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Differences between the wear couples metal-on-polyethylene and ceramic-on-ceramic in the stability against dislocation of total hip replacement

RAINER BADER*, ERWIN STEINHAUSER, SUSANNE ZIMMERMANN, WOLFRAM MITTELMEIER
Klinik für Orthopädie und Sportorthopädie, Technische Universität München, Germany
E-mail: rainer.bader@LRZ.tum.de

ROGER SCHOLZ
Klinik und Poliklinik für Orthopädie, Universität Leipzig, Germany

RAYMONDE BUSCH
Institut für Medizinische Statistik und Epidemiologie, Technische Universität München, Germany

After total hip replacement an insufficient range of motion (ROM) can lead to contact between femoral neck and rim of the cup (= impingement) causing dislocation and consecutive material failure. The purpose of this study was to analyse the influence of different wear couples on the ROM and stability against dislocation.

By means of a special testing device the ROM until impingement, the ROM until dislocation as well as the resisting moment against levering the head out of the cup were experimentally determined. Various total hip systems with cup inserts made of ceramic and polyethylene were comparatively examined in different implant positions.

Maximum resisting moment as well as the ROM until impingement and dislocation were clearly influenced by the implant position. Furthermore, the stability against dislocation was affected by design parameters, whereas in the case of appropriate implant position differing wear couples (metal-on-polyethylene *vs*. ceramic-on-ceramic) had a minor impact. However, as shown by tests under lubricant conditions, ceramic-on-ceramic couples provided less dislocation stability in unfavourable implant position in comparison to metal-on-polyethylene. Therefore, ceramic-on-ceramic couples should only be applied in the case of optimised implant orientation preventing impingement and dislocation with subsequent material failure like chipping off or breakage.

Introduction

Modular total hip replacement (THR) systems have been clinically proven. Due to increased life expectancy of the population and a broadening of indications for hip arthroplasty a lengthening of good performance and life times of THR has become necessary [1]. The most frequent reason for total hip endoprosthesis failure is the particle induced aseptic loosening [2]. It has been recognised that particulate debris from polyethylene (PE) cups is responsible for inflammatory reactions and osteolysis in many cases [1]. Lower wear rates are provided by hard bearing surfaces like ceramic-on-ceramic [3], which are increasingly used for that reason [4, 5].

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 [6]. An insufficient ROM can lead to contact between the femoral neck of the stem and the rim of the cup (= prosthetic impingement) [6]. The consequent material stress may result in deformation by creep and subsequent onset of higher PE wear [7] (Fig. 1(a)) or chipping off or fracture of ceramic components (Fig. 1(b)) [1, 6].

Furthermore, impingement may cause subluxation and dislocation of THR [8]. The incidence of dislocation following primary THR is on average between 2 and 5% [9] and significantly higher after revision surgery [10]. The most important risk factors related to instability of hip endoprostheses are, apart from the surgical approach itself [11], an inadequate implant design and unfavourable implant orientation [12].

*Author to whom all correspondence should be addressed.

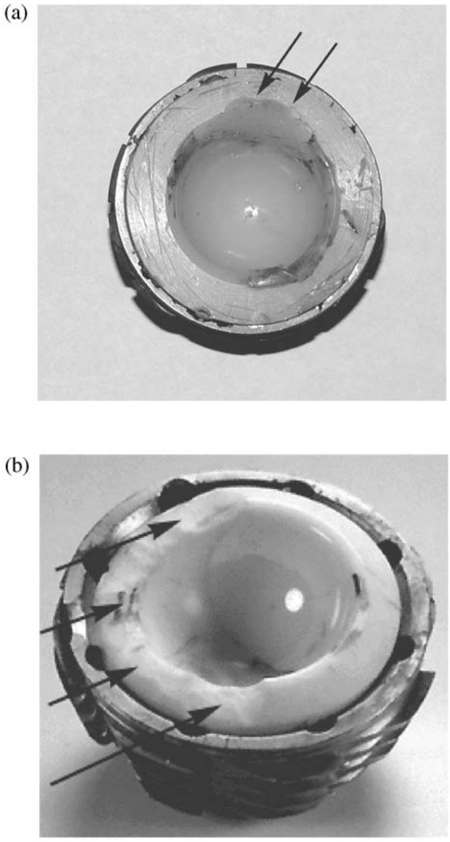

Figure 1 (a) Retrieved acetabular cup showing deformation of the PE insert (creep and wear) due to prosthetic impingement. (b) Retrieved screw cup with semi-circular rim flaking (chipping off) of the aluminium-oxide ceramic insert.

