Surgical considerations to avoid adverse mechanics

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Abstract: Surgeons performing hip resurfacing arthroplasty (HRA) or planning to do so need to understand the surgical considerations that can help them avoid adverse mechanics and therefore possibly avoidable complications. We review the key features that must be considered when selecting patients for HRA, the importance of implant selection, surgical factors to minimise wear including both femoral and acetabular positioning and also surgical approach.

Keywords: Hip resurfacing arthroplasty (HRA); edge loading; patient selection

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Introduction

Hip resurfacing arthroplasty (HRA) continues to divide surgical opinion. Surgeon's deciding to introduce this procedure into their practice need to understand what risks and benefits it offers over conventional hip arthroplasty, the importance of patient selection, implant selection, surgical approach and; the pitfalls that ought to be avoided. There are several presumed advantages that make HRA the intuitive arthroplasty option particularly for the young active patient (*Table 1*) (1,2).

The advantages are not evident in all cases, as incorrect implant selection, implant positioning and patient selection may all lead to a poor outcome. The formation of adverse soft-tissue reactions around the Metal on metal hip resurfacing arthroplasty (MoMHRA) has caused considerable concern internationally. These reactions have been termed Adverse Reactions to Metal Debris (ARMD) and have been shown to have a strong association with increased wear (3). The wear debris is associated with soft-tissue necrosis and nonspecific foreign-body macrophage response coupled with a variable adaptive or specific immune response. Patient, implant and surgical factors have all been found to contribute to the wear process.

The aim is to review factors that are potentially controllable by the surgeon to optimize surgical outcome and reduce the risk of femoral component failure (femoral neck fracture or aseptic loosening) as these reasons for revisions can often be avoided by adequate component positioning and knowledge of the vascular anatomy. Understanding the importance of component orientation as well as the association between head-neck ratio (HNR) alterations occurring secondary to the resurfacing procedure and subsequent risk of ARMD (4-6).

Patient and implant selection

Patient selection

Identifying appropriate patients to perform a HRA is a factor that can reduce the incidence of ARMD formation as well as risk of early femoral component failure. Beaulé et al. established a set of risk factors for early failure after metal on metal hip resurfacing: Surface Arthroplasty Risk Index (SARI) (7). This encompassed femoral bone quality, history of previous hip surgery, component sizing and activity level where a score greater than 3 was associated with a 12-fold increase in having early signs of failure (7). These identified risk factors were also found by others and also included female gender, small size, hip dysplasia, and in

Table 1 Advantages of hip resurfacing

Preservation of the femoral head and neck
Reducing stress-shielding due to normal femoral loading
Reduced risk of dislocation compared to THA with 28 to 32 mm diameter head
May be a superior alternative to THA in cases with extra-articular femoral deformity and/or pre-existing metalwork
Lower prevalence of thromboembolic phenomena

women age less than 40 (8). In young women, hip dysplasia is the predominant reason for development of premature arthritis (9). In females below 60 years undergoing a HRA, 32% had a primary diagnosis of DDH compared to only 6% in men (9). It is thought that both the acetabulum and femoral components size and component orientation have an influence on the high failure rates reported in the dysplastic cohort. Although cup inclination and anteversion were within the acceptable range in many cases, excess femoral anteversion from minor hip dysplasia was overlooked, leading to excess combined anteversion, edge loading and high wear (9). Because dysplastic hips tend to have smaller sized components, the arc of cover or contact patch rim distance is at risk range.

Many failures may simply be related to the smaller sized components as a smaller size has been shown to have higher ion levels and are theoretically more likely to edge load since component size influences the acetabular component's arc of cover (10). Increased edge loading will lead to increased wear and may lead to increase ARMD risk (11). Femoral heads below 44 mm had a five-fold increased revision risk in comparison to femoral heads above 55 mm (12). Although the majority (80%) of ARMD are associated with high volume wear a minority of are associated with low wear and a prominent immune response (3). A proportion of patients will therefore be likely to develop an ARMD regardless of methods used to prevent significant wear. Innate and adaptive immune responses to metal wear are seen in periprosthetic histological tissue in patients with both elevated and non-elevated metal ion levels (13). Although metal ion levels are elevated in most cases of ARMD, the finding of a normal metal ion level does not exclude this diagnosis (13). This should be explained to the patient during the consent process. It is important to note that to-date no preclinical testing has been identified to identify patients at increased risk to developing a predominantly immune, ARMD-type response in the presence expected wear.

