Background of metal-on-metal resurfacing

H C Amstutz and M J Le Duff
Joint Replacement Institute, Orthopaedic Hospital, Los Angeles, CA, USA

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Abstract: Hip resurfacing is not a new concept and attempts to treat hip arthritis without resecting the femoral head and neck have been made since the 1950s. The resurgence of new and better-engineered metal-on-metal bearings has provided the means to develop a viable prosthetic solution from a concept that was once abandoned. The lessons drawn from the early resurfacing era led to modern designs all using a cementless fixation of the acetabular component and a short metaphyseal stem designed for component alignment on the femoral side. Currently, only metallic devices can be manufactured with sufficient strength as a thin one-piece shell, combining excellent wear properties for large femoral heads and a bone-conserving device on the acetabular side. The early results of these new designs are extremely encouraging but the rapid development of the procedure needs to be controlled by appropriate training programmes to ensure its future success.

Keywords: resurfacing, metal-on-metal, hip, arthroplasty

1 INTRODUCTION

One of the most important recent evolutions of hip arthroplasty is the emergence of hip resurfacing with metal-on-metal bearings as a viable solution for patients with end-stage osteoarthritis, especially for the young patient [1–5]. However, hip resurfacing is not a new concept and previous attempts to treat hip joint arthrosis without resecting the femoral head and neck have been made with various levels of success. The history of hip resurfacing has previously been described in the literature [6, 7] but the continued study of the early results of the current prosthetic solutions has provided probable explanations for some of the most common modes of failure associated with the successive resurfacing designs.

2 HISTORY OF RESURFACING

The origin of hip resurfacing is generally attributed to Smith Petersen [8] whose mould arthroplasty was not intended as a hip replacement originally but as a mould for cartilage regeneration, with the intention of removing the mould when the femoral head and acetabulum would have become smooth and congruent (Fig. 1). This concept was abandoned as the regenerated surfaces were incomplete, mainly composed of fibrous cartilage, and not optimal for weight bearing in most patients and the moulds were never removed. However, the concept inspired several subsequent designs (cup arthroplasty) based on the interposition of a cup between the femoral head and the acetabular cartilage, with varying degrees of freedom between the cup and the femoral head and neck, illustrated here by the Luck cup (Fig. 2). The main criticism associated at the time with these designs was that avascular necrosis developed under the cup, leading to a necessary revision. In fact, confusion was made between necrosis and erosion of the femoral head owing to a lack of fixation of the component. Osteonecrosis was not present in most of those cases of collapse of the reshaped femoral head. Later on appeared the double cup arthroplasty in which weight bearing was provided by a double cup, limiting the friction between the bone and a foreign material. A few pioneers made unsuccessful attempts, such as Charnley with Teflon bearings in the 1950s, Müller and Boltzy [9] with metal-on-metal in the 1960s (Fig. 3), and Gerard [10] also with metal-on-metal and later metal-on-polyethylene [11] but with components allowing...
The very first surface replacement with metal-on-metal bearing was developed by Müller and Boltzy [9] who implanted 18 of these press-fit devices and reported their results in 1968. Note the presence of Teflon pads on the bearing surface of the acetabular component.

Although the target age was younger than total hip replacement (THR), the majority of the results from these early designs exhibited poor long-term performance compared to THR [12–14] and these high early failure rates were later explained by the effects of increased polyethylene wear debris generated by large femoral heads articulating with UHMWPE [15]. In the meantime the procedure had been largely abandoned and the resurfacing concept itself rejected by the orthopaedic community. As an example of the performance of the devices used during this era the results of the cemented components articulating with polyethylene bearings and implanted by the senior author are discussed below.

### 2.1 An example of all-cemented metal-polyethylene device: the THARIES

In 1973, the total hip articular replacement using internal eccentric shells (THARIES) was developed at the UCLA Medical Center by Amstutz and Clarke and was commercialized in 1975. The femoral component was cemented, made of Co–Cr–Mo, and articulated with an all-polyethylene acetabular com-

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**Fig. 1** Smith-Petersen’s mould arthroplasty. The vitalium (CoCrMo alloy) component (1938) replaced the original moulds made of glass, too brittle for the procedure and was designed to restrict motion between the reshaped femoral head and the component.

**Fig. 2** The Luck cup (1948) featured a collar and, although cementless, did not allow as much motion between the reshaped femoral head and the component.

