Original article

A pilot trial comparing the tear-out behavior in screw-sockets and cemented polyethylene acetabular components – a cadaveric study

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\begin{abstract}
Background: The removal of well-fixed acetabular components following THA (total hip arthroplasty) is a difficult operation and could be accompanied by the loss of acetabular bone stock. The optimal method for fixation is still under debate. The aim of this pilot study was to compare the tear-out resistance and failure behavior between osseo-integrated and non-integrated screw cups. Furthermore, we examined whether there are differences in the properties mentioned between screw sockets and cemented polyethylene cups.

Hypothesis: Tear-out resistance and related mechanical work required for the tear-out of osseo-integrated screw sockets are higher than in non-integrated screw sockets.

Patients and methods: Ten human coxal bones from six cadavers with osseo-integrated screw sockets (n = 4), non-integrated (implanted post-mortem, n = 3) screw sockets and cemented polyethylene cups (n = 3) were used for tear-out testing. The parameters axial failure load and mechanical work for tear-out were introduced as measures for determining the stability of acetabular components following THA.

Results: The osseo-integrated screw sockets yielded slightly higher tear-out resistance (1.61 ± 0.26 kN) and related mechanical work compared to the non-integrated screw sockets (1.23 ± 0.39 kN, P = 0.4). The cemented polyethylene cups yielded the lowest tear-out resistance with a failure load of 1.18 ± 0.24 kN. Compared to the screw cups implanted while alive, they also differ on a non-significant level (P = 0.1). Osseous failure patterns differed especially for the screw sockets compared to the cemented polyethylene cups.

Discussion: Osseo-integration did not greatly influence the tear-out stability in cementless screw sockets following axial loading. Furthermore, the strength of the bone-implant-interface of cementless screw sockets appears to be similar to cemented polyethylene cups. However, given the high failure load, high mechanical load and because of the related bone failure patterns, removal should not be performed by means of tear-out but rather by osteotomies or other curved cutting devices to preserve the acetabular bone stock.

Level of evidence: Level III, case-control-study.
\end{abstract}

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1. Introduction

Total hip arthroplasty (THA) is one of the most frequently performed orthopedic procedures with very high success rates [1].

Regarding the acetabular component, there are various methods for fixation into the coxal bone. Cemented polyethylene cups, screw sockets or press-fit systems are frequently used [2,3]. The optimal method for the fixation of the acetabular component still remains controversial [4–7]. The cemented fixation method shows a high primary stability in the early postoperative phase [8]. It is also well established that the surface porosity of cementless implants allows for sufficient osseo-integration into the pelvis [9–11].

Nevertheless, one of the most common complications in clinical practice is aseptic loosening of the acetabular component [12–16].

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Furthermore, there are indications for the revision of a well-fixed acetabular component, including malpositioning, infection or polyethylene wear [17]. The removal of the acetabular component can be demanding and requires patience and caution. It should therefore be performed by experienced surgeons only [17–19]. The reason for this is, because removal is often associated with extensive bone loss and fracturing, especially in osteoporotic bone [18,20–22]. Therefore, during revision of acetabular components, one of the priorities must be the preservation of the remaining bone stock at the acetabulum. Many techniques have been documented for the removal of the acetabular component, which can be achieved with the use of drills, screws, reamers, curved blades, chisels or osteotomes [23–27]. However, there is no optimal removal tool as a “gold standard” in current practice. Possibly, this is due to missing mechanical data such as tear-out resistance or mechanical work necessary to explant an acetabular component of different types and fixation methods. These data could possibly provide a basis for the development of new surgical methods and devices for a less invasive removal of the acetabular component. Given the lack of mechanical data, the aim of the current study was to compare the mechanical parameters axial failure load and mechanical work as well as the failure characteristics between osseo-integrated and non-integrated screw sockets following a tear-out. Furthermore, we examined whether there were differences in the properties mentioned between screw sockets and cemented polyethylene cups. The following hypothesis was addressed with the tests on human cadavers: the mechanical parameters axial failure load and mechanical work required for the tear-out of osseo-integrated screw sockets are significantly higher than in non-integrated screw sockets.

2. Patients and methods

2.1. Human tissues and anatomical preparation

Ten coxal bones were removed from six human cadavers (bilateral: 4 cadavers, unilateral: 2 cadavers) (Table 1). While alive, all body donors gave their informed and written consent to the donation of their bodies for teaching and research purposes. Being part of the body donor program regulated by the Saxonian Death and Funeral Act of 1994 (third section, paragraph 18 item 8), institutional approval for the use of the post-mortem tissues of human body donors was obtained from the Institute of Anatomy, University of Leipzig.