Implant selection

The Birmingham Hip Resurfacing (BHR) (Midland Medical Technologies), and the Conserve Plus (C+) hip resurfacing (Wright Medical), were both released in 2007 and remain two of the most popular HRAs on the market. Since their introduction the Articular Surface Replacement (ASR; DePuy, Warsaw) and the Durom Acetabular Component (Zimmer Inc.) have both been launched and now no longer manufactured due to high failure rates. CORIN is the other design, CORMET 2000 that received FDA approval which also has a cementless femoral component fixation option.

The ASR system resulted in poor early/mid-term survivorship in both independent centre studies as well as in the national registry data (14-16). The incidence rates for ARMD revision between the BHR, the ASR and the Conserve Plus prostheses demonstrated a ten-fold increase in the incidence of AMRD with the ASR (17). These findings subsequently led to the withdrawal of the ASR resurfacing system. The failure of the implant is felt to be primary related to the characteristics of the acetabular component, particularly the ability to prevent deflection and the lower head coverage (subtended angle), which has been implicated in the ASR and other sub-hemispherical designs (18). Lower clearance, as seen with the ASR, may also increase wear and subsequent failure (19). The Durom Acetabular Component was removed from the market due to a high incidence of early failure (20) but without a clearly described reason for failure. The BHR results on mid/long-term survivorship continue to be promising with data in male patients being reported regularly over 96% at 10 years (21), 98% at 10 years (22). A study in Japan with an average population age of 52 with a mix of male and female patients recorded a 96.5% survival at 10 years and 93.6% at 15 years (23). In England and Wales national joint registry (NJR) 2018, the revision rate at 14 years was 11% (16). The Conserve Plus (C+) hip resurfacing also has good survival results with five-year survival was 94.5% (24) and at 10 years survival has been shown to be at 89% with no

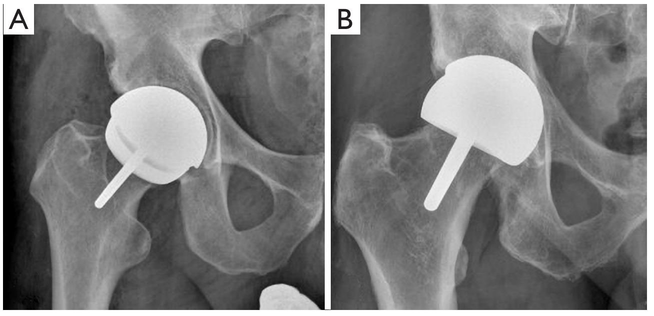

Figure 1 Acetabulum inclination (A) correctly position, (B) excess inclination.

revisions in acetabular components with a diameter greater than 46 mm (25). The NJR 2018 results found the survival to be 84% at 14 years but this included a 37% population of females (16). The CORMET hybrid resurfacing analysis reveals good 10 year survivorship with Kaplan-Meier survivor analysis showing 93% at nine to ten years and with survivorship in the osteoarthritis subgroup reaching 96.7% (26) in a single surgeon analysis 11-year survival was 93% (27). The fully uncemented CORMET results have shown a 95% survivorship at four to five years (28).

Pre-operative surgical planning is always advised particularly when performing a HRA. In the case of performing a BHR, in 2015 there was a voluntary removal from the market of femoral head sizes 46 mm and below. It is advised that a minimum of a 50 mm femoral head size should be used but size 48 mm heads continue to be manufactured in case intraoperative downsizing is needed (29). Similarly, Conserve Plus is no longer available in sizes <48 mm (30). If a patient is potentially going to be close to this cut-off size they should be informed and consented for a THA.

Surgical factors to minimise wear

Once patient selection has been optimized surgeons should aim to minimize wear of MoMHRA with appropriate implant selection and surgical technique. Three important surgical factors to observe include edge loading, impingement and HNR.

Edge loading

Edge loading should be avoided, to facilitate low wear. This can be achieved with the correct orientation of the femoral and acetabular components preventing contact area between the two components at the edge of the acetabular component. The incidence of ARMD occurring when the acetabular component is correctly positioned (45°±10° inclination and 20°±10° anteversion) is four times lower, than when not optimally positioned (4). Positioning the component in the optimum position allows an entrainment wedge to form aiding the separation of the two articulating surfaces with a thin layer of joint lubricant. If film lubrication is disrupted, MOM implants will exhibit increased wear due to the inability to form the tribolayer (31). This typically occurs during edge loading, preventing the entrainment wedge effect and fluid entrainment (18). Furthermore, finite element modelling has shown edge-loading can double contact stresses (32). *Figure 1* shows correct acetabular positioning and excessive inclination that will result in edge loading occurring. In vivo evaluation of edge loading supports it as an important mechanism leading to localised excessive wear. There is significantly longer duration and greater magnitude of force compared to the MoMHRA hips without ARMD during activities of daily living (33). Both the femoral head and acetabular component have six independent degrees of freedom, three rotational and three translational. Rotational or translational mal-positioning of implants could theoretically result in edge loading. Rotational mal-positioning can result in a wear rate of 1 to 5 mm^3/million cycles, whilst translational mal-positioning can increase wear by 10 to 100 mm^3/million cycles (34-36). Rotational mal-positioning leading to edge loading (1° edge loading) occurs when the acetabular component is positioned with excessive inclination or inappropriate version. Translational mal-positioning occurs when impingement or joint laxity would lead to levering out of femoral head and contra-coup edge loading occurs (2° edge loading).

