Push-Out Testing of Cementless Acetabular Components with Equatorial Roughened Surface

Aseptic loosening due to wear particles is the most important long-term complication after total hip arthroplasty. One concept to improve acetabular fixation is to focus on long-term preservation of bone at the equatorial area of uncemented acetabular components. This goal may be achieved by constructing acetabular components with an equatorial area which is rougher than the dome so that stress-shielding is less likely to occur within this area. This could potentially result in improved sealing of the implant-bone interface against wear particles and improved long-term fixation of acetabular implants. In this study we tested the primary press-fit quality of such uncemented acetabular components. With the chosen experimental setting we found that an uncemented acetabular component with a rough equatorial area and a smooth dome may have a press-fit quality comparable to that of a fully roughened acetabular component. This finding supports the idea to construct acetabular components with equatorial coating from the perspective of primary press-fit.

Introduction

Aseptic loosening due to wear particles is the most important long-term complication after total hip arthroplasty [8, 10, 13]. An important goal of cementless acetabular fixation should be to consolidate the bond between implant and bone at the entrance to the implant-bone interface. By consolidating the bond at this location a more effective barrier against intrusion of wear particles into the interface may be created. This concept may lead to new cementless acetabular implants with improved long-term results. Remodeling of the bone adjacent to hip replacements has been described in great detail for the femoral side, but only a few reports and data are available for the acetabular side [4, 6, 7, 9, 11, 12, 15]. According to Wolff’s law [14] local bone is preserved as long as stresses are applied and is resorbed when stresses are transferred elsewhere. This latter phenomenon is known as stress-shielding. For cementless acetabular components it has been described using quantitative bone density measurements [15]. Using a finite element analysis it has been predicted that long-term bone density will be greatest at the superomedial aspect of the cup [5]. With this as the area of greatest load transfer the equatorial area, which is most important for primary press-fit fixation [3], is prone to stress-shielding. This implies that access of wear particles to the implant-bone interface may be facilitated as equatorial stress-shielding progresses.

One concept to improve acetabular fixation is to focus on long-term preservation of bone at the equatorial area of uncemented acetabular components. This goal may be achieved by constructing acetabular components with an equatorial area which is rougher than the dome so that stress-shielding is less likely to occur within this area. This may result in improved sealing of the implant-bone interface against wear particles and prolonged long-term fixation of acetabular implants.

Here we investigated whether an acetabular component which was designed to promote better long-term bone preservation at the equatorial area has a press-fit quality which is comparable to a conventional fully roughened cementless acetabular component. We hypothesized that an acetabular
component with a rough equatorial area and a smooth dome has a press-fit quality comparable to that of an acetabular component which is fully roughened.

**Materials and Methods**

**Acetabular components**

We used two conventional cementless acetabular components made from titanium alloy. The cup size was 62mm. The surface was roughened titanium plasma spraying. Five surface roughness measurements with a laser profilometer (UBM Messtechnik, Ettlingen, Germany) according to DIN 4768 were performed. The measured length was 5mm with a resolution of 2000/mm. Mean R_a was 25.96 +/- 1.24 pm, mean R_z was 98.96 +/- 12.6mm, and R_max was 123.82 +/- 6.64mm. The two acetabular components used were of the same shape, material, surface roughness, and design features. The only design difference was that Cup A (Fig. 1) was fully covered with a rough macrostructure whereas Cup B was covered with a rough macrostructure only at the equatorial area with a smooth dome (Fig. 2). Pure PUR RG 80 polyurethane foam blocks sized 100mm x 1000mm x 70mm with a central hole of 8.5mm were ordered from the manufacturer (Gaugier & Lutz oHG, Aalen-Ebnat, Germany). An acetabular cavity of 60mm was reamed manually into these foam blocks by an experienced surgeon.

A hydraulic testing machine (RM 25, Schenck Trebel Corp., Deer Park, NY) was used to insert and to push-out the acetabular components. Testing was performed at room temperature (22°C Celsius), with a vertical advance rate of 10mm per minute. Motion and impaction force were recorded to control uniform impaction throughout the experiment. The depth of insertion was determined by inserting the cup level to level with the foam block which was confirmed optically and by a rise in impaction force (Fig. 3).

