Surface Replacement Arthroplasty of the Hip

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Abstract

Treatment of the young patient with degenerative disease of the hip has historically been a difficult problem for the orthopaedist. Total hip arthroplasty in the young patient has generally produced inferior results as compared to older patients. Surface replacement arthroplasty (SRA) was initially developed over 50 years ago to treat degenerative disease of the hip. It has regained enthusiasm over the last 10 to 15 years as an alternative to total hip arthroplasty for the treatment of degenerative disease of the hip in younger patients. The modern metal-on-metal bearing provides improved wear characteristics over its metal-on-polyethylene predecessor. Multiple studies have demonstrated mid-term results of metal-on-metal SRA, which are comparable to total hip arthroplasty. The long-term survival data of SRA remains to be seen, as does the long-term effect of elevated serum ion levels.

The first hip arthroplasty was performed by Philip Wiles (Middlesex, England) in the 1930s. Although his records were lost, one of his patients was reported to have their implant in situ after 35 years.1 Subsequently, a student of Wiles, George Mckee, developed a metal-on-metal (MOM) uncemented total hip arthroplasty (THA) in the 1940s and 1950s. These were characterized by early pain relief, followed by implant loosening and failure. Following the advent of polymethylmethacrylate bone cement, McKee developed the cemented MOM McKee-Farrar THA in 1960. This was the first widely used THA.

Sir John Charnley was convinced that the frictional torque from the MOM articulation was unsatisfactory and the cause of the failures of the early McKee prothesis. He did not believe that the synovial fluid could provide sufficient lubrication to decrease this friction. This drove him to develop an arthroplasty fabricated from materials that provided low frictional torque. Charnley’s first attempt at this was the Teflon-on-Teflon low-frictional arthroplasty (an SRA). Unfortunately, the Teflon-on-Teflon bearing was subject to early catastrophic failure from wear.2 His next attempt at an arthroplasty (1958-1962) was a THA with a cemented femoral stem similar to that of the McKee prosthesis. The bearing was metal-on-Teflon. This, too, was characterized by early catastrophic failure from osteolysis and implant loosening, secondary to wear from Teflon particulate debris.3 He noted from this series that of the four femoral head sizes employed the larger heads were subject to increased wear. He determined to use a small head (22.5 mm) in future models to decrease this wear.

In 1962, Charnley began his third attempt at hip arthroplasty. This implant was characterized by a cemented femoral stem, a 22.5 mm metal head, and a high-density cemented polyethylene acetabular cup. This design was widely successful and proved to be the model for all subsequent models of hip arthroplasty. Charley, however, realized that the success of this design was limited by the rate of polyethylene wear and cautioned against the use of his design in young patients.

Peter Ring (Surrey, England) produced the next innovation in design of THA. He distrusted both bone cement and polyethylene debris and developed a “self-locking” uncemented MOM THA in the 1960s. By 1970, there were three
predominant designs of THA used in practice: the McKee-Farrar, the Charnley, and the Ring prostheses. Satisfactory results were reported for all of the designs, with the revision rate of the Ring prosthesis only 5% at 17 years.4-7 However, the widespread belief that frictional torque associated with the MOM bearing led to the dominant use of the Charnley prostheses, despite less enthusiastic results in the young patient.8,9

Early Surface Replacement Arthroplasty (SRA)
The initial SRA design was a hemi-resurfacing introduced by Smith-Petersen in 1948.10 Although it had no method of stable fixation to the femoral head, some survived for many years, but the results were unpredictable. In the 1950s, Charnley introduced the low friction arthroplasty with the outcome mentioned above. In 1967, Muller designed a MOM articulation.11 Despite good early results, he abandoned this bearing in favor of a metal-on-poly articulation. Most of the initial MOM bearings survived over 25 years. Multiple other metal-on-poly designs were introduced in the 1970s and demonstrated high-volumetric wear, massive osteolysis and bone loss and catastrophic early failure.12-15 By the 1980s, most of these designs were abandoned in favor of THA.

THA in the Young Patient
Charnley stated that, in regards to THA, “Below the age of 65, the situation is very different. The younger the patient, the more the surgeon must guard against allowing the patient’s subjective symptoms to influence his judgement.”9 He also said regarding the surgeon, “He must turn deaf ears to exaggerated adjectives used to describe the intolerable quality of the pain.”9 Charnley described various methods for delaying the decision to perform THA in the young patient as well.