Impingement

In 2006 it was reported that up to 56% of hips prior to surgery who underwent a HRA had an abnormal offset ratio (37). The two main groups making up this percentage were patients with osteonecrosis or osteoarthritis, both these conditions have been associated with impingement in the periarthritis state (38,39). Femoral acetabular impingement (FAI) is a common cause of arthritis believed to result from a lack of femoral head-neck offset in the anterolateral region of the femoral head-neck junction. This must be recognised and addressed during the HRA procedure or ongoing impingement may occur (40). Painful impingement of HRA is a known cause for revision, it will also lead to increased wear. The reduced HNR of HRAs, relative to THAs, coupled with the younger patient with greater range of movement (ROM) during normal activities render acetabular component position of great importance to avoid impingement and edge loading. Impingement will lever out the femoral head leading to translational mal-positioning and as such contra-coup edge loading. These effects can be minimised by appropriate femoral component placement (8). The concept of combined version was first described with the McKibbin index in relation to instability of newborns hips (41). This provided the understanding that the effects of femoral and acetabular anteversion may be additive or may offset each other. Combined acetabular and femoral anteversion for a THA should be 45° or less, to avoid edge loading and posterior impingement and high enough (>20°) to prevent anterior impingement and posterior edge loading (42). Impingement can also be caused by decreased offset or by medial or superior translation of the centre of acetabular component; factors that the surgeon may be able to optimize (43,44).

Unlike THA, positioning of the femoral component to prevent impingement is limited due to the lack of modularity and preservation of the native femoral neck. Thus the HNR following hip resurfacing is less compared to a THR. To reduce the occurrence of impingement, it is important to remodel the head/neck junction by removing osteophytes and performing an anterior femoral osteochondroplasty in order to restore head sphericity, adequate head-neck contour and sufficient anterior offset (37). In addition, translation of the femoral component can be undertaken to improve anterior offset and therefore decrease the risk of anterior impingement but potentially results in decreased posterior offset. Due to the limited capacity of changing the femoral version, appropriate acetabular positioning is important to aim towards preventing impingement.

Component size decision & HNR

HNR is defined as the femoral head diameter divided by the femoral neck diameter. A decrease in HNR may lead to a decrease in functional ROM (45) and will increase risk of impingement and hence wear. Most hips undergoing resurfacing have an abnormal femoral head/neck offset, which is best assessed in the sagittal plane (6). Surgeons should aim to use as large of a component as possible, considering acetabular anatomy and acetabular bone preservation. In order to achieve this, after surgical dislocation of the femoral head, surgeons should use a femoral sizing ring placed over the articular surface and make a note of the femoral head size. Implanting as large of a component as possible, i.e., one as similar as possible to native femoral head diameter, would increase HNR, decrease impingement risk and in turn reduce risk of edge loading and increased wear. Most surgeons would measure the diameter of the femoral head and the widest diameter of the femoral neck in order to decide on femoral component size, which would in turn dictate acetabular component size too. Thus, a surgeon has to put as large of a component as possible in order to improve HNR and mechanics, respecting however the acetabular bone stock and ensuring no excessive reaming takes place to accommodate for a larger diameter acetabular component. Relative to the femoral head size, it is most usual that the femoral component will be of similar size to the native femoral head or 2 mm less.

Surgical factors to avoid femoral neck fracture

Femoral neck fracture is an early-term failure mode with an incidence reported in early studies up to 12% (45,46) but in more recent literature this has fallen to 1.1% (47). Patient and surgical technique related risk factors for femoral neck fracture have been described, including gender (48), proximal femoral bone quality, vascular compromise (49), prosthesis placement (48) and cementation. Other recognized failure modes include component loosening (50,51), avascular necrosis (AVN) of the femoral head (49) and painful impingement (52).

Stress loading proximal femur

It is generally agreed that maintenance of bone in the proximal aspect of the femur is desirable and is of importance if the need for revision arises as preservation of femoral bone stock to support an implant during revision becomes especially important. One of the proposed advantages of HRA has been the theoretical ease of conversion to THA. This is thought to be the case due to the normal proximal femoral loading preventing stress shielding and the preservation of the native femoral neck and intramedullary canal architecture (49,53).

