The Self-locking Balgrist Hip Socket for Cementless Fixation: Biomechanical Principles and Clinical Results

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Abstract. The Balgrist hip socket, initially made entirely of HDPE (high molecular weight polyethylene), now made of outer titanium alloy shell that faces the bone of the acetabulum has been in clinical use for 10 years. The purpose of this presentation is to illustrate the biomechanical principles that have governed this unique design and to present the clinical results that we have obtained until the end of 1991 with 717 implants. From 1982 to 1987 Balgrist HDPE sockets had been implanted for 346 hips, from 1984 to 1991 Balgrist Titanium alloy sockets have been implanted for 371 hips. The number of revision are 55 of 717 hips. 48 hips out of 55 were with Balgrist HDPE sockets. On the contrary, only 7 hips were with Balgrist titanium socket. The greatest benefit of Balgrist Titanium socket is the excellent mechanical lock with subchondral bone of the acetabulum. (Keio J Med 42 (2): 53-59, June 1993)

Key words: total hip arthroplasty, revision hip surgery

Introduction

The Balgrist hip socket, the first artificial joint socket capable of self-adjustment, has been in clinical use for 10 years now. Initially made entirely of HDPE (high molecular weight polyethylene), the design now incorporates an outer shell of titanium alloy that faces the bone of the acetabulum. The surface that mates with the spherical head of the femoral endoprosthesis continues to be of HDPE. The purpose of this presentation is to illustrate the biomechanical principles that have governed this unique design and to present the clinical results we have obtained until the end of 1991 with 717 implants (864 have been implanted up to the end of November, 1992).

The artificial hip socket has always presented problems peculiar to its own that might well be characterized by the difficulty in finding acceptable solutions; as seen by the fact that although satisfactory femoral prostheses for intramedullary fixation have been obtainable ever since Moore and Thompson introduced their models in 1950/51, no satisfactory acetabular component was available for many years. It was only after the introduction of bone cement (polymethylmethacrylate or PMMA) on a broad scale through Charnley in 1962 that an artificial replacement of the acetabulum became feasible; not only because of the cement employed to anchor the artificial socket within the bone, but also because of the choice of socket material, which was finally HDPE.

Several earlier attempts to attach a metallic socket to the bone by means of screws or pins were unsuccessful. In spite of the initially good results obtained with bone cement, some remained sceptical and further endeavoured to fix a metal socket to the bone otherwise. Amongst these was Ring, who used a long central screw of attachment to the bone, but who then abandoned this in favour of a polyethylene socket that is pegged into the pelvic bone.

Towards the end of the seventies, several investigators reported loosening of about 25% of all hip implants within a period of five years and, amongst other factors, the bone cement was made at least partially responsible for the unsatisfactory results. The search for a socket that could be fixed to the bone without the use of cement led Mittelmeier to a new principle of attachment. He employed an external thread around the tapered socket so that on screwing it into the previously prepared acetabulum the socket would become tightly fixed. Aluminium oxide ceramic (Al₂O₃) was the material of choice for this socket.

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In the meantime, stress-analysis investigations on epoxy resin models of the human pelvis showed that the subchondral cortex of the acetabulum was responsible for the greater part of hip force transmission. Also, like all elastic bodies, the acetabulum too deflects under load. If the bone were to be loaded as physiologically as possible after implantation of a prosthesis, it should be required to continue behaving in this manner. Therefore we suggested retaining the layer of subchondral cortical bone as far as possible and also advocated the use of a flexible socket that would comply with the deflection of bone under load. Because of our conviction that these principles must be maintained, we refrained from using the very rigid ceramic socket of Mittelmeier.

In 1978 Endler developed a hip socket that was basically of the same form as that of Mittelmeier's, but made of HDPE. This polyethylene socket now had the elastic properties we considered favourable and therefore, towards the end of 1980, we began to implant the Endler tapered screw socket regularly in cases indicated for cementless total hip arthroplasty.

