1.4 The Influence of the Wear Bearing Coupling on Range of Motion and Stability against Dislocation of Total Hip Replacement

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Introduction

Modular total hip replacement (THR) systems have been clinically proven and usually consist of a stem onto which a metal or ceramic femoral head is fixed. The acetabular cup is composed of a metal-back and an insert. Due to increased life expectancy of the population and a broadening of indications for hip arthroplasty a lengthening of performance life times of THR has become necessary. The most frequent reason for total hip prosthesis failure is the particle induced aseptic loosening [5], therefore low wear bearing couples like ceramic-on-ceramic are increasingly used.

An important factor for the life quality of patients and undisturbed long-term function of THR is the range of motion (ROM) of the artificial hip joint. An insufficient ROM can lead to contact between the femoral neck of the stem and the rim of the cup (= prosthetic impingement). The consequent material stress may result in deformation by creep (cold flow) and subsequent onset of higher polyethylene wear or chipping off or fracture of ceramic components [1].

Furthermore impingement may cause subluxation and dislocation of THR. The incidence of dislocation following primary total hip replacement is on average between 2% and 5% [12] and significantly higher after revision surgery. The most important risk factors related to prosthetic instability are, apart from the surgical approach itself, an inadequate implant design and unfavourable implant orientation [9].

The objective of this study was to analyse the influence of different wear couples (ceramic-on-ceramic vs. metal-on-polyethylene) on the range of motion and the stability against dislocation of THR.

Materials and Methods

With different implant designs the ROM until impingement and the ROM until dislocation of THR was determined by means of an especially developed testing device (Fig. 1).

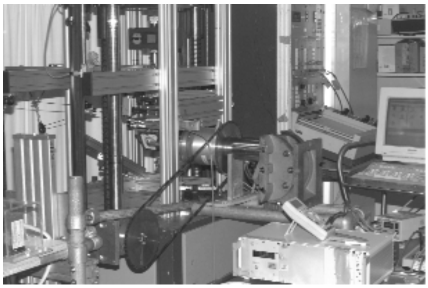
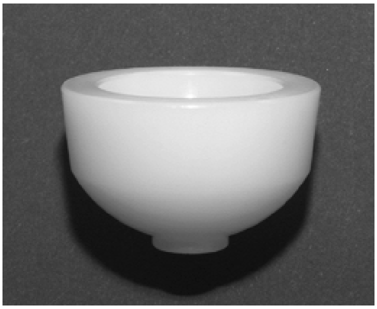


Figure 1: Dislocation testing device in the lateral view, mounted in an universal testing machine. Examined movements: maximum internal and external rotation combined with 10° extension and 15° adduction.

In addition the occuring resisting (subluxation) moments against levering the femoral head out of the acetabular cup or insert were recorded [2].
For this rotation movements of the prosthetic femoral stem (in accordance with an internal and external rotation movement of the leg) were carried out subsequently to adjusting the flexion/extension and abduction/adduction movements respectively, i.e. the influencing combined movements for dislocation of total hip replacement could be set reproducably.

In this study standard hip implants with different wear bearing couples were compared concerning their stability against dislocation. Both examined acetabular cups (CL-Metallsockel size 4, Fa. ESKA Implants, Lübeck and Plasmacup® SC size 52, Fa. Aesculap, Tuttlingen, respectively) were modular. The metal-backs were embedded in the acetabular implant fixture by means of epoxy resin (Ureol®). Due to the modular structure of the acetabular cup the inserts could be implanted or exchanged during the testings.

The stability against dislocation in dependence on the wear bearing couples metal-on-polyethylene vs. ceramic-on-ceramic was analyzed on the basis of a cup system with differing geometry of the polyethylene (PE) and ceramic insert respectively, and on the basis of a system with similar insert design.
For this a neutral polyethylene insert (Fa. ESKA) (Fig. 2) with an internal diameter of 28 mm and a slightly raised rim (displacement of the centre of the articulating femoral head towards the dome of the cup of approx. 2 mm) was implanted in the CL-socket. The inner rim was only rounded off slightly (radius of the rim about 0.5 mm). The other insert used was a neutral ESKA-Ceram® insert (composite material made of aluminium-oxide ceramic (Al_2O_3) and polyurethane [13] with an internal diameter of 28 mm) (Fig. 2). Compared to the polyethylene insert this insert showed several differences in design, e.g. an approx. 1.5 mm displacement of the centre as well as a clearly rounded off inner rim.