Ten push-out tests were performed in with Cup A and ten with Cup B by turning the foam block with the acetabular component upside down perpendicular to the implants. Using the hydraulic testing machine the cups were pushed out of the foam block with a metallic pin through the 8.5mm hole (Fig. 4).

A pin with a diameter of 8mm was fixed in the crossarm to avoid any movement during push-out. Again, motion and force were recorded (Fig. 5, 6). After each test, the cups were cleaned of foam debris with compressed air and acetone solution.

Student's t-test for unpaired data was applied to determine the significant differences in the mean maximum push-out forces for both acetabular components. A p-value of <0.05 was considered statistically significant.
Results
After being pushed out of the foam blocks all the cups were covered by polyurethane debris in a uniform equatorial pattern. In both types of cup most debris was found at the periphery with less or almost no debris in the dome region. The mean maximum push-out force for Cup A was 143.7N +/- 34.2N (range: 90N to 182N); the mean maximum push-out force for Cup B was 176.6N +/- 27.4N (range: 117N to 210N) (Table 1). This difference was of borderline statistical significance (p=0.054).

<table>
<thead>
<tr>
<th>Cup, Group A</th>
<th>F_{max} [N]</th>
<th>Cup, Group B</th>
<th>F_{max} [N]</th>
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<tr>
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<td>B#01</td>
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Table 1: Maximum push-out forces recorded for both types of cups.

As can be seen from the curves in Figures 5 and 6, the slope of the curves ahead of the maximum was always higher when compared to the slope after it. This can be explained by the differences in static and dynamic friction. Before the highest force is attained, the cup is moving vertically without loosing the mechanical grip to the polymer (static friction). However, when the forces exceed the values of the static friction, the cup starts to move relative to the foam block and dynamic friction predominantly occurs. The dynamic frictional forces are mainly influenced by the degree of mechanical interlocking (i.e. surface roughness) and abrasive wear of the polyurethane, respectively.

Discussion
Hypothesis
With this experiment we were able to substantiate our hypothesis: an acetabular component with a rough equatorial area and a smooth dome had a press-fit quality which was comparable to a fully structured acetabular component in our experimental setting. Of course, it is not known how this will translate into in vivo conditions and additional research is needed here.

Why was there a difference?
We expected the push-out forces for the cups with an equatorial roughened surface to be similar to the completely structured cups because it was suspected by others that the equatorial area may play an important role in the primary stability of press-fitted uncemented acetabular components [1, 2]. This remained to be proven for an almost completely smooth dome. We were surprised that the push-out forces were in fact borderline significantly higher for the cups with an equatorial roughened surface with the chosen experimental setting. This difference is difficult to explain. One possibility is that cups with a flatter pole could be implanted more deeply into the foam blocks. In fact, the removal of the rough surface of Cup B made these cups at least 0.3mm flatter in the polar region. Nonetheless, we believe that deeper impaction of the cup because of the flatter pole is not a likely explanation here because insertion of the cups was terminated in each case when the rim of the cup and the foam block were level with each other. This was ensured by the pushing device which had a greater diameter than the cup (Fig. 3), by optical control of insertion, and by controlling the impaction force.

A more probable explanation is that the flatter pole in Cup B led to less elastic deformation of the polymeric material within the polar region during the insert procedure. This effect which is mainly due to a reduced height of the type B cup may increase the elastic repulsion forces acting on the pole and consequently ease the push-out of the cup.

Push-out testing
Push-out testing of acetabular components may not be representative of the forces which occur in vivo. In fact, mechanical in vitro testing of implant-related issues will always be a simplification of in vivo forces. We chose to measure straight push-out forces because this made the press-fitted cups most vulnerable to loose fixation.

We were not aiming primarily at retrieving data similar to in vivo forces. Our aim was to compare different cup designs. Therefore, the experimental set-up with non-anatomical foam blocks seemed to be sufficient here.

Summary
With the experimental setting chosen we found that an uncemented acetabular component with a rough equatorial area and a smooth dome may have a primary press-fit quality which is comparable to a fully roughened acetabular component. This finding may lead to the design of new types of acetabular components which may enhance long-term sealing of the implant-bone interface against wear particles and thus improve long-term fixation.

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Zusammenfassung

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