So far no experimental or prospective clinical studies are published, in which the stability against dislocation of artificial hip joints in dependence on the used type of wear couple was analysed explicitly.

The purpose of this *in vitro* study was to analyse the influence of different wear couples (ceramic-on-ceramic *vs*. metal-on-polyethylene) on the ROM and the stability against dislocation of THR.

Materials and methods

Using an especially developed testing device [13] (Fig. 2) different THR systems can be tested for the ROM until impingement and the ROM until dislocation. In addition, the occurring resisting (subluxation) moments against levering the femoral head out of the acetabular cup are recorded.

In the present study the stability against dislocation concerning the wear couples metal-on-polyethylene *vs*. ceramic-on-ceramic was analysed on the basis of a THR system with differing design of the PE and the ceramic insert respectively and on the basis of a system with similar geometry of both inserts.

Following modular total hip systems were investigated:

Implant system I[1]

Hemispherical acetabular cup (CL socket, outside diameter 56 mm, cemented femoral stem (Simplex) with taper 12–14 and neck diameter of 14 mm, matched with cobalt-chromium or aluminium-oxide ceramic spherical heads with a diameter of 28 mm. Each head articulated with the corresponding standard PE (UHMW-PE[2]) and aluminium-oxide ceramic (Biolox® forte[3]) insert. The standard PE insert (Fig. 3(a)) provided an internal diameter of 28 mm and a slightly raised rim, that is displacement of the centre of the articulating femoral head towards the dome of the cup of approximately 2 mm relative to the opening plane of the insert. The inner rim was only rounded off slightly (radius of the rim approximately 0.5 mm). The other insert used was an aluminium-oxide ceramic insert (Biolox® forte) with an internal diameter of 28 mm (Fig. 3(b)). Compared to the PE insert (Fig. 4(a)) the ceramic insert showed several differences in design, for example approximately 0.5 mm less head inset as well as a clearly rounded off inner rim (Fig. 4(b)).

Implant system II[4]

Hemispherical acetabular cup (Plasmacup® SC size 52 mm), cemented femoral stem (Bicontact® S) with

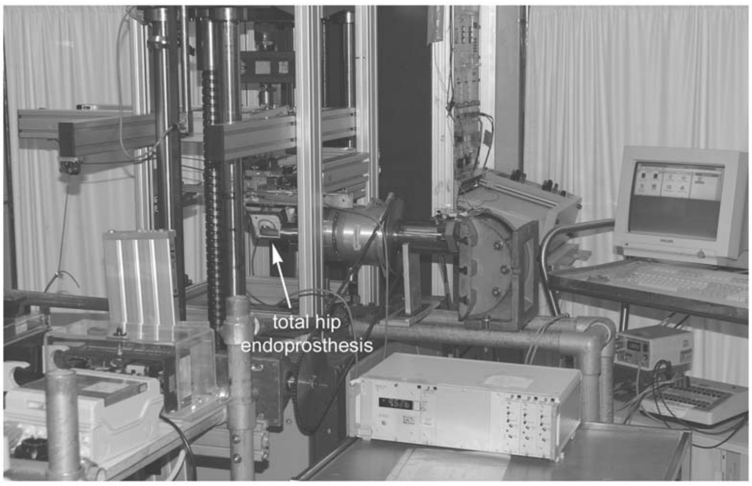

Figure 2 Dislocation testing setup with measurement device and movement actuator in the lateral view, mounted in a universal testing machine. Examined movements: maximum internal and external rotation combined with 90° flexion and 0° adduction.