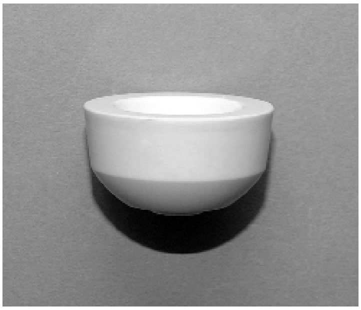


Figure 2:
Left: neutral (standard) polyethylene insert (Fa. ESKA Implants).
Right: neutral composite ceramic insert (ESKA-Ceram)

In the Plasmacup® SC a neutral polyethylene insert with an internal diameter of 28 mm (Fig. 3) and a neutral aluminium-oxide ceramic insert (Biolox® forte, Fa. CeramTec, Plochingen, with an internal diameter of 28 mm (Fig. 3) were implanted. Both insert designs showed similar geometry. In both cases the inner rim was clearly rounded off (radius approx. 2 mm) and the inset of the centre for the articulating femoral head was about 1 mm in the case of the ceramic insert and only slightly increased in the case of the polyethylene insert.

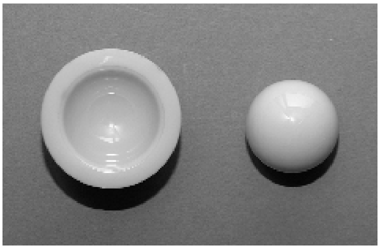


Figure 3:
Left: Tested neutral polyethylene insert (Aesculap AG).

Right: tested neutral aluminium-oxide ceramic insert and spherical head (Biolox® forte)

The opening plane of the embedded cup was non-recessed and orientated centrical towards the acetabular implant fixture. A reproducable positioning of the acetabular cup in a lateral inclination angle of 30°, 45° or 60° could be achieved by means of a form fitted link with the implant fixture. At the same time angles of the acetabular cup of -15°, 0°, +15°, +30° for retro- and anteversion respectively could be set and the centre of rotation of the cup always fell within the respective opening plane.

Matching cobalt-chromium or aluminium-oxide standard spherical heads with a diameter of 28 mm each one articulated with the corresponding insert. The femoral heads were fixed onto total hip stems (C-Hüftstiel Simplex, taper 12-14, Fa. ESKA Implants as well as Bicontact® S, taper 12-14, Fa. Aesculap, Tuttlingen) designed for cemented fixation. The femoral stems were embedded in a special fixture, which was integrated into a measurement device, by means of epoxy resin. The measurement device included a rotational angle detector (type MA 751, Fa. Megatron, Putzbrunn) and a torque detector (type 8628-5100, Fa. Burster, Gernsbach). In this study the position, i.e. rotation of the stem (ante- or retrotorsion) was not varied and held constantly in the 0°-position respectively.
In order to realize realistic stress situations, in vivo data by Bergmann et al. [4], who measured resulting hip joint forces by means of instrumented prosthetic stems telemetrically, were referred to. The examinations were carried out under dry conditions and at room temperature.

After implantation of the required implants, setting of their position and a rotation position of 0° and the subsequent application of the hip joint forces, following dislocation-associated movements were carried out on the artificial hip joint:

- Maximum internal and external rotation after 90° flexion and 0° adduction (Fig. 1), in accordance with an increased risk of posterior dislocation in low sitting position [8].
- Maximum external and internal rotation after an extension movement of 10° and 15° adduction, in accordance with an increased risk of anterior dislocation connected with hyperextension movements of the patient [8].