Despite good, predictable results of metal-on-poly THA in older patients, THA in young patients consistently provided inferior results. Chandler reported 58% loosening and 21% revision at 5.5 years follow-up of cemented THA.16 Dorr reported only 58% satisfactory results at 10-year follow-up in patients less than 45 years old.17,18 Cornell and Ranawat reported 30% failure at 13 years in their young patient subset.19

Uncemented THA has also shown inferior results in younger patients. Heekin and colleagues reported good functional results but significant osteolysis in 27% of young patients at 5 to 7 years.20 Piston also demonstrated high rates of early osteolysis in young patients.21 These high rates of early osteolysis in the young patient subset is most certainly due to increased polyethylene particulate debris. The rate of poly wear and osteolysis has a positive correlation to the number of cycles that the articulation performs.22 Therefore, the poly of the younger and more active patient will undergo more wear and produce more particulate debris. However, MOM designs do not show this cycle dependent wear phenomenon.23 This will be addressed later in the discussion of tribology. Is it possible that Ring had solved the problem of osteolysis over 40 years ago?

The Renaissance of SRA
However, the solution of the problems encountered in THA of the young patient was still unknown. In the late 1980s, a resurgence in enthusiasm for the SRA was provided by the Metasul bearing developed by Weber in 1988.24 This was a CoCr bearing with high carbide content developed in order to decrease frictional torque and early loosening and was employed as the bearing for THA in Europe with good early results. In 1991, both Wagner and McMinn developed SRAs that employed the Metasul-type bearing.25,26 These served as the models for subsequent modern designs and will be the basis for the following discussions.

Tribology of Modern Metal-on-Metal Bearings
Tribology is the study of lubrication, friction, and wear during surface interaction under an applied load and in relative motion. This discussion will focus on modern, high carbide MOM bearings. The loosening associated with early MOM designs is attributed to suboptimal implant design and manufacturing, as well as poor surgical technique.27-31 These bearings did not fail from wear properties, as retrieval studies have consistently shown that the original McKee-Farrar prostheses demonstrated significantly better wear than conventional metal-on-polyethylene designs.32,33 Hip simulators have shown that metal-on-metal bearings have up to a 200-fold reduction in volumetric wear rates, compared to conventional polyethylene articulations.34-41

The articulation of hard-on-hard bearing surfaces, whether metal-on-metal or ceramic-on-ceramic, is characterized by the phenomenon of thick film lubrication. Thick film lubrication means that the articulating surfaces are not in sliding contact; instead, they are separated by a synovial fluid film and this has profound implications for wear and friction of the bearing. Thick film lubrication is not possible in a metal on polyethylene or ceramic on polyethylene bearing because of the high surface roughness of polyethylene and clearance distances.73

The ability for thick film lubrication to occur is influenced heavily by an “intentional mismatch” between the diameter of the femoral head and of the acetabular shell. This mismatch cannot be too small, or the bearing may seize-up due to geometric surface irregularities. This was likely the common mode of failure in early metal-on-metal articulations. However, if the mismatch is too great, high contact stresses produce exceedingly high wear. The clearance (i.e., intentional mismatch) of most current prostheses is on the order of 150 microns.32

The wear of metal-on-metal articulations is not constant over time. Rather, there is an initial “run-in” phase followed by a “steady-state” phase. Run-in wear occurs as the surface imperfections on each side of the joint bearing wear down
during initial use. After this occurs, there is a more constant rate of wear when the surfaces are smoother. Run-in wear is typically higher as the two metal surfaces co-adapt. There is also a higher serum and urine ion concentration during this period. This initial phase is followed by the steady state phase. Both wear and ion concentrations decrease during this phase to a relatively constant rate over time.\(^\text{42}\)

### Metal Ion Release

All metal-on-metal articulations release metal ions in vivo. The levels of cobalt and chromium are elevated in both the patient’s serum and urine, and particles can be found in erythrocytes, lymph nodes, liver, and spleen.\(^\text{43}\) There are no documented adverse effects of this phenomenon although there are theoretical concerns. The main hypothetical concern is the carcinogenic effects of persistent elevation in serum and urine ions. Visuri and associates reported on 579 metal-on-metal McKee-Farrar hips from the Finnish registry.\(^\text{44}\) They reported no difference in malignancy in either incidence or type of malignancy observed in this group, as compared to expected values for the general population. However, given the low incidence of many malignancies, a study including over 25,000 patients would be required to produce sufficient power to evaluate the true incidence of malignancies in this patient population. Another concern related to metal ions is the transmission of elevated ion levels to the placenta in pregnant patients. However, Brodner demonstrated that neither cobalt nor chromium ions cross the placental membrane.\(^\text{45}\)

Nonetheless, these hypothetical concerns do not exist when considering other bearing surfaces.