Recruitment of the cadaveric tissues took place between 1 January 2014 and 31 December 2014. All cadavers underwent X-ray imaging of the pelvis to clarify the presence of implanted total hip arthroplasties and to rule out additional pathologies or fractures before mechanical testing. Seven cadaveric coxal bones contained ingrown THA acetabular components with screw sockets \((n = 4, \text{3rd generation, type biconical, manufacturer unknown})\) or cemented PE cups \((n = 3, \text{type and manufacturer unknown})\). The specimens with ingrown implants all showed macroscopic signs of osseo-integration into the coxal bone and were defined as osseo-integrated for the investigations. Three native cadaveric coxal bones were held as a control group for implanting screw sockets post-mortem. None of the acetabula without an implant showed excessive signs of osteoarthritis. Immediately after removing the innominate bones from soft tissues, the anatomically unfixed tissues were precooled and then shock frozen at \(-80\,^\circ\text{C}\).

2.2. Mechanical testing

In preparation for the mechanical tests, the coxal bone specimens were thawed carefully and embedded in a custom-made form by means of polyurethane foam (Götz Service GmbH, Premium TEC Hartschaum, Göppingen, Germany). The socket entrance level was grossly aligned perpendicular to the horizontal plane and fine adjusted after mounting the specimens in the materials testing machine. Into three native coxal bones without implants, size-matched biconical screw sockets, made of titanium (Bicone plus, Smith&Nephew GmbH, Hamburg, Germany) were implanted manually post-mortem by an experienced orthopedic surgeon immediately before the tests. Two additional steel rods were mounted on top of each of the coxal bones to reinforce the bone-polyurethane-composite from loosening. Metallic sockets were mounted to the testing machine by means of a surgical extractor tool (Endocon GmbH, Heidelberg, Germany), tightened with 60 Nm. The testing setup is depicted in Fig. 1. The coxal bones containing polyethylene sockets were mounted to the testing machine by means of a custom-made ball extractor, fixed to the sockets by means of bone screws (Fig. 1). Before the mechanical tests started, the coxal bones were moistened and warmed in isotonic saline (0.9% by mass, \(T = 37\,^\circ\text{C}\)).

Uniaxial tensile tests were performed using a mechanical testing device (Dyna-Mess, Aachen, Germany). A preload of 10 N was defined for all experiments. The testing rate was 20 mm/min ranging up to the point of material failure, indicated by a visible extraction of the implant and a loss of strain of at least 30% of \(F_{\text{max}}\). A 10-kN load cell was utilized to record the force-displacement data. The site and type of implant loosening was photo-documented for a qualitative description of the implant behavior.

2.3. Statistical analysis

Statistical comparison of the data was performed by using Microsoft Excel (version 2013, Redmond, USA) and SPSS software.

Table 1

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Age</th>
<th>Sex</th>
<th>Cup size (left/right)</th>
<th>Cup type</th>
<th>State of ingrowth</th>
<th>Cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>31–13</td>
<td>60</td>
<td>♂</td>
<td>×(\times)/54 mm</td>
<td>Screw socket – Bicone plus</td>
<td>Post-mortem implanted</td>
<td>Cardiac insufficiency</td>
</tr>
<tr>
<td>43–14</td>
<td>77</td>
<td>♂</td>
<td>54 mm/54 mm</td>
<td>2× screw socket – Bicone plus</td>
<td>Post-mortem implanted</td>
<td>Respiratory insufficiency</td>
</tr>
<tr>
<td>45–14</td>
<td>84</td>
<td>♂</td>
<td>48 mm/52 mm</td>
<td>2× screw socket – type: biconical</td>
<td>Osseo-integrated</td>
<td>Glomerulonephritis</td>
</tr>
<tr>
<td>49–14</td>
<td>87</td>
<td>♂</td>
<td>48 mm/50 mm</td>
<td>2× PE – type: unknown</td>
<td>Cemented</td>
<td>Epilepsy</td>
</tr>
<tr>
<td>91–14</td>
<td>91</td>
<td>♂</td>
<td>52 mm/54 mm</td>
<td>2× screw socket – type: biconical</td>
<td>Osseo-integrated</td>
<td>Anemia</td>
</tr>
<tr>
<td>94–14</td>
<td>90</td>
<td>♂</td>
<td>×(\times)/48 mm</td>
<td>PE – type: unknown</td>
<td>Cemented</td>
<td>Respiratory insufficiency</td>
</tr>
<tr>
<td>Mean value</td>
<td>81.5</td>
<td>♂</td>
<td>4(\times)/2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>10.7</td>
<td>♂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PE: polyethylene cemented cup.
(version 22.0, IBM, IL, USA). The Kolmogorov-Smirnov test was used to determine normal distribution of the data, followed by the non-parametric Mann-Whitney U-Test. \( P \)-values of 0.05 or less were considered statistically significant.