**Fig. 3** The very first surface replacement with metal-on-metal bearing was developed by Müller and Boltzy [9] who implanted 18 of these press-fit devices and reported their results in 1968. Note the presence of Teflon pads on the bearing surface of the acetabular component.
Fig. 4 This panel is visible in the historical display on joint arthroplasty at the Joint Replacement Institute in Los Angeles. Six early double cup designs are featured, all using cemented polyethylene acetabular components and cemented CoCrMo femoral components. From left to right and top to bottom: Paltrinieri and Trentani (1971), ICH (Eicher and Capello, 1973), Wagner (1974), THARIES (Amstutz and Clarke, 1975), ICLH (Freeman and Swanson, 1976), and TARA (Townley, 1977)

Table 1 Summary of the early hip resurfacing designs

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Date of first implantation</th>
<th>Implant fixation</th>
<th>Shape of the prepared femoral head</th>
<th>Bearing material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charnley</td>
<td>Early 1950s</td>
<td>Cementless</td>
<td>Cylindrical</td>
<td>Polytetrafluoroethylene (Teflon)</td>
</tr>
<tr>
<td>Townley (TARA)</td>
<td>1964</td>
<td>Cemented</td>
<td>Cylindrical</td>
<td>Polyurethane then UHMWPE</td>
</tr>
<tr>
<td>Müller</td>
<td>1968</td>
<td>Cementless</td>
<td>Cylindrical</td>
<td>Metal/metal (CoCr) + Teflon spacers</td>
</tr>
<tr>
<td>Paltrinieri and</td>
<td>1971</td>
<td>Cemented</td>
<td>Cylindrical</td>
<td>UHMWPE</td>
</tr>
<tr>
<td>Trentani</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furuya</td>
<td>1971</td>
<td>Cemented</td>
<td>Cylindrical</td>
<td>Steel cup and UHMWPE head then UHMWPE cup and steel head then Al/Al</td>
</tr>
<tr>
<td>Freeman (ICLH)</td>
<td>1972</td>
<td>Cemented</td>
<td>Cylindrical</td>
<td>Metal cup and UHMWPE head then UHMWPE cup and metal head</td>
</tr>
<tr>
<td>Eicher (ICH)</td>
<td>1973</td>
<td>Cemented then porous coated on femoral side</td>
<td>Cylindrical</td>
<td>UHMWPE</td>
</tr>
<tr>
<td>Wagner</td>
<td>1974</td>
<td>Cemented</td>
<td>Spherical</td>
<td>UHMWPE cup and metal head then Alumina heads</td>
</tr>
<tr>
<td>Amstutz (THARIES)</td>
<td>1975</td>
<td>Cemented</td>
<td>Chamfered cylinder</td>
<td>Moulded UHMWPE cup and CoCr head</td>
</tr>
<tr>
<td>Amstutz (PSR)</td>
<td>1983</td>
<td>Cementless chamfered cylinder with mesh then hemispherical with beads</td>
<td>Chamfered cylinder then tapered cylinder (1990)</td>
<td>UHMWPE liner and CoCr head, then Alumina head</td>
</tr>
</tbody>
</table>
as much femoral head and neck bone as possible. Following is a summary of the results of the authors’ experience with THARIES, which has been previously published [16, 17].

Between 1975 and 1984 322 THARIES were implanted by the senior author. The mean patient age at the time of surgery was 51 years (range 20–67 years) and 55 per cent were male. The primary diagnoses were: osteoarthritis 53 per cent, osteonecrosis 16 per cent, developmental dysplasia 10 per cent, rheumatoid arthritis 7 per cent, post-trauma 5 per cent, slipped capital femoral epiphysis (SCFE) 4 per cent, and other diagnoses 5 per cent and were consistent with the etiology of arthritis in a young population. The average follow-up was 117 months with 172 patients over 10 years at the last review. Survivorship data shown in Fig. 6 included 189 revisions. Only four were consecutive to femoral neck fracture. Aseptic loosening of one or both components was the main mode of failure and accounted for 97 per cent of the failures with a higher incidence of acetabular failures compared to femoral failures at revision surgery. With revision as the endpoint, the 5, 10, and 16-year survivorship for the entire group was 88, 48, and 26 per cent respectively. The best survivorship of hips was in osteoarthritic males who had larger component sizes than women. Survivorship was 91 per cent at 5 years, 66 per cent at 10 years, and 43 per cent at 15 years (Fig. 6). There was a significant difference between the etiologies ($p=0.011$, Logrank test) and the 10-year estimated survivorships were: osteoarthritis 51 per cent, rheumatoid disease 50 per cent, osteonecrosis 33 per cent, developmental dysplasia 28 per cent.

![Fig. 5](image1.png)  
**Fig. 5** First generation of metal-on-polyethylene resurfacing system: the total hip articular replacement with internal eccentric shells (THARIES, Zimmer, Warsaw, IN, USA) developed by Amstutz and Clarke. Both components were cemented and the femoral head reamed with a chamfer, a pattern now adopted by most current resurfacing devices.