Another concern of metal ions in metal-on-metal hip arthroplasty is the issue of hypersensitivity. There is an unclear incidence of this phenomenon and, unfortunately, there are no reproducible or confirmatory diagnostic tests. It may, however, be a cause of persistent pain in an otherwise healthy patient and may also present as an aseptic effusion and interfacial loosening.\(^\text{46}\)

### Technical Considerations

All current commercially available SRA systems share certain key characteristics; all are fabricated from high-carbide cobalt chrome, preformed with a press-fit acetabular component, and preformed with a cemented femoral component. However, there are manufacturing differences in the cobalt chrome. These differences are in the post-cast heat treatment and the use of wrought metal or cast metal. Although there are theoretical differences in implant performance implied by these manufacturing differences, this difference has not been reflected in hip simulator studies.\(^\text{47}\)

### Surgical Approach

Proper visualization of the acetabulum and femoral head are vital for correctly performing an SRA. The anterior approach requires a large soft tissue dissection, but, nonetheless, acetabular visualization remains difficult, and, therefore, the posterior approach to the hip is used by the majority of surgeons. This approach, however, has its own inherent pitfalls and should not be considered the same as the posterior approach used in THA. Most importantly, care must be taken to preserve the medial femoral circumflex artery (MCFA) and its terminal branches to the femoral head via the lateral ascending cervical artery (Fig. 1). Preservation of this blood supply is believed to be of paramount importance in preservation of femoral head viability and avoiding progressive necrosis of the head after SRA, which may compromise implant fixation and stability.

Two important facets of the posterior approach for SRA are capsulotomy and soft tissue release for proper femoral positioning. It is recommended to perform a circumferential capsular release at the level of the acetabulum to facilitate acetabular position while minimizing the chance of vascular disruption (Fig. 2). It is also recommended that the gluteus maximus tendon be released at its femoral insertion to allow sufficient femoral rotation for femoral head preparation and instrumentation (Fig. 3). Based on the results of a biologic study of circulation patterns at the proximal femur, Nork and coworkers recommended that SRA be performed through a posterior or lateral approach, combined with digastric osteotomy of the greater trochanter to minimize the chance of disrupting the MCFA (located distal to piriformis insertion) and its terminal contribution to femoral head circulation.\(^\text{48}\)

There have been several studies conducted to identify and quantify the presence of vascular insult to the femoral head encountered during SRA. Steffen and colleagues measured the intraoperative oxygen concentration in the femoral head during SRA. They reported that the approach alone caused a mean 60% drop in oxygen concentration and component insertion caused a further 20% drop.\(^\text{49}\) These concentrations did not improve following wound closure. McMahon and associates used technetium Tc 99m bone scan to evaluate the vascularity of the femoral head in 36 asymptomatic SRAs at an
average of 26 months postoperative. They found that all hips had adequate vascular supply comparable to that of normal hips, and postulated that the preserved vascularity after SRA was attributable to increased intraosseous blood supply from metaphyseal vessels in the arthritic hips. Forrest and coworkers used fluoride positron emission tomography to examine the viability of femoral heads in 10 patients after successful unilateral SRA 20 months after surgery. The contralateral hip was used as control. They specifically evaluated four specific anatomic locations: the lateral aspect of the femoral head, the medial aspect of the femoral head, the lateral aspect of the femoral neck, and the proximal aspect of the femur. They found no areas of osteonecrosis. Khan and colleagues compared the effect that surgical approach had on the vascularity of the femoral head during SRA. They compared the posterolateral approach and a transgluteal approach, and indirectly measured blood flow by measuring cefuroxime concentrations in bone samples of the femoral head. They found that cefuroxime concentration was significantly greater in patients undergoing transgluteal approach and discovered a significant reduction in femoral head blood supply using a posterolateral approach.

Outcomes

The outcomes following SRA have been reported in numerous recent studies. It is important to recognize that the modern SRA has been used for less than 15 years, and therefore only midterm data is available. Multiple aspects of the SRA have been examined, including survival, biomechanics, and use in specific patient subsets. Further, it has been compared to THA in several studies. Most studies demonstrate that SRA can produce equivalent results to THA, albeit with its own unique subsets of complications (Fig. 4).