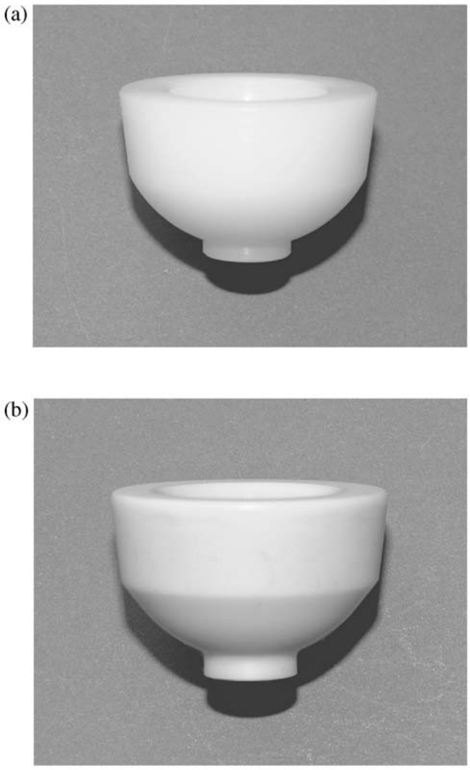

Figure 3 (a) Standard (neutral) PE insert (system I). (b) Standard (neutral) aluminium-oxide insert (system I).

taper 12–14 and neck diameter of 13.5 mm, matched with cobalt-chromium or aluminium-oxide ceramic spherical heads with a diameter of 28 mm.

Each head articulated with the corresponding insert, that is a standard polyethylene (UHMW-PE) insert with an internal diameter of 28 mm (Fig. 5(a)) and a standard aluminium-oxide ceramic insert (Biolox® forte) with an internal diameter of 28 mm (Fig. 5(b)) which were implanted in the Plasmacup® SC. Both insert designs

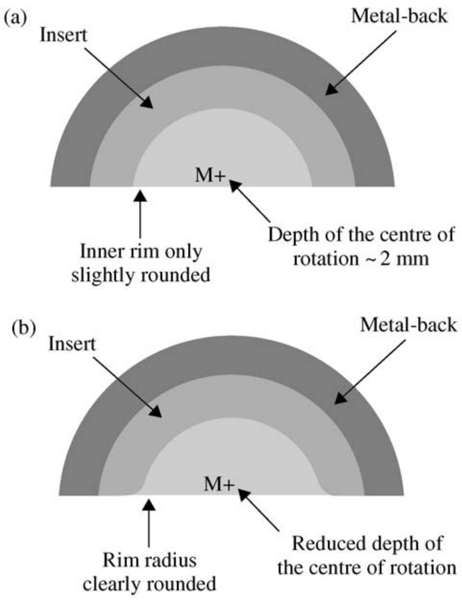

Figure 4 (a) Sketch of the metal-backed standard PE insert (system I) with slightly rounded rim and pronounced head inset. (b) Sketch of the metal-backed standard ceramic insert (system I) with clearly rounded rim and less head inset.

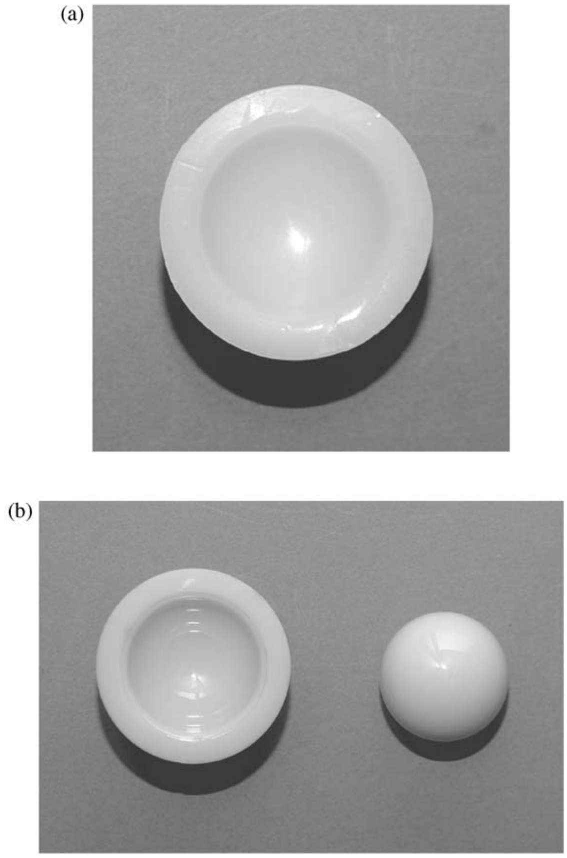

Figure 5 (a) Standard (neutral) PE insert (system II) with clearly rounded rim. (b) Standard (neutral) aluminium-oxide insert (system II) with clearly rounded rim and the corresponding 28 mm femoral head.

showed similar geometry. In both cases, the inner rim was clearly rounded off (radius approximately 2 mm) and the inset of the centre for the articulating femoral head was approximately 1 mm.