### 3. Results

Mechanical data were obtained from ten coxal bones, originating from six human cadavers (Table 1). Four coxal bones contained osseo-integrated screw cups (size 48 to 54 mm, type biconical, manufacturer unknown), three non-integrated screw cups (size 54 mm, Bicon plus, Smith\&Nephew, Hamburg, Germany) and three contained cemented polyethylene cups (size 48 to 50 mm).

The mean axial failure load for the osseo-integrated screw sockets was \( 1.61 \pm 0.26 \) kN and ranged between 1.26 and 1.98 kN (Fig. 2). The mechanical work required for the tear out of the osseo-integrated screw sockets was \( 9.86 \pm 1.78 \) Nm, ranging between 8.27 Nm and 12.74 Nm (Fig. 2). The mean failure load of the post-mortem implanted screw sockets was \( 1.26 \pm 0.39 \) kN, ranging between 0.71 and 1.67 kN. Mechanical work was slightly lower in the non-integrated than in the osseo-integrated screw sockets with \( 7.47 \pm 0.69 \) Nm, ranging from 6.84 to 8.42 Nm. Comparison of the mean axial failure load between the osseo-integrated and the post-mortem implanted screw sockets yielded no significant differences in failure load (\( P = 0.400 \)) and mechanical work (\( P = 0.114 \)). No fracturing related to the tear-out was observed in either one of the groups.

The mean failure load of the cemented polyethylene cups implanted during the lifetime of the donors was slightly lower than in the screw sockets with \( 1.18 \pm 0.24 \) kN (\( P = 0.114 \); Fig. 2), ranging from 0.91 kN to 1.48 kN. Also, the related mechanical work was non-significantly lower with the polyethylene cups compared to the screw sockets with mean values of \( 6.95 \pm 1.42 \) Nm (\( P = 0.114 \); Fig. 2) and ranged from 5.05 Nm to 8.74 Nm.

Osseous failure patterns differed for the screw sockets compared to the cemented polyethylene cups. Comparison of the cemented polyethylene cups to the screw sockets showed a different failure behavior. In the cemented polyethylene cup-group, parts of the bone cement remained attached to acetabular bone stock after the tear out, whereas penetrating bone cement and bone stock also remained attached to the explant, extending to the superior ramus of the pubic bone, the supra-acetabular sulcus of the iliac bone and to the corpus of the ischium (Fig. 3). In one of these specimens, tear-out-related fracturing occurred, causing fracturing of the superior pubic ramus and of the margin of the acetabulum. This finding is confirmed by the recorded force-displacement curves. The differences lie mainly in the falling load curve after reaching the maximum force. The cemented polyethylene implants showed much flatter curves suggesting a delayed tear-out due to the bone cement. One example of each is depicted in Fig. 4.

No differences were observed with regard to the types of osseous failure site in osseo-integrated and post-mortem implanted screw sockets (Fig. 5). In both groups, a similar pattern was observed concerning the screw thread with minor damage to the acetabular margin. Also, no bone fragments caused by fracturing were observed in the acetabular bone cavity after tear out.

### 4. Discussion

This pilot study was the first to compare the mechanical properties and related failure behavior following tear-out of osseo-integrated and non-integrated THA screw sockets (biconical type). Furthermore, mechanical data of cemented polyethylene cups were obtained. For this purpose, THA screw sockets and cemented polyethylene cups, implanted during the donors’ lifetime, could
be utilized on basis of cadaveric tissues. Initial stability and osseo-integration are important factors for long-term survival in acetabular components [2,8]. Previous cadaveric tests in the context of stability parameters and failure mechanics showed a high variability and inaccuracy in methods of testing [2,16,28]. Thus, a standardized testing method for the different implant systems may be required. The uniaxial tear-out test of acetabular components presented here may be considered as a highly unphysiological situation in the context of THA. Nevertheless, these data contain important information for the development of explant techniques and devices for the removal of acetabular components in different implant types. The preservation of the remaining bone stock is one of the main goals in the context of acetabular revision [17–19,21,23,24,26,29]. In the current study, the parameters axial failure load and mechanical work for tear-out were introduced as measures for determining the stability of osseous ingrowth in the acetabular components following THA. Both tear-out work and failure load may serve as indicators of mechanical strength for the bone-implant interface during explantation.