Results

A low inclination angle of the CL-socket (i.e. 30°) with no anteversion and no stem antetorsion respectively merely allowed an insufficient range of motion for the movement "internal rotation with flexion movement of 90° and adduction movement of 0°" until impingement (ROM_{Imp}) or allows no ROM for internal rotation at all (Fig. 4). With increasing cup inclination angle (45° or 60°) significantly larger range of motion (ROM_{Imp}) for the internal rotation movement was possible. With regard to the used wear bearing couples the ESKA-Ceram® insert showed an increased ROM of up to 5° for internal rotation compared to the ESKA neutral polyethylene insert.

The ROM until impingement is particularly influenced by the cup version. Thus e.g. a cup retroversion (at an inclination angle of 45°) always led to impingement in the whole interval of internal rotation movements with both wear bearing couples (Fig. 5). Sufficient range of motion can only be achieved through cup anteversion and stem antetorsion.

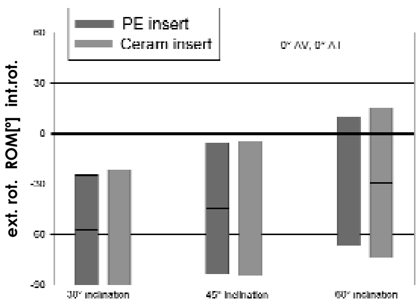


Figure 4:
Maximum range of motion until impingement (ROM_{Imp}) for interal rotation and external rotation. The columns show the impingement-free interval in the above-mentioned rotation movements for the femoral stem (up to ± 90°). Test conditions: Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene (PE-Insert, Fa. ESKA) and ceramic-on-composite ceramic (Ceram-Insert, ESKA-Ceram).
Different inclination angles (CL-socket version of 0° and stem torsion of 0°, neck taper always 12-14).

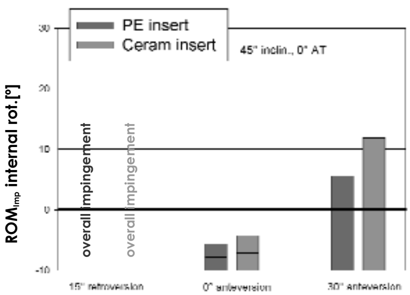


Figure 5:
Maximum range of motion until impingement (ROM_{Imp}) for interal rotation. The columns show the impingement-free interval in the internal rotation movements for the femoral stem. Test conditions: Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene and ceramic-on-composite ceramic. Different ante- and retroversion angles (CL-socket inclination of 45° and stem torsion of 0°, neck taper always 12-14).

Concerning the maximum subluxation (resisting) moment in the course of internal rotation movement significantly higher values were recorded for cups with a low inclination angle (Fig. 6). For example the 28 mm femoral head in combination with a neutral PE-insert at a cup inclination angle of 30° almost led to a doubling of the subluxation moment compared to an inclination angle of 60°. Additionally, clear differences in subluxation moments were recorded between metal-on-polyethylene and ceramic-on-composite ceramic (ESKA-Ceram®) wear bearing couples (Fig. 6). On average the subluxation moment at an inclination angle of 45° was 1.56 Nm for the combination of metal-on-polyethylene and 1.07 Nm for the couple with the ESKA-Ceram® insert.

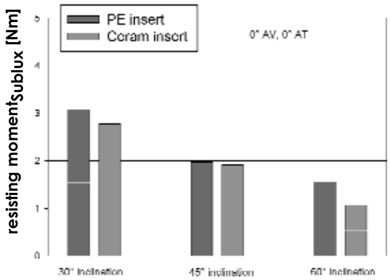


Figure 6:
Maximum resisting moment (in subluxation) for interal rotation movements.
Test conditions:
Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene and ceramic-on-composite ceramic.
Different inclination angles (CL-socket version of 0° and stem torsion of 0°, neck taper always 12-14).

For the actual point of dislocation during the movement "internal rotation with 90° flexion and 0° adduction" a significantly delayed dislocation in posterior direction was achieved by increased anteversion of the acetabular cup with both low and high inclination angles (Fig. 7, 8). An increasingly steep positioned cup (inclination angle of 60°) caused earlier dislocation especially in combination with cup retroversion (Fig. 7). Unlike with the neutral PE-insert, no stable articulation in the artificial hip joint could be realized with the ESKA-Ceram® insert. However, during pronounced cup anteversion of a steep or flat positioned cup (inclination angle of 30°) increased range of motion until dislocation (ROM_{Lux}) was recorded for the wear bearing couple ceramic-on-composite ceramic (Fig. 7, 8).