Both metal-backed acetabular cups were embedded in an implant fixture by means of epoxy resin (Ureol®[5]). Due to the modular structure of the acetabular cups the inserts could be implanted or exchanged during the testing. The opening plane of the embedded cups was non-recessed and orientated centrically towards the acetabular implant fixture. A reproducable positioning of the acetabular cups in a lateral inclination (abduction) angle of 45 and 60° could be achieved by means of a form fitted link with the implant fixture. At the same time angles of the acetabular cups of $-15, 0, +15$ and $+30°$ for retro- and anteversion respectively could be set and the centre of rotation of the cups always fell within the respective opening plane.

The femoral stems were embedded in a special fixture, which was integrated into a measurement device, by means of epoxy resin. In this study the position, that is rotation of the stem (ante- or retrotorsion), was not varied and held constantly in the 0°-position. In order to realise close to physiological conditions of hip joint loading, *in vivo* data from Bergmann *et al.* [14], who measured the resulting joint forces by means of instrumented femoral stems telemetrically, were referred to.

After implantation of the respective implants, adjustment of implant position and the subsequent application of the hip joint forces internal and external rotation movements of the femoral stem (in accordance with an internal and external rotation movement of the leg) were carried out up to dislocation of the femoral head or up to $\pm 90°$ (truncation condition). Following dislocation-associated movements were executed at the artificial hip joint:

1. Maximum internal and external rotation after 90° flexion and 0° adduction (Fig. 2), in accordance with an increased risk of posterior dislocation in low sitting position [15].
2. Maximum external and internal rotation after 10° extension and 15° adduction, in accordance with an increased risk of anterior dislocation connected with hyperextension movements of the patient [15].

The examinations were carried out at room temperature (25 °C) as well as under dry conditions and after lubrication of the articulating surfaces with calf serum (Newborn calf serum[6]). During the tests the angle of internal and external rotation and the corresponding moment were continuously monitored and sampled with the use of a computerised data-acquisition system (SNAPMASTER V 3.1[7])

The recorded data (ROM and resisting moment) were evaluated statistically by an analysis of variance with several factors with the software package SPSS, version 11.5 (SPSS Inc., Chicago). The LSD test was used as a *post hoc* test. All tests were carried out two-sided. The level of significance was assessed at 5%.

Results

Influence of implant position and wear coupling

A sufficient ROM until impingement (ROM_{Imp}) could not be achieved for the movement ''internal rotation after 90° flexion and 0° adduction'' in all cup inclination angles (45 or 60°) with low cup anteversion and stem antetorsion angles (Figs. 6 and 7).

Thus, for example retroversion of the cup combined with an inclination angle of 45° always led to impingement in the whole interval of internal rotation movements with both implant systems (I and II) and wear bearing couples.

Clear differences of the maximum ROM_{Imp} were determined between system I and system II ($p < 0.001$) (Fig. 6). With regard to the used wear bearing couples of system I (i.e. different insert design) the ceramic insert (Biolox® forte) showed an increased ROM_{Imp} of up to 5° for internal rotation compared to the corresponding PE insert ($p < 0.001$) under dry conditions (Fig. 6).

Using system II (Plasmacup® SC as metal-back and inserts with similar design) the ceramic insert (Biolox® forte) led to a decrease of the overall ROM_{Imp} of internal and external rotation (after 90° flexion and 0° adduction) of by about 5° compared to the standard PE insert.