However, it soon became apparent that tapping a tapered thread within the acetabulum is not always unproblematic and that in the case of severe acetabular defects dysplastic acetabuli, implantation of the Endler socket was sometimes impossible. Also, the tendency of the ventral part of the acetabulum to break away (Fig 1), with subsequent danger of damaging the femoral nerve and blood vessels, was always near. Because of these drawbacks, we decided to develop a socket of our own which would not include the use of threads.

The 'Balgrist' Hip Socket

The socket consists of two parts, namely an outer split ring and a tapered insert (Fig 2). The outer split ring has been given the form of a truncated cone instead of a hemispheres since we firmly believe that the surrounding bone finds better purchase on the former shape, especially for primary fixation. Experience with the Endler screw-socket showed that the taper angle of 30° (+/−15°) had been well chosen (initially by Mittelmeier), because with this taper angle the subchondral cortical bone in the region of the lunate articular surface is hardly removed. Through this compromise of removing very little bone stock from the medial aspect of the acetabulum, an excellent primary fixation of the socket has been gained, which would certainly not be possible with a hemispherical socket unless such accessories as screws, pegs, plates, etc are also incorporated together with the necessity to ream the acetabulum highly precisely.

At present, the outer split ring with a taper of 30° facing the bone is made of a titanium alloy. The tapered insert with a taper of 10° (+/−5°) remains HDPE but has a titanium plate as an interface between the HDPE and the bone (Fig 2). The design of the Balgrist socket is such that after the outer split ring alone, in a contracted state has been introduced into the prepared acetabulum, the

![Fig 1](image1.jpg) The danger of the ventral part of the acetabulum breaking away when tapping threads.

![Fig 2](image2.jpg) The Balgrist self-locking hip socket.
A simple tapered reamer is used to prepare the acetabulum by removal of all cartilagenous tissue from the lunate articular surfaces. An entry angle of 45°, measured in the frontal plane, and with about 10° anteversion is chosen. After reaming, which involves exposure of some cancellous material in the medial part of the recess, with care taken to prepare the bed for the socket deep enough, the outer split ring of the socket is first introduced and positioned at the base of the prepared tapered recess. The slot of the ring would now have closed in. The tapered insert is then introduced and driven in. It is advisable not to drive the insert fully home, but to have it to stand proud of the outer ring by about 3 mm. This permits the outer ring to re-tighten its seating in the surrounding bone when the patient has begun to load the limb during the critical phase of bone remodelling in the course of the first few weeks after implantation. This self-locking possibility is a unique characteristic of this socket design which is probably the first with a really firm primary press-fit that also incorporates the possiblity of re-tightening.

The design is such that after the tapered insert has moved fully home, it comes up against a stop in the outer ring thus disabling further movements. This usually takes place between 3 and 6 months postoperatively. Even though the outer split ring is now made of titanium alloy, the socket exhibits the elastic characteristics of one made of HDPE, since the stiffness is determined almost entirely by the tapered insert.

By virtue of the specific tightening mechanism, this socket lends itself particularly well for use in dysplastic acetabuli or in cases of revision hip surgery where bone grafts are required to fill cavities that have resulted from severe bone loss. The same property of the socket also ensures good primary fixation without calling for any precise workmanship on the part of the surgeon.

Sometimes, however, one does encounter acetabuli with such heavy bone loss and/or protrusion into the lesser pelvis that a special outer split ring is required. In such cases the split ring is furnished with peripheral tags that engage with the rim of the acetabulum (Fig 4).

The socket is available presently in five sizes, with outer diameters of 47, 50, 56, 60 and 64 mm and, with the exception of the smallest size, will suit any ball head of 32 mm diameter. The smallest socket is designed to

![Fig 3](image1.png)  
*Fig 3* Locking through expansion of the outer ring as the insert is forced inwards.

![Fig 4](image2.png)  
*Fig 4* The Balgrist revision socket for special cases.
mate with a ball head of 28 mm diameter. In the near future, however, all the remaining socket sizes will also be available for use with 28 mm heads.