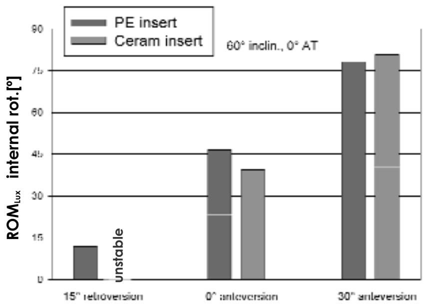


Figure 7:
Maximum range of motion until dislocation (ROM_{Lux}) for interal rotation. The columns show the dislocation-free interval in the internal rotation movements for the femoral stem.
Test conditions:
Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene and ceramic-on-composite ceramic.
Different ante- and retroversion angles (CL-socket inclination of 60° and stem torsion of 0°, neck taper always 12-14).

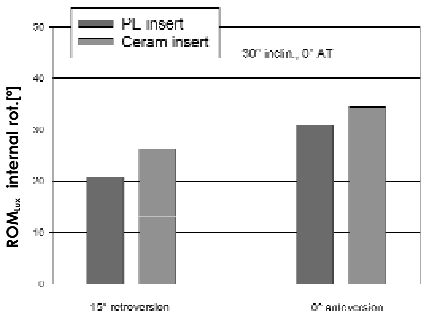


Figure 8:
Maximum range of motion until dislocation (ROM_{Lux}) for interal rotation. The columns show the dislocation-free interval in the internal rotation movements for the femoral stem.
Test conditions:
Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene and ceramic-on-composite ceramic.
Different ante- and retroversion angles (CL-socket inclination of 30° and stem torsion of 0°, neck taper always 12-14).

On the inner rim of the tested PE-insert significant deformations (cold flow) consequent to recurrent impingement and dislocation of the femoral head could be detected. However, minor material damage also appeared on the rim of the ESKA-Ceram, inserts.

Using the Plasmacup® SC as metal-back and inserts with similar design a decrease of overall ROM of about 5° compared to the neutral PE-insert (Fa. Aesulap) was achieved in the movement "internal and external rotation with a flexion movement of 90° and adduction movement of 0°" using the ceramic insert (Biolox® forte) (Fig. 9).

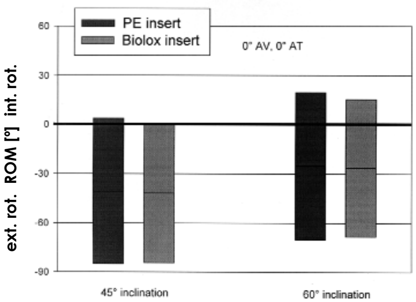


Figure 9:
Maximum range of motion until impingement (ROM_{Imp}) for interal rotation and external rotation. The columns show the impingement-free interval in the above-mentioned rotation movements for the femoral stem (up to ± 90°).
Test conditions:
Combination with 90° flexion and 0° adduction using the wear couples metal-on-polyethylene (PE-Insert, Aesculap AG) and ceramic-on-ceramic (Biolox, forte, CeramTec AG).
Different inclination angles (Plasmacup SC version of 0° and stem torsion of 0°, neck taper always 12-14).

In this case no significant differences in degree of maximum occuring subluxation moments in the course of an internal rotation movement could be observed between the wear bearing couples metal-on-polyethylene and ceramic-on-ceramic (Table 1). However, with a low inclination angle or with an anteverted cup increased moments were recorded.

		internal rotation (with 90° flexion und 0° adduction)	
		PE-insert	**ceramic insert**
45° inclination 0°AV, 0°AT	RM_{Sublux}	1,28 ± 0,1 Nm	1,30 ± 0,1 Nm
	ROM_{Lux}	42,4 ± 0,1°	48,8 ± 0,2°

Table 1:
Maximum resisting moment (in subluxation) (RM_{Sublux}) und ROM until dislocation (ROM_{Lux}) for internal rotation movement in combination with 90° flexion and 0° adduction for the wear couples metal-on-polyethylene and ceramic-on-ceramic (Biolox® forte) in case of identical metal-back (Plasmacup SC) in 45° inclination and 0° anteversion, each with 28 mm metal or ceramic head, identical femoral stem with taper 12-14 and 0° antetorsion.