Importance of neck shaft angle (NSA)

Several retrospective reviews have correlated errors in

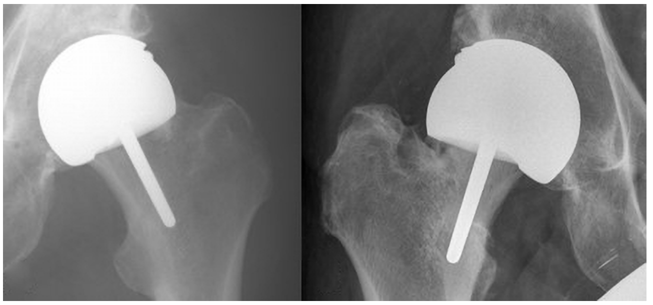

Figure 2 Excessive valgus positioning of femoral component.

surgical technique with the risk of periprosthetic femoral neck fracture (48,49,53,54). These include notching of the superior aspect of the femoral neck, a varus position of the femoral component, and inadequate coverage of the reamed femoral head. The importance of the NSA has been shown in several studies (48,54). The surgeon should tend towards a valgus position of the femoral component. In the coronal plane the aim should be to place the femoral component into a relative valgus angle of 5–10 degrees to minimize tensile stress at the superior bone junction (55,56). The tensile stress of the superior neck has been calculated to decrease by up to 31% whilst walking with a change from 140 degrees to a more varus 130 degrees. If the femoral component angle is less than 130 degrees, the risk of adverse outcome is increased by a factor of over 6 (57). The valgus positioning should not be to the extent that it causes notching in the superior neck in order to prevent fracture of the femoral neck (*Figure 2*).

Surgical approach

Understanding the anatomy of the hip is not only important for implant positioning but also the preservation of blood supply to the femoral neck particularly the MFCA to prevent osteonecrosis and consequently aseptic loosening. The rate of AVN following uncomplicated dislocation of the hip and fracture-dislocation of the hip are significantly different. After an uncomplicated dislocation treated non-operatively the incidence of AVN is up to 11% (52,58) while in fracture-dislocation treated operatively, it rises to 31% (48,50,58,59). The only significant difference between these two groups may be the iatrogenic trauma to the medial femoral circumflex artery (MFCA) and/or its peripheral anastomoses. Protection of vascular structures during HRA is essential in order to prevent osteonecrosis and consequently aseptic loosening. In this centre a direct anterior surgical approach is favoured as the pelvic position is more reliable when the patient is in the supine position, leading to more consistent orientation of the acetabular component (60,61). The approach also reduces the soft tissue trauma to the hip as it does not require muscle detachments from the bone (62). The Posterior approach for HRA has also been shown to result in a potential vascular insult to the femoral head, with posterior zones more affected than the anterior zones (63). A modified posterior approach, unlike the standard extended approach, may be utilized as this does not significantly compromise the blood supply to the head (64).

Biomechanics of hip resurfacing vs. total hip

Patients following unilateral hip resurfacing do have some degree of gait asymmetry between the operated hip and the unoperated side in long term (65). However, there are a number of factors that may contribute to this observation including the fact the patient may have had an abnormal gait that contributed to the original pathology. However, it is of interest that patients who undergo a unilateral HRA do have recorded biomechanical characteristics that could allow their gait pattern to closely replicate what takes place in the non-diseased state compared to patients that have undergone a THA (66). To that effect, HRA has been shown to preserve a more normal weight acceptance and patients have been reported to reach a higher walking speed with better hip flexion relative to their unoperated leg compared to patients who have undergone a unilateral THA (67).

Summary

Surgical considerations to avoid adverse mechanics:

- ❖ Understand the importance of patient selection and patient education;
- ❖ Select a surgical implant with a good long-term outcome;
- ❖ Aim to use as large of a component as possible, considering acetabular anatomy and acetabular bone preservation;
- ❖ Understand the vascular anatomy of the femoral neck with importance of the MFCA;
- ❖ Cup inclination should be 45°±10°;
- ❖ When performing a HRA using a posterior approach Cup anteversion should be 20°±10°;
- ❖ NSA should have mild valgus alignment with

avoidance of varus positioning;

- ❖ Medialize the acetabular cup to ensure containment of the component but do not excessively medialize the acetabular cup as it will decrease native offset and contribute to impingement—this is a factor that cannot be corrected on the femoral component due to the lack of modularity;
- ❖ Regular post-operative monitoring should be undertaken with an emphasis on clinical review.

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