Concerning the maximum resisting moment in subluxation (RM_{Sublux}) in the course of internal rotation movement clear differences were recorded between the metal-on-polyethylene and ceramic-on-ceramic wear bearing couples of system I ($p = 0.01$) (Table I). For example, at an inclination angle of 60° the subluxation moment for the combination of metal-on-polyethylene was approximately 0.5 Nm higher than for the ceramic-on-ceramic couple.

In contrast, no significant differences in degree of maximum occurring 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 of system II ($p = 0.167$), apart from a slight tendency towards higher moments in the case of the ceramic insert (Tables I and II). With implant system II lower maximum resisting moments were determined in each case compared to implant system I ($p \leq 0.001$) (Table I). In general, a low inclination angle or an anteverted cup led to increased resisting moments (Table II).

Concerning the actual point of dislocation during the movement ''internal rotation after 90° flexion and 0° adduction'' a significantly delayed dislocation ($p < 0.001$) in posterior direction was achieved by increased anteversion of the acetabular cup testing both implant systems. In particular, a steep positioned acetabular cup (inclination angle of 60°) caused earlier posterior dislocation in combination with cup retroversion.

Under dry conditions no significant differences of the ROM until dislocation (ROM_{Lux}) in the movement ''internal rotation after 90° flexion and 0° adduction'' were recorded between the PE insert and ceramic insert of system I ($p = 0.766$) (Table I). Using system II, however, the ROM until dislocation (ROM_{Lux}) in the above-mentioned movement was significantly higher for the ceramic-on-ceramic couple ($p < 0.001$) (Table I), that is a slightly delayed dislocation in posterior direction in contrast to the metal-on-PE couple.

Regarding both tested implant systems a clearly higher ROM until dislocation was determined with the system II in the case of favourable cup position (45° inclination and 15° AV), independently of the used wear couple ($p < 0.001$) (Table I). On the other hand, only small differences in the ROM_{Lux} could be registered between implant system I and II with a steep positioned acetabular cup combined with the PE inserts.

TABLE I Maximum resisting moment (in subluxation) (RM_{Sublux}) and ROM until dislocation (ROM_{Lux}) for internal rotation movement in combination with 90° flexion and 0° adduction using implant system I and II with the wear couples metal-on-polyethylene (PE insert) and ceramic-on-ceramic. The inserts articulated with 28 mm spherical femoral heads under dry test conditions. Implant position: cup inclination of 45°, anteversion of 15° (AV), stem antetorsion (AT) of 0°

		System I		System II	
		PE insert	Ceramic insert	PE insert	Ceramic insert
45° inclination, 15° AV, 0° AT	RM_{Sublux}	2.96 ± 0.14 Nm	2.39 ± 0.25 Nm	1.20 ± 0.02 Nm	1.46 ± 0.18 Nm
	ROM_{Lux}	$47.2 \pm 0.3°$	$47.1 \pm 0.2°$	$65.9 \pm 0.4°$	$70.2 \pm 0.1°$