![Fig. 6](image2.png)  
**Fig. 6** Kaplan–Maier survivorship curve of the THARIES devices implanted by the senior author, illustrating the variation in implant durability as a function of gender and etiology.
Despite these disappointing survivorship results, the patients benefited from good functional outcomes (Fig. 7) and whenever revision became necessary, newer and more advanced implants were available (including cementless acetabular and femoral stem-type components) implanted into a virgin femoral canal to secure long-term function for these patients, some of whom were still young and active.

2.2 Cementless metal-polyethylene hip resurfacing: the PSR

The development of a cementless fixation for resurfacing devices was driven by the belief that cement was the main cause of implant failure, as the role of polyethylene debris was still unknown in the component loosening process. Furthermore, the absence of additional reaming of the acetabulum to provide space for the cement mantle was a major factor in the adoption of porous coating or titanium mesh for the fixation of hip resurfacing components. These modifications to resurfacing devices were made in parallel to the evolution of stem-type devices during the early 1980s. The survivorship performance of these devices did not improve compared to the THARIES, as it is now known that high wear of UHMWPE remained the dominant cause of failure, but two consecutive designs of the acetabular components, the chamfered cylinder design (Zimmer) and the hemispherical design (Depuy) provided important information for the development of future prostheses. Acetabular durability improved considerably with the chamfered cylinder design, which was press-fit without screw holes, but femoral osteolysis and fracture of the femoral neck occurred with much greater frequency than in the authors’ cemented THARIES. Bone ingrowth around the socket prevented debris penetration into the acetabulum but the femoral component mesh–bone interface showed greater vulnerability, illustrating the hypothesis that the debris travels a path of least resistance [18]. The subsequent osteolysis caused loosening or fracture due to loss of structural integrity.

The gain in acetabular bone preservation associated with the chamfered cylinder design was large enough to outweigh the difficulty of positioning of these components and the authors changed to a hemispherical socket design to facilitate insertion. However, the acetabulum became vulnerable to osteolysis as a result of debris penetration through the screw holes into the superior acetabulum. On the femoral side the cementless components almost without exception became fixed in spite of some malposition and incomplete bone ingrowth (whether TiAlloy/CP Ti mesh or the later beaded cobalt chrome porous) and the fixation remained good until osteolysis, facilitated by the gaps under the femoral component, undermined the stability of the component.
However, for patients with a moderate activity level, some of those prostheses are still functioning nearly 20 years later (Figs 8 and 9).

### 2.3 Hemi-resurfacing

The validity of the resurfacing concept was then restored by the analysis of the results of hemi-resurfacing, where a resurfaced femoral head articulates directly with the host acetabular cartilage (Fig. 10). These procedures are generally reserved for patients with Ficat stage III or early stage IV osteonecrosis in which the acetabular cartilage involvement has been kept to a minimum. In this procedure, aseptic loosening of the device is extremely rare and no such outcome was observed in 22 years of experience in the senior author’s series [19, 20]. Revision of the femoral component became necessary mainly when the acetabular cartilage wore out. This observation supported the resurfacing concept and suggested that a low-wear bearing material was the likely key to the success of total resurfacing.

### 3 WHAT WERE THE LESSONS DRAWN FROM THE EARLY ERA OF RESURFACING?

While long-term durability was unlikely for young and active patients implanted with conventional polyethylene devices, the resulting lessons of this early era of hip resurfacing were useful in designing the present generation systems. The lessons from this era (1973–1992) include:

1. The preservation of femoral bone stock.
2. Stability was increased and the prevalence of dislocation was reduced markedly compared to THA [16].
3. The procedure did not cause femoral head necrosis [21] because the blood supply in the arthritic hip is primarily intra osseous from the metaphysis!! The ‘normal’ extra osseous retinacular vessels which enter the posterior head–neck junction are altered by the osteoarthritic disease and compromised by the growth of osteophytes at the head–neck junction.

**Fig. 8** (a) Antero-posterior pelvic radiograph of a 54-year-old male with bilateral osteoarthritis; (b) an AP radiograph showing the patient 15 years after resurfacing (right) and 14 years after (left). The patient is still pain free and the components well fixed. Insert shows the Chamfered Cylinder PSR (Zimmer, Warsaw, IN, USA) with titanium mesh used for porous coating.
Background of metal-on-metal resurfacing

Fig. 9 (a) An antero-posterior pelvic radiograph of a 48-year-old male with osteoarthritis secondary to an old slipped capital femoral epiphysis; (b) an AP radiograph showing the patient 14 years after resurfacing. A small area of bone erosion at the supero-lateral junction of the neck and femoral component and radiolucent zones around the socket suggest the presence of osteolysis. Insert shows the hemispherical PSR (Depuy, Warsaw, IN, USA) with beaded porous coating.