Early and Mid-Term Survival

There have been numerous articles reporting on the early and mid-term survival and patient activity of SRA of the hip. Most of these are produced from centers specializing in SRA and many investigators are the pioneers of modern SRA. Daniel and associates, a group that included McMinn, in 2004, reported on 446 resurfacings at mean 3.3 year follow-up (maximum 8.2 years). They reported a survival of 99.98% with one revision. The vast majority of these patients (92% of males with unilateral resurfacings and 87% of overall patients) participated in a leisure-time sporting activity. Later that same year, McMinn again reported on survivorship. This patient group was composed of 1,209 BHRs (Birmingham hip resurfacing) performed. The most common diagnosis was osteoarthritis (78%). He reported seven failures, including four femoral neck fractures, two infections, and one collapsed femoral head from progressive osteonecrosis. When compared to a prior group of earlier designs, he found that the early group had eight failures out of 294 performed. Five of the failed prostheses were revised for cup loosening. McMinn attributed these failures to a change in the post-casting heat treatment that decreased the carbide content and lead to greater wear, metallosis, and frictional torque.

Treacy and coworkers reported a 98% overall survival (99% aseptic survival) of 144 consecutive BHR at a minimum of 5 years. They had only 1 fracture in their patient cohort. Shimmin and Young reported 99.14% survivorship at average 3 years follow-up of their first 230 patients. In fact, one of the investigators underwent SRA during the experimental period. Other reports support these findings of good, predictable survivorship in the early- to mid-term follow-ups.

Amstutz and colleagues reported on the survivorship of 400 consecutive SRAs, performed between 1996 and 2000. The average patient age was 48 years; 73% were male, and average follow-up was 4 years. The 4-year survivorship was 94.4% for all hips. For patients with a surface arthroplasty risk score of greater than 3, the survivorship was 89% versus 97% for patients with scores less or equal to 3.

Both Mont and McMinn have compared the results of
SRA through a minimally invasive approach (mini-incision resurfacing arthroplasty of the hip, MIRAH) with results from a standard approach. Minimally invasive procedure was associated with decreased intraoperative blood loss, improved hip scores at 3 months, and shorter hospital stay. McMinn, however, cautions against its use because he found a slight increase in failures in this group and recommended that MIRAH be performed only after 500 SRAs from a standard posterior approach.

Comparison to THA

The true test of the SRA is to compare its performance to the current standard of care, that of THA. Vail and associates retrospectively compared the 2-year results of metal-on-metal SRA with THA, evaluating the outcomes of 57 SRAs with 93 THAs. After controlling for age, gender, and preoperative differences, hip scores and pain scores were similar for the two groups. The SRA group had higher activity and range of motion scores. Complication and reoperation rates were similar between the two groups. Pollard and colleagues compared the 5- to 7-year results of SRA with hybrid THA. The two groups were composed of 54 patients and were controlled for age, gender, body habitus, and activity level. Both groups did well, but the SRA group had a higher UCLA (University of California Los Angeles) activity score and a better quality of life score. Also, 12% of the THA group had osteolysis secondary to polyethylene wear, while 8% of the SRA group demonstrated migration of the femoral component. Vendittoli and coworkers conducted a randomized trial to compare the amount of acetabular bone resection of SRA versus THA; 210 hips were randomly assigned to each group. They found no difference in the amount of acetabular bone resection during THA in comparison to SRA.

Several biomechanical parameters of SRA have been compared to THA. Loughead and colleagues examined the offset in SRA and compared it to hybrid THA. They found that SRA was associated with significant reduction in femoral offset and an increase in length. They concluded that SRA is unable to restore hip mechanics as accurately as THA. Conversely, Girard reported being more likely to restore femoral offset with SRA (57%) versus THA (25%), and that THA was associated with increased offset as compared to the uninvolved, contralateral hip. Mont and associates performed gait analysis of patients with SRA and compared it to patients with standard THA. They found that SRA patients walked faster and were comparable to normals. They found no significant difference in hip extensor or abductor moments. They attributed the more normal hip kinematics
of SRA to the large femoral head.

**Patient Subgroups**

**Osteonecrosis**

There have been recent reports on the results of SRA performed for osteonecrosis of the femoral head. Mont and coworkers analyzed the clinical and radiographic results of 42 patients who underwent SRA and compared this to a group of patients who underwent SRA for osteoarthritis.69 Subjects were matched for age, gender, prosthesis, surgeon, and approach. The mean patient age was 42 years and the mean follow-up was 41 months. They reported good or excellent results for 93% of patients with osteonecrosis and 98% of patients with osteoarthritis. There were two failures in either group requiring conversion to THA. Survivorship was similar between the groups.