Clinical Experiences

As mentioned earlier, the first design of the Balgrist socket that was introduced for clinical evaluation was made of HDPE alone. A total of 346 sockets of this type were implanted from March 1982 up to November 1987. Several reports on the early results with this socket design have been issued.\textsuperscript{10,13–16} During this period of time, however, although the Balgrist socket was faring better than the Endler threaded device,\textsuperscript{10} it was becoming known that HDPE debris, mainly produced by a loosened socket rubbing against the surrounding bone, could well cause osteolysis through granulomas and further loosening of the implant.\textsuperscript{17,18} Therefore, in spite of the very encouraging early results with the Balgrist socket made entirely of HDPE, we strove to find an acceptable solution in which the outer split ring was made of titanium.

The first clinical trial of an outer ring made of titanium was in fact already in 1984 (Fig 5). The device was, however, too stiff and therefore an intermediate solution was chosen in which a very thin coating of titanium was deposited on the outer surface of the HDPE split ring. A total of 61 sockets of this coated type were implanted.

In the meantime, design details of an outer split ring made only of titanium were worked out so that from November 1987 onwards just this type of outer ring has exclusively been employed. Figure 6 shows one of the earliest sockets of this type which is still performing well.

Results

Even though we are no longer using the initial design that was entirely of HDPE (high density polyethylene), but since 1987 an outer split ring of titanium alloy instead, we nevertheless present all the results we have obtained up to the end of 1991 as follows.

A total of 346 sockets with an outer split ring of HDPE were implanted in 309 patients of 23 to 76 years of age (average age 53.8 yrs). This number of sockets also includes 61 that received a very thin layer (6 μm) of pure titanium on the outer surface in an attempt to further
encourage osteointegration of the device. Since the behaviour of these 61 was identical with the remaining 285, this whole group of 346 will be treated as one. The period of observation was from 1 to 116 months (average 55.4 months). 200 men (57.8%) and 146 women (42.2%) received this implant.

These 346 sockets were used in 318 (91.9%) primary interventions and 28 (8.1%) revision cases. Bilateral implantations were carried out in 86 (24.9%) patients. In the meantime, 27 patients (8.7%) of this collective have been lost.

The Balgrist socket with a titanium alloy outer split ring has been implanted in 371 hips in 335 patients between 24 and 57 years (average 56yrs) of age. The observation period extends from 0.5 to 60 months (average 15.6 months). The distribution between men and women was 207 (55.8%) and 164 (44.2%), respectively. 280 (75.5%) operation were primary interventions and 91 (24.5%) were revisions. In 65 (18.4%) patients bilateral implantations were performed. 11 patients (2.9%) of this collective have been lost.

All patients were examined 3, 6 and 12 months after surgery and following this, once a year regularly. The functioning of a prosthesis can be evaluated in many ways and several schemes have been worked out up to now. Perhaps the most significant sign of a failed prosthesis is when it requires replacement. Therefore, we shall refrain from the usual presentation of subjective data which would involve terms such as “very good, good, unsatisfactory, etc” and only use the number of sockets which have been replaced as a reciprocal measure of success. Table 1 illustrates the situation as determined up to the end of 1991.

Furthermore, having collectives of considerable size, we have been able to apply modern statistical methods to analyse our results and to describe the survivorship of the two main socket types we have used, that is, the “Balgrist HDPE” and the “Balgrist Titanium”. Figure 7 shows the results obtained according to the Kaplan-Meier procedure.19

It must be noted that Fig 7 includes the sockets that

![Survivorship curves, according to Kaplan-Meier, of the Balgrist hip sockets as observed up to the end of 1991.]