In the movement "internal rotation with flexion of 90° and adduction of 0°" the range of motion until dislocation (ROM_{Lux}) was slightly higher for the ceramic-on-ceramic couple, i.e. a slightly delayed dislocation in posterior direction than with the metal-on-polyethylene couple (Table 1). Again, significant deformations (cold flow) were visible on the inner rim of the PE-insert, whereas no defects could be detected macroscopically on the ceramic insert (Biolox® forte).

In an external and internal rotational movement in combination with an extension of 10° and adduction of 15° the range of motion until impingement clearly depended on the implant position. For example between 15° retroversion and 30° anteversion of the acetabular cup the decrease in ROM for external rotation amounted to about 40° (Fig. 10). According to further investigations steep positioned cups in combination with a stem rotation in anterior direction were especially susceptible to posterior impingement. Only slight differences in

ROM existed between the wear bearing couples metal-on-polyethylene and ceramic-on-ceramic. With the use of the ceramic insert a decrease in range of motion of about 2° was recorded (Fig. 10).

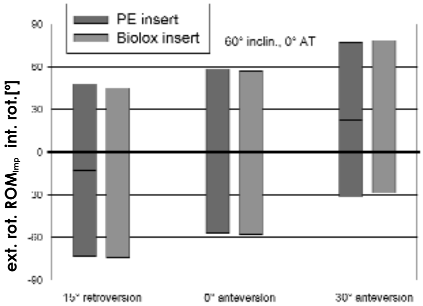


Figure 10:
Maximum range of motion until impingement (ROM_{Imp}) for internal and external rotation movements. The columns show the impingement-free interval in the above-mentioned rotation movements for the femoral stem.
Test conditions:
Combination with 10° extension and 15° adduction using the wear couples metal-on-polyethylene and ceramic-on-ceramic (Biolox® forte).
Different anteversion angles (Plasmacup SC cup inclination of 45° and stem torsion of 0°, neck taper always 12-14).

Discussion

Recurrent dislocation following total hip replacement (THR) is a serious postoperative complication, which makes a revision surgery necessary in about one third of these cases [16]. Important risk factors apart from the surgical approach itself are inadequate implant design and poor implant position [10]. Increased dislocation rates have been clinically observed for high inclination angles [7]. Furthermore an increase of the cup anteversion was described as being more beneficial for the hip stability [11]. The stability of THR against dislocation is also affected by implant design variables like head-neck-ratio and cup / insert geometry [14]. Especially using smaller femoral head sizes, there is the danger of the head sliding over the rim of the cup [3]. A weak hip musculature favours dislocation as does poor tissue tension.

Furthermore, leg movements which exceed the guaranteed ROM of total hip replacement can lead to the leverage of the femoral head out of the cup consequent to contact between the femoral neck and the rim of the cup (prosthetic impingement). In this case, subluxation, dislocation, and the subsequent repositioning of the femoral head involving ceramic inserts may lead to local overstress of the implant material due to a reduced contact area with the possibility of failure (rim flaking, fracture) [6]. This is promoted by the lower damage tolerance of ceramic materials in comparison to polyethylene.

To our knowledge there are no experimental studies so far, in which the stability against dislocation of artificial hip joints in dependence on the implanted wear bearing couple was analyzed explicitly. In clinical studies no increased dislocation rate for hard-hard wear couples could be observed up to now. An exception to this is the recently presented study by Toni et al. [15] about the survival rate of various total hip arthroplasty systems with ceramic-on-ceramic and metal-on-polyethylene respectively. In a follow-up of 7 years a significantly lower total revision rate was registrated for ceramic-on-ceramic wear bearing couples compared to metal-on-polyethylene. However the revision rate for ceramic cups due to dislocation was higher (0,51% vs. 0,14%) [15], but possible reasons for this observations were not given.