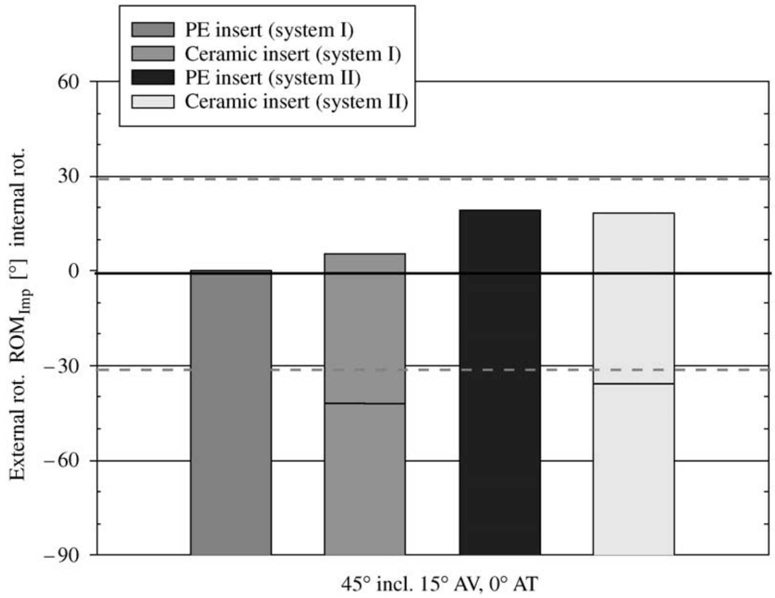

Figure 6 Overall range of motion until impingement (ROM_{Imp}) for the internal and external rotation movement in combination with 90° flexion and 0° adduction comparing the polyethylene (PE) and ceramic inserts of implant system I and II. The inserts articulated with 28 mm spherical femoral heads under dry test conditions. Implant position: cup inclination of 45°, anteversion of 15° (AV), stem antetorsion (AT) of 0°. The columns show the impingement-free interval in the rotation movements for the femoral stem (up to $\pm 90°$). The dashed lines show the physiological range of motion for above-mentioned movements (according to Genoud *et al.*) The hip joint range of motion: a cadaveric study. Proceedings 12th ESB Conference, Dublin, Ireland (2000) p. 137).

During external and internal rotation movements in combination with 10° extension and 15° adduction, the ROM until impingement (ROM_{Imp}) also depended on the implant position. For example between 15° retroversion and 30° anteversion of the acetabular cup the decrease in the ROM_{Imp} for external rotation amounted to about 40°. According to further investigations steep positioned cups in combination with a stem rotation in anterior direction were especially susceptible to posterior impingement. The tests performed showed only slight differences in ROM_{Imp} between wear bearing couples metal-on-polyethylene and ceramic-on-ceramic with similar insert design. For example, the ceramic insert of system II provided a decrease in the ROM_{Imp} of external rotation of approximately 2° in comparison to the PE insert of system II.

After testing significant deformations (cold flow) consequent to recurrent neck impingement and dislocation of the femoral head could be detected on the inner rim of all tested PE inserts, whereas no defects could be observed macroscopically on the ceramic inserts (Biolox® forte).

Influence of lubrication of the articulating surfaces

After lubrication of the articulating bearing surfaces with calf serum no significant differences regarding the ROM until impingement, resisting moment and ROM until dislocation could be determined within the wear couplings metal-on-polyethylene and ceramic-on-ceramic in the case of a flat positioned acetabular cup (e.g. 45° inclination) combined with 15° anteversion ($p \geq 0.057$) (Fig. 7 and Table II).

However, under lubricated conditions dislocation of the head without previous impingement occurred partially with steep positioned acetabular cups (60° inclination) using the PE insert of system II and the ceramic inserts of system I and II (Fig. 7 and Table II). The femoral head slides from the insert without contact (impingement) of the femoral neck with the rim of the cup.

With the wear couple metal-on-polyethylene the point of dislocation occurred slightly earlier compared to dry conditions ($p = 0.015$), but with the ceramic-on-ceramic

TABLE II Maximum resisting moment (in subluxation) (RM_{Sublux}) and ROM until dislocation (ROM_{Lux}) for internal rotation movement in combination with 90° flexion and 0° adduction using implant system II with the wear couples metal-on-polyethylene (PE insert) and ceramic-on-ceramic. The inserts articulated with 28 mm spherical femoral heads under dry and lubricant test conditions. Implant position: cup inclination of 45° with anteversion (AV) of 15° and cup inclination of 60° with anteversion of 0°, stem antetorsion (AT) always 0°

		PE insert		Ceramic insert	
		Dry	Lubricant	Dry	Lubricant
45° inclination, 15° AV, 0° AT	RM_{Sublux}	1.20 ± 0.02 Nm	1.25 ± 0.02 Nm	1.46 ± 0.18 Nm	1.51 ± 0.14 Nm
	ROM_{Lux}	$65.9 \pm 0.4°$	$65.4 \pm 0.2°$	$70.2 \pm 0.1°$	$70.0 \pm 0.1°$
60° inclination, 0° AV, 0° AT	RM_{Sublux}	0.40 ± 0.08 Nm	/*	0.42 ± 0.11 Nm	/*
	ROM_{Lux}	$44.3 \pm 0.5°$	$36.2 \pm 0.5°$	$52.3 \pm 0.3°$	$13.7 \pm 4.9°$

*Dislocation occurred without impingement.