Table 1  Distribution of the Total Number of 717 Balgrist Hip Sockets Used from 1982 Up to the End of 1991

<table>
<thead>
<tr>
<th></th>
<th>Balgr. HDPE*</th>
<th>Balgr. Titan***</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Still Implanted</strong></td>
<td>298</td>
<td>364</td>
<td>662</td>
</tr>
<tr>
<td><strong>Removed</strong></td>
<td>48</td>
<td>7</td>
<td>55</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>346</td>
<td>371</td>
<td>717</td>
</tr>
<tr>
<td><strong>Primary Interventions Only:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Still Implanted</strong></td>
<td>275</td>
<td>278</td>
<td>553</td>
</tr>
<tr>
<td><strong>Removed</strong></td>
<td>42</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>317</td>
<td>280</td>
<td>597</td>
</tr>
<tr>
<td><strong>Revision Arthroplasties Only:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Still Implanted</strong></td>
<td>23</td>
<td>86</td>
<td>109</td>
</tr>
<tr>
<td><strong>Removed</strong></td>
<td>6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>29</td>
<td>91</td>
<td>120</td>
</tr>
</tbody>
</table>

were removed because of technical mistakes during implantation (6 of the HDPE and 7 of the titanium alloy) and even those due to an infection (8 of HDPE). If these were eliminated from the statistical assessment, the survival rate would appear even better in both cases.

Discussion and Conclusion

The ten years of experience now gained with the Balgrist hip socket has shown that this device with its wide versatility has indeed fulfilled all the requirements we expected of it. The self-locking effect which characterizes this socket design has been regularly seen to take place usually between 3 and 6 months postoperatively. This ‘settling’ of the prosthesis is best seen in radiographs of the early design of the socket which incorporated components that were made entirely of HDPE (Fig 8). As can be seen in Fig 8, the contrast wire rings, built into the outer split ring as well as into the tapered insert, have obviously moved relative to each other. This retightening possibility allows for some compensation of bone resorption that takes place during the important bone remodelling phase that follows shortly after implantation.

The further development of this prosthesis that was effected by changing the material of the outer split ring from HDPE to titanium alloy in order to avoid aseptic loosening problems similar to those being encountered with other cement-free systems in which HDPE had been brought directly in contact with bone,17 has now been rewarded by exhibiting a survival rate better than 98.86% during an observation period extending up to 8 years (the first implantation of a titanium outer split ring was performed in 1984, and since then sporadically until 1987 after which date such rings were exclusively used). For the Kaplan-Meier survival probability analysis that issued this value (Fig 7), we included those first few sockets that were removed within a short time postoperatively due to technical mistakes made during the implantation. In fact it was these early errors in the indication that led us to design the special outer ring for those cases with such acetabular defects that called for some additional structural support and bone grafts (Fig 4). If we had omitted taking these into account as failures, the survival rate would be even better. The same strict criteria were applied to the manner in which even the sockets with an outer ring of HDPE were treated. In this series, for instance, 8 of the sockets with an outer ring of HDPE loosened because of infection and 6 were wrongly implanted during the early stages of becoming familiar with the device.

That this unique socket design lends itself particularly well for revision arthroplasties, even when loosened cemented sockets are to be replaced, was demonstrated already in 1983. The ability for the outer ring to expand and lock itself into the surrounding bone enables even the standard socket to retain bone grafts that might be required to fill in defects, without the use of screws or other retaining devices. In about 50% of the 91 revision cases we used the standard Balgrist socket (Fig 2) and in the remaining revision cases the so-called Revision socket with bone grafts (Fig 4) was employed.

In conclusion we may state that the Balgrist socket for cementless fixation that might be characterised through; self-adjustment to accommodate for initial bone resorption; an angle of taper that permits retention of the greater part of the important subchondral bone in the area of the lunate surface; a tapered form that permits a true press-fit over a large surface area; an expansive outer ring that enables a tight fit even in acetabuli that require reconstruction through use of bone grafts; no screw threads; no high-precision sculpturing required on the part of the surgeon, therefore ease of implantation; has given extremely satisfactory clinical results up to now and most encouraging survival prediction for the future.

References