Ravel and colleagues analyzed the mid-term clinical and radiographic results of 73 SRA in 60 patients with osteonecrosis of the femoral head.70 The patient group included 42 males and 18 females. The mean age was 43 years. They reported an overall survival of 93.2% at a mean of 6.1 years (range, 2 to 12 years). There were four revisions performed, two of which were for aseptic loosening of the femoral component. They believe SRA to be an effective form of treatment for osteonecrosis of the femoral head.

**Childhood Disorders**

Performing an SRA in patients with an etiology of LCP (Legg-Calves-Perthes), SCFE (slipped capital femoral epiphysis), or DDH (developmental dysplasia of the hip) can be more demanding because of the effects that the deformity may have on the anatomical relationship between the femoral head and neck. Amstutz and associates described the proximal femoral anatomy with focus on the head and neck relationship in 14 patients with LCP and 11 patients with SCFE who underwent SRA.71 The average patient age at the time of surgery was 38.1 years; 20 patients were male (3 bilateral) and two were female (both SCFE). Despite the difficulty of abnormal anatomy, only one patient (bilateral LCP) required conversion to THA due to aseptic failure of the femoral component. SRA was associated with improved hip scores, SF-12 physical scores, and ROM (range of motion) in all patients.

Amstutz and coworkers also reported on SRA results in patients with degenerative disease secondary to developmental dysplasia.72 SRA was performed in 59 hips (51 patients; 42 female). Average age was 43.7 years, and average time to follow-up was 6 years. There were significant improvements in pain score, walking tolerance, function score, range of motion score, and activity score. Four patients delivered six healthy babies during the postoperative period. There were five femoral failures requiring conversion to THA. The investigators were disappointed with the femoral component results, but encouraged by the results of acetabular component stability without adjuvant fixation.

The etiology of hip disease differs between ethnic groups. Nishii and colleagues reported on 50 arthroplasties in 45 Japanese patients with a predominant diagnosis of hip dysplasia (70%).73 The minimum follow-up was 5 years. The overall survival was 96% at 5 years. There was one femoral neck fracture and one case of septic loosening.

**Complications**

**THA and SRA**

Complications encountered with SRA can be divided into two categories: those found in common with THA (thromboembolic phenomenon, heterotopic ossification, dislocation, neurovascular injury) and those unique to SRA [femoral neck fracture, avascular necrosis (discussed above)]. Dislocation following SRA is typically less than 1%.74 Rates of deep venous thrombosis, pulmonary embolus, heterotopic ossification, and neurovascular insult are similar to those encountered in THA.

**Femoral Neck**

Retaining the femoral neck presents the patient with a risk of femoral neck fracture indefinitely following SRA. Shimmin and Back demonstrated 1.46% incidence of femoral neck fractures identified in a national registry of 3,429 cases.74 The mean time to fracture was 15.4 weeks. Influential factors associated with increased rate of fracture included patient factors, surgical factors, and postoperative factors.

Patient factors associated with increased rate of femoral neck fracture were female gender and proximal femoral bone quality. Female patients were twice as likely to suffer from postoperative femoral neck fracture as male patients. Surgical factors associated with postoperative femoral neck fractures are notching of the femoral neck and varus placement of the prosthesis. Twenty-six cases of femoral neck notching and 42 cases of varus implant placement were associated with the 50 femoral neck fractures reported from the Australian registry.74 Although most surgeons fully weightbear patients after SRA, it has been suggested that the femoral neck is “stressed” from intraoperative instrumentation and that protected weightbearing postoperatively may be advisable.75

**Summary**

Modern SRA represents the continued efforts to treat the young patient with advanced degenerative disease of the hip. Early and mid-term data demonstrate that SRA has survival results similar to THA. SRA has its own inherent difficulties that are magnified when treating advanced cases of disease and associated deformity and cystic degeneration. The success of modern SRA hinges on the mechanics of the large, metal-on-metal bearing. The long-term survival of SRA remains to be seen, as does the long-term effect of elevated levels of metal ions in the serum, urine, and lymphatics. Further research needs to be conducted regarding the effects of metal ions, vascular insult, and comparative studies with THA using comparable bearing surfaces.
Disclosure Statement
None of the authors have a financial or proprietary interest in
the subject matter or materials discussed, including, but
not limited to, employment, consultancies, stock ownership,
onoraria, and paid expert testimony.

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