapse. Deviations of the acetabular center and excessive varus/valgus neck-shaft angles may constitute contraindications to MoM-HRA. The diameter of the femoral head should be larger than the diameter of the neck, and the center of rotation of the femoral head must lie close to the axis of the neck. These latter requirements protect against femoral notching during surgery. Combined acetabular and femoral anteversion should be 45° or less, as more anteversion would require derotational osteotomy to avoid edge loading and impingement.[34,35]

Beaulé and colleagues[36] reported that 57% of hips that underwent resurfacing arthroplasty demonstrated decreased head-neck offset ratio (≤ 0.15) on preoperative radiographs. Diminished head-neck offset (eg, from cam-type deformity) places the femoral neck at risk for notching and requires correction to prevent impingement, pain, and abnormal component wear.[36]

Technique of Templating in Hip Resurfacing

The goals of templating are to optimize femoral and acetabular component sizes and position and thus decrease risk factors for failure.[37] It is generally agreed that the optimal stem-neck angle is 135° to 145° in the coronal plane,[38] and optimal acetabular component positioning is defined as 40°±10° of abduction with 20°±5° of anteversion.[39] Beaulé and Amstutz[40] noted that resurfacings with a femoral stem-shaft angle of 130° or less had an increase in the relative risk for an adverse outcome by a factor of 6.1, and De Haan and colleagues[3] found that an association between a steeply inclined acetabular component (>55°) with small component sizes and significantly higher metal ion levels.

The femoral component is usually templated first, as the size of the smallest one that can be safely implanted dictates the size of the acetabular component. Most modern resurfacing systems have a 6-mm differential between the outer and inner diameters of the acetabular component. If the native acetabulum appears incapable of accepting the complementarily sized implant, because of acetabular dysplasia or insufficient bone stock, then the surgeon should be prepared to perform THA.

Templating the femoral component begins with drawing a line along the long axis of the femoral diaphysis and a line from a point approximating the center of the femoral head through the midpoint of the isthmus of the femoral neck.[32,37] The intersection of these lines defines the native femoral neck-shaft angle. Whether the angle is in relative varus or valgus should be noted.

Figure 3. Anteroposterior pelvis radiograph shows osteophytes at superior and inferior femoral head-neck junctions bilaterally. Lines delineate osteophytes to be removed during surgery; preoperative plan should account for removal of these osteophytes.

Next, femoral templates are used to determine the size and position of the component. The center of the articular surface of the femoral implant is referenced. This point lies superior to the fovea on the femoral head. The distance between the fovea and this point is measured and used during surgery to determine the correct starting point for the alignment guidewire. The articular surface of the femoral head template is placed at this point, and the femoral stem is aligned with, or placed in slight valgus relative to, the native neck-shaft angle, taking care to ensure that the superior femoral neck will not be damaged by the superior aspect of the cylindrical reamer (Figure 2).

Sizing the femoral component proceeds such that the base of the implant template sits just proximal to the native femoral head-neck junction. Proper sizing restores head-neck offset and mitigates postoperative impingement.[41] Tangential lines are drawn along the anterior and inferior surfaces of the femoral neck to delineate osteophytes to be removed during surgery and to reveal the true head-neck junction (Figure 3). Failure to remove osteophytes results in femoral component oversizing and unnecessary removal of acetabular bone to accommodate a larger acetabular component.

The acetabular component is templated in a fashion similar to that for THA. The base of the teardrop, ilioischial line, and superolateral border of the acetabulum are marked. The acetabular template is positioned with the medial border approximating the ilioischial line, such that the cup has adequate lateral bony coverage, and minimal supportive subchondral bone will be removed.[8] The superior-inferior placement of the acetabular implant is debatable, as some surgeons prefer to place the inferior border of the implant level with the inferior border of the teardrop, and others contend that this leads to unnecessary removal of acetabular bone.[8]

Acetabular templating for MoM-HRA must take into account that supplemental screw fixation is not an option. Therefore, sufficient acetabular coverage and fixation are imperative. The native acetabulum should be assessed for signs of dysplasia, such as a steep inclination angle, superolateral migration of the femoral head, and deficient anterolateral bone stock. In mild to moderate dysplasia, options for obtaining adequate bony coverage include medialization of the acetabulum and raising the acetabular center of rotation.[8]

Most MoM-HRA sockets are thicker at the apex than at the surrounding walls. This design improves hip range of motion before impingement but results in higher functional inclination angles than would be expected based on radiographic measurements.[34] Excessive inclination increases edge loading and serum metal ion levels.[3,34,42-44] Therefore, most resurfacing surgeons will err toward more horizontal cup orientation than they would for THA. For the same reasons, excessive anteversion of the acetabulum should be avoided, and the presence of anterior acetabular deficiencies, which can lead the surgeon to place the cup in increased anteversion, should be assessed before surgery. On the preoperative template, with the acetabular component placed in a relatively horizontal position, the superolateral edge of the implant will protrude 5 to 8 mm beyond the bony acetabulum. This is a helpful relationship to reproduce during surgery.

Leg-length discrepancy can be assessed by drawing a horizontal line that connects the base of the teardrops, and measuring the perpendicular distance from the proximal corner of the lesser trochanter to this reference line for each hip. The difference between these 2 distances is the radiographic leg-length discrepancy. This discrepancy should be compared to the leg-length determined during the physical examination. Changes in leg length and femoral offset are dictated by differences in the centers of rotation of the femoral component and the acetabulum.[8] For MoM-HRA, these parameters are dictated mostly by the patient's native anatomy, and adjustments through size changes of the femoral component are not possible.