5. Limitations

The current study has limitations:

• the uniaxial tear-out setting presented is a highly unphysiological situation in the context of THA. However, the presented data shown here gives upper limits of potential forces occurring in acetabular revision;
• there were only a very limited number of human coxal bones and lifetime implanted acetabular components available for the experiments. Thus, the study must be regarded as underpowered;
• there is a lack of information with regards to implant materials, manufacturers and surface coatings due to medical data protection issues. Moreover, variations in the cadaveric tissues potentially impacted the tear-out characteristics, underlining the need for further research with a much larger sample size and different implant geometries;
• removing the surrounding soft tissues changed, but also normalized biomechanical properties of the coxal bone;
• the performed uniaxial tensile load test does not correspond to physiological stress on the acetabulum nor to the acetabular component following THA.

However, the given setup may be regarded as a standardized procedure for comparing the fixation strength of various THA
components, serving as a maximum threshold value of tear-out resistance.

Osseo-integrated and non-integrated screw sockets only showed minor differences in tear-out behavior. There were minor and non-significant differences in the failure loads and related mechanical work for tear out between osseo-integrated and post-mortem implanted screw sockets. Consequently, screw sockets appear to already have their stability immediately following the implantation of the thread into the acetabulum. Therefore, similar to cemented cup fixation [30,31], screw sockets appear to have a high initial stability. Vice versa, ingrowth mechanisms appear not to have a major impact compared to other cementless fixation methods like press-fit cups [32–36]. Failure characteristics were also nearly equal for osseo-integrated and non-integrated screw sockets (Fig. 5).

Tear-out characteristics were similar for the different types of acetabular implants though the osseous damaging pattern varied to some extent. There were only minor differences in the tear-out characteristics and in the osseous failure sites regarding the different types of the cadaveric implants (screw sockets vs. cemented polyethylene cups). Visible imprints of the screw thread were observed along with minor damage at the acetabular margin. The loss of bone stock was more pronounced in the cemented cups than in the screw sockets. Bone fracturing was observed in the coxal bones containing cemented cups, accompanied by bone stock adjacent to the cement removed with the implant. This finding is however in line with the recommendation to drill burr holes into the pubic, iliac and ischial part of the coxal bone prior to cement application in order to enhance the stability of the implant [37]. Further objective evidence is the difference in the failure behavior also shown by the recorded force-displacement curves (Fig. 4). In particular, the load drop of the cemented sockets is much flatter and more prolonged than in the uncemented screw sockets. This finding indicates a partial breaking of the bone-cement-interface until final failure.

Based on the collected data, acetabular components are well fixed in the bone stock. This applies to both the cemented and the cementless fixation technique. Additionally, recently implanted and therefore non-integrated screw sockets are also firmly fixed to the acetabulum. To preserve the acetabular bone stock in revision surgery, it is recommended to remove the acetabular component gently instead of using a forceful device to punch or lever out the component. Osteotomy may be a potential alternative to minimize the tear-out resistance for disrupting the bone-implant interface [19,26,38,39]. Furthermore, our experimental data with cemented cups have strongly indicated that the acetabular bone stock becomes harshly damaged, as shown in our results. However, this damage may not reflect the clinical routine in which the chisel can be placed within the bone cement or between the implant and the cement, thus minimizing the extent of bone stock loss. Based on the given data, the development of surgical explantation instruments may encompass the application of chisels with a vibration energy input or osteotomes with wear-resistant blades to further minimize the loss of bone stock.

6. Conclusion

Osseo-integration following THA does not greatly influence the strength of the bone-implant-interface in biconical acetabular screw sockets. Furthermore, the resistance against tear out in cemented acetabular components is very similar to cementless components. In contrast to cemented polyethylene cups, the tear-out of the screw sockets damage the acetabular bone stock to a minor extent. The described testing setup allows only a statement with regard to an axial tensile loading and biconical thread cups but it could be developed into a standardized method in future for in vitro comparison of the fixation strength of various acetabular components.

Disclosure of interest

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References