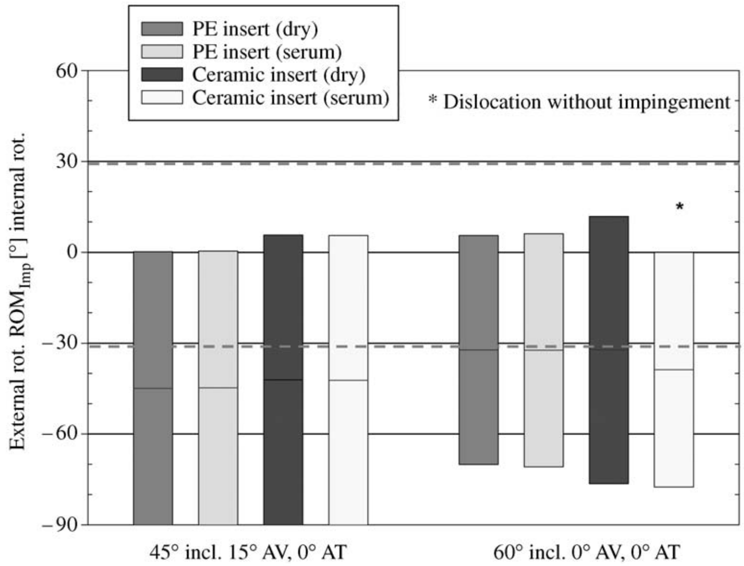

Figure 7 Overall range of motion until impingement (ROM_{Imp}) for the internal and external rotation movement in combination with 90° flexion and 0° adduction comparing the PE and ceramic inserts of implant system I. The inserts articulated with 28 mm spherical femoral heads under dry and lubricant test conditions. Implant position: cup inclination of 45° with anteversion (AV) of 15° and cup inclination of 60° with anteversion of 0°, stem antetorsion (AT) always 0°. The columns show the impingement-free interval in the rotation movements for the femoral stem (up to $\pm 90°$). The dashed lines show the physiological range of motion for above-mentioned movements.

couples clear discrepancies could be observed in the ROM_{Lux} under lubricated conditions in contrast to dry conditions $(p < 0.001)$ (Table II). It is remarkable that under wet environmental conditions the dislocation of the head out of the ceramic insert occurred clearly earlier than with the PE insert contrary to dry conditions (Table II). For example, under dry conditions dislocation of the ceramic head was observed after an internal rotation movement of 52°, compared to 13° when the articulating surfaces were lubricated. (Table II).

In addition, under lubricated conditions and with a steep positioned acetabular cup (60° inclination) the femoral head dislocated out of the ceramic insert of system I in the movement ''internal rotation after 90° flexion and 0° adduction'' about 6° later than using the ceramic insert of implant system II.

Discussion

Recurrent dislocation following THR is a serious postoperative complication, which makes revision surgery necessary in about one third of these cases [16]. Important risk factors are an inadequate implant design and a poor implant position [17]. Increased dislocation rates have been clinically observed for high inclination angles [11]. In addition, the wear rate of PE cups increased with higher inclination angles [18], whereas the lower wear rate of ceramic-on-ceramic couples was not affected by increased cup inclination [19]. Furthermore, an increase of the cup anteversion was described as being more beneficial for the hip stability [10]. The stability of THR against dislocation is affected by implant design variables like the head-to-neck ratio and the cup/insert geometry [20]. Especially using smaller femoral head sizes, there is a risk that the head might slide over the rim of the cup [13]. Moreover, poor tissue tension including weak hip muscles favours dislocation [10].

Furthermore, leg movements which exceed the guaranteed ROM of THR can lead to the leverage of the femoral head out of the cup consequent to the contact between the femoral neck and the rim of the cup (so-called prosthetic impingement) [6]. 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, 21, 22]. This is encouraged by the lower damage tolerance of ceramic materials in comparison to PE [6].