In our experimental study the question was whether the implanted wear bearing couple has an influence on the range of motion and the stability against dislocation of artificial hip joints and to what extent the design and position of the implants is of importance.

Our results demonstrate the close connection between the position of the hip implants and the maximum range of motion leading to impingement (ROM_{Imp}) and to dislocation (ROM_{Lux}) as well as the maximum subluxation moment. This applies to all used wear bearing couples. In order to achieve a sufficient range of motion of the total hip replacement a horizontal position (e.g. inclination angle of 30°) and a cup retroversion respectively as well as a stem retrotorsion must be avoided in any case.

In particular, pronounced cup anteversion leads to higher subluxation (resisting) moments and increased ROM until dislocation, i.e. an enhanced stability against the posterior dislocation. However, excessive anteversion (>30°) in combination with stem antetorsion should be avoided due to increased risk of posterior impingement and anterior dislocation by combined extension, adduction and external rotation movements.

design between the ESKA polyethylene insert and the composite ceramic insert (ESKA-Ceram®). Because the centre of rotation of the femoral head is located closer to the opening plane of the cup and the inner rim is rounded off on the ESKA-Ceram® insert it lead to an increased ROM_{Imp} in all tested movements and implant positions, but also a lower subluxation moment was observed. For the time of actual joint dislocation especially in unstable joint positions, this leads to an earlier dislocation than with a PE-insert. Furthermore, no stable condition in the artificial hip joint can be achieved with a steep positioned cup and additional retroversion using the ESKA-Ceram® insert. Due to above-mentioned design features of the insert the prosthetic head can slide over the inner rim of the insert or dislocate at an early stage.

However, with adequate anteversion combined with a flat cup position (45° or 30°) larger range of motion until dislocation (ROMLux) was recorded using the ESKA-Ceram® insert compared to the wear bearing couple metal-on-polyethylene. The earlier dislocation and shorter subluxation period respectively with stable implant position is likely to be due to the elastic and/or plastic deformation of the PE-insert, which favours the femoral head sliding out of the cup.

In case of similar insert geometry in combination with the Plasmacup® SC socket no substantial difference of the ROM until impingement was observed between the couple metal-on-polyethylene and ceramic-on-ceramic. In the case of a ceramic-insert made of Biolox® forte the ROM is slightly decreased, because the inner rim was not deformed during the tests consequent to recurrent prosthetic impingement unlike the PE-insert. The maximum subluxation moments in the course of the examined rotational movements showed no significant differences between the metal-on-polyethylene and the ceramic-on-ceramic wear bearing couples. Using the Biolox® forte insert a slightly increased range of motion until dislocation (ROM_{Lux}) was recorded. The longer subluxation period is probably linked to the absent deformation of the ceramic insert and the accompanying enhanced stability.

In order to be able to completely rule out the effect of differences in design of the implants on the assessment of stability against dislocation of differing wear bearing couples, further examinations on an absolutely identical design of THR implants are in process. For this dislocation testings are carried out on the same prosthetic stem and metal-back, into which polyethylene and aluminium-oxide ceramic inserts with identical internal and external geometry are implanted.

Conclusion

Due to their effect of minimizing aseptic implant loosening caused by wear particles, hard-hard wear couples are increasingly used in young or active patients. Inadequate implant position can result in restricted range of motion and instability of THR. With implantation of ceramic components specific risks have to be considered such as intra-operative handling, implant orientation and post-operative patient behaviour. Therefore ceramic-on-ceramic couples should only be applied in case of optimized implant position to prevent impingement and dislocation with following material failure (enhanced wear or brittle fracture).
In the presented study the maximum resisting moment and the range of motion until impingement and dislocation were mostly influenced by the implant position. In addition, the stability of THR against dislocation was clearly affected by design variables of the insert like chamfer angle and inset of the head center, whereas the use of different wear couples, i.e. metal-on-polyethylene vs. ceramic-on-ceramic, had less impact.

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