Accuracy of Preoperative Templating

Even with technique being carefully applied, patient body habitus, anatomical variability, and radiograph quality may become sources of error in preoperative templating. In a retrospective study, Choi and colleagues[29] found that the overall accuracy of templating for MoM-HRA on conventional radiographs within 1 size of the actual component was 80.6% for the femoral component and 98.5% for the acetabular component. Overall, intraobserver reliability and interobserver reliability were found to be fair to substantial, and surgeon experience was noted as having a significant effect on accuracy and reliability.[29]

Konan and colleagues[45] reported on a prospective study in which 2 arthroplasty fellows independently performed digital templating for a cohort of 30 consecutive patients undergoing MoM-HRA. There was a significantly high rate of coincidence between templated estimates and actual implant sizes, with intraclass correlation coefficients of 0.798 and 0.870 for the acetabular components and 0.888 and 0.784 for the femoral components in the 2 groups.[45] Olsen and colleagues[37] noted agreement between the digitally templated and actual component sizes in 47% of acetabular components and 54% of femoral components. However, agreement increased to more than 76% and 86%, respectively, when a 1-component-size margin of error was accepted. The reported level of accuracy underscores the importance of intraoperative confirmation of preoperative measurements.

Intraoperative Alignment Guides and Navigation

Several intraoperative tools can be used to improve accuracy of MoM-HRA implant sizing and orientation. Correct preparation of the femoral head ensures optimal component alignment in the coronal, sagittal, and axial planes and is dependent on proper insertion of the initial femoral guidewire. Systems commonly used to assist guidewire placement include lateral pin jigs, intertrochanteric pin jigs, neck-centering jigs, head-planing jigs, and computer navigation using imageless and computed tomography (CT).[46,47] Use of custom-molded jigs has been reported recently.[48]

Olsen and colleagues[46] compared 5 conventional jigs to imageless navigation for accuracy and precision of inserting the femoral neck guide pin. Range of error was 2 to 8 times higher for the conventional jigs than for the imageless navigation with respect to coronal inclination, but all methods were similar with respect to version. After navigation, lateral pin jigs provided the most accuracy, and neck-centering jigs provided the most precision. Of the conventional jigs, the head-planing jig was the least precise, and its use was associated with the longest guidewire insertion time.[46]

Cobb and colleagues[47] evaluated the relative accuracy and precision of conventional instrumentation, imageless navigation, and CT-based navigation for insertion of the initial guide pin. For operators with limited experience, all 3 methods had acceptable accuracy, though CT-based navigation was most accurate and precise for intraoperative confirmation of guide pin position.[47]

Preferred Technique

For the preferred technique used by the senior author (EPS), preoperative templating is performed with conventional radiographs and transparent templating guides. Pin position for an intertrochanteric pin jig is also templated at a distance measured from the medial aspect of

Table. Key Preoperative Measurements and Landmarks for Hip Resurfacing

Femoral neck-shaft angle
Femoral head osteophytes
Femoral component size and position
Distance between fovea and center of articular surface of femoral head
Distance between most medial aspect of lesser trochanter and tip of femoral stem
Size of acetabular component and position relative to teardrop
Estimated amount of subchondral bone to be removed from acetabulum
Expected superolateral bone coverage
Cup positioning relative to teardrop

the lesser trochanter to the projected tip of the femoral stem (Figure 2). Key measurements and landmarks are recorded (Table).

The posterior approach to the hip is used. After the hip is dislocated, the proximal femur is assessed for presence of osteophytes at the head-neck junction. The osteophytes are removed. Sizing calipers are used to estimate the size of the native femoral head, which acts as a reference for the minimum size of the acetabular component needed for the resurfacing and for the accuracy of the preoperative template. Next, the femoral head is displaced anteriorly under the abductor musculature, and the acetabulum is prepared in standard fashion. After acetabular preparation and placement of a trial component in the appropriate amount of abduction and anteversion, electrocautery is used to mark the borders of the trial socket along the superior, anterior, and posterior walls, where the native acetabulum is exposed. A pen is used to mark the alignment of the insertion handle along the skin. The marks serve as references for both abduction and anteversion during final component implantation. After implantation, any remaining periacetabular osteophytes are removed. Attention is then turned toward preparing the femoral head. The templated distance from the fovea to the center of the articular surface is marked as the starting point for the initial guidewire. Two additional lines are made using electrocautery along the surface of the femoral head: one projecting from the center of the femoral neck through the center of the femoral head along the posterior surface, and the other along the superior surface. The intersection of these 2 lines serves as a check for the starting point of the guidewire. The templated distance from the medial aspect of the lesser trochanter to the projected tip of the femoral stem is marked along the intertrochanteric ridge, and a pin for the alignment jig is placed. The guidewire is placed, and preparation of the femoral head begins. Of note, in our experience, it is not uncommon for more bone to be removed along the posterior and inferior aspects of the femoral head during reaming, as patients often have increased retroversion of the femoral head because of a subclinical SCFE.

Conclusion

MoM-HRA is a technically demanding procedure. Its results can be optimized through prudent patient selection, meticulous preoperative planning, and surgeon experience. Templating is crucial to the assessment of patient candidacy and to preoperative planning for resurfacing surgery. The preoperative plan begins with the history and physical examination and proceeds with a careful survey of radiographic findings. Templating enriches the surgeon's understanding of an individual patient's pathoanatomy and allows the resurfacing surgeon to develop a precise operative plan that anticipates intraoperative contingencies. Consistent marriage of the preoperative template to intraoperative findings allows the surgeon to perform the procedure in an efficient manner and to achieve reproducible results. Modern jigs and navigation systems augment the surgeon's accuracy and precision.

Authors' Disclosure Statement

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