4. There were some short-term neck fracture failures which appeared to be bone stock and technique-related.

5. Although acrylic fragmentation was a factor, the majority of the failures were due to component loosening, secondary to polyethylene debris-induced osteolysis as the wear of polyethylene was increased 4–10 times, with large femoral heads compared to the smaller sizes utilized at that time with total hip arthroplasty.

6. Femoral fixation was critical owing to a small fixation area with larger diameter components having better survivorship [22].

7. The revision to a conventional stem-type device was easy for the femoral component because the femoral canal was left intact by the resurfacing procedure. However, there was often extensive acetabular bone loss due to osteolysis, especially with cemented components in patients who were not followed regularly.

8. Although socket loosening was dramatically reduced with cementless components, the device did not conserve acetabular bone stock because of the two-component system of a metallic shell and a liner insert. It was, however, the first system (1983) with both femoral and acetabular components available in 3 mm increments to increase the surgical technique flexibility and to minimize bone resection of the acetabulum. Later, in 1990, hemispherical components with a porous beaded surface became available in 2 mm increments.

4 WHY METAL-ON-METAL BEARINGS?

In addition to the poor results of the early resurfacing designs, one of the main criticisms directed towards resurfacing was that the procedure was not bone-conserving on the acetabular side compared to a conventional total hip arthroplasty, because of the need to accommodate for a femoral head of a larger diameter. Among the potential bearings materials available to provide a satisfactory alternative to UHMWPE, cross-linked polyethylene and ceramics require too thick an acetabular system (because of the two-part components) to be optimal for a bone-conserving resurfacing. Currently, only metallic devices can be manufactured with sufficient strength as a thin one-piece shell, combining a low-wear bearing with an outside rough surface such as sintered porous beads or other suitable coating for a cementless fixation (Fig. 11).
Fig. 10 (a) An 18-year-old male with post-traumatic induced osteonecrosis, Ficat stage III; (b) a total of 16 years after hemi-resurfacing, the cementless Alumina femoral resurfacing component shows excellent fixation. There is preservation of some articular space. Note the formation of new bone in the acetabular fossa (arrow), which has uniformly prevented a protrusion of the hemi-resurfacing component into the acetabulum. The component was eventually revised 18 years after surgery as the result of complete acetabular cartilage wear.

In addition, the excellent wear properties of large femoral heads [23, 24], and self-healing capacity of metal-on-metal bearings [25] confirm that metal-on-metal is currently the optimal bearing of choice for resurfacing.

5 MODERN GENERATION OF RESURFACING

The current generation of hip-resurfacing devices uses exclusively cobalt–chromium–molybdenum alloy (CoCrMo) metal on metal bearings. The first two designs to appear were introduced in the early 1990s by Heinz Wagner [26] in Germany and Derek McMinn [27] in England. Initially, both systems were all-cementless. The Wagner design used forged cobalt-chrome alloy (F799 with high carbon content) as a bearing surface and a grit-blasted, titanium alloy shell with macro features for fixation to the bone. The initial McMinn resurfacing used a cast high-carbon CoCrMo alloy, uncoated, and press-fit (cementless fixation) both on the femoral and the acetabular side. The preparation of the femoral head was similar to that of the total hip articular replacement by internal eccentric shells (THARIES, Zimmer, Warsaw, IN, USA) with a chamfered cylinder in the same 4 mm increments. The femoral component had peripheral anti-rotation ridges and a short metaphyseal stem to assist with the alignment of the femoral component and its initial stability. Some of the early components were HA-coated. Later, McMinn modified the components further for cementless fixation on the acetabular side using a series of sharp fins and reintroduced HA coating.

In October 1993, the authors began a pilot programme with metal-on-metal resurfacing, using four Wagner resurfacing devices and 42 McMinn cemented femoral components, articulating with four different socket systems (two cemented and two cementless). These devices were implanted over a 3-year period and the midterm results of this experience have been recently reported [4]. The average
Background of metal-on-metal resurfacing

...femoral components) and extremely similar to the Conserve® Plus with a thin-walled one-piece acetabular component and a femoral component that features a short metaphyseal stem designed for component alignment during insertion. The most recent reports from these series are extremely encouraging [1, 2, 5] (Fig. 12) and illustrate the importance of surgical technique, instrumentation, and patient selection as key elements for the success of resurfacing [3, 28, 29].

Hip-resurfacing, once abandoned, has recently emerged as a viable option for young and active patients in need of a prosthetic solution. This is primarily because of the introduction of improved metal-on-metal bearings, design, and technique. The safety and efficacy of the procedure, and conse-
quently its future popularity, will now rely heavily on the quality of the training programmes associated with the availability of the devices, as well as a better understanding and prevention of neck fractures and loosening.

REFERENCES