To our knowledge no experimental studies have been presented so far, in which the stability against dislocation of artificial hip joints in dependence on the implanted wear bearing couples was specifically determined. In clinical studies, no increased dislocation rate for hard-hard wear couples has been described up to now. An exception to this is the recently presented study by Toni *et al.* [23] about the survival rate of various total hip arthroplasty systems with ceramic-on-ceramic and metal-on-polyethylene respectively. In a follow-up of seven years a significantly lower total revision rate was observed for ceramic-on-ceramic wear couples compared to metal-on-polyethylene. However, the revision rate for ceramic cups due to dislocation was slightly higher (0.51 *vs.* 0.14%) [23], but possible reasons for these observations were not given. In our experimental study, the question was whether the used wear bearing couple has an influence on the ROM 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 ROM until impingement (ROM_{Imp}) and until dislocation (ROM_{Lux}) as well as the maximum subluxation moment. This applies to all wear bearing couples used. In order to achieve a sufficient ROM of the THR flat position (e.g. inclination angle of 30°) and retroversion of the cup respectively as well as stem retrotorsion must be avoided in any case.

In particular, pronounced cup anteversion leads to higher subluxation (resisting) moments and increased ROM until dislocation, that is an enhanced stability against the posterior dislocation. In contrast, excessive anteversion of more than 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 [15].

Concerning the wear bearing couples metal-on-polyethylene and ceramic-on-ceramic of system I the discrepancies in ROM_{Imp} mainly are related to differences in design between the PE insert and the ceramic insert. 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 ceramic insert an increased ROM_{Imp} was observed in all tested movements and implant positions, whereas the subluxation moment was lower. The point of actual joint dislocation in unstable joint positions (60° cup inclination) therefore occurs earlier than with the PE insert. Due to the above-mentioned design features of the insert the femoral head can slide over the inner rim of the insert and can dislocate at an early stage.

However, with an adequate anteversion (15° up to 20°) combined with an appropriate inclination angle of the cup (45° inclination) [13] a similar ROM until dislocation (ROM_{Lux}) is recorded using the ceramic-on-ceramic couple compared to metal-on-polyethylene.

In order to completely rule out the effects of differences in implant design on the assessment of stability against dislocation regarding differing wear bearing couples, tests were performed using hip implant components with similar design (system II). In these additional tests a PE and an aluminium-oxide ceramic insert with similar internal and external geometry were used.

In this case no substantial differences of the ROM until impingement (ROM_{Imp}) are observed between the couples metal-on-polyethylene and ceramic-on-ceramic. Using the ceramic-insert (Biolox® forte) the ROM_{Imp} 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 show no significant differences between the metal-on-polyethylene and the ceramic-on-ceramic wear bearing couples. Under dry conditions a slightly increased ROM until dislocation (ROM_{Lux}) is recorded using the ceramic insert. In a stable implant position (i.e. 45° inclination and 15° anteversion of the cup) the earlier dislocation and shorter subluxation period respectively 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. However, under lubricant conditions both tested ceramic-on-ceramic couples provide less ROM_{Lux} in a steeper cup position or retroversion in comparison to the metal-on-polyethylene couples. Concerning the two different implant systems the discrepancies in the ROM_{Imp} between system I and II are design-related, that is different insert and neck designs. In favourable cup position the implant system II has advantages regarding the ROM until impingement and dislocation. In a steep position or with an inadequate anteversion of the cup, however, no reduced ROM until dislocation occurs using system I, in spite of an earlier appearance of prosthetic impingement.

It must be emphasised that in our experimental test model the anterior and posterior dislocation can only be initiated by applying uniform rotational movements under constant joint loading. In the patient, however, changing forces and moments, which depend on a complex interaction of muscle forces, soft tissue tension and inertial body segment loading, affect the artificial hip joint [20]. Total hip dislocation is clinically based on dynamic processes, which could not be incorporated in laboratory models so far [20]. In our current test model the soft tissue tension, which significantly affects the stability against dislocation of THR [24], is only indirectly considered by application of the resulting hip joint forces. Further limitations of our study are the non-consideration of possible effects caused by capsule structures, absence of appropriate tissue surrogates [20] and peri-articular bone prominences leading to bony contact of the endoprosthesis [8] or bone-to-bone impingement [8, 10].

Due to the effect of minimizing aseptic implant loosening caused by wear particles, hard-hard bearing couples can offer prolonged implant durability, particularly in young or active patients [1, 5]. Inadequate implant position can result in restricted ROM and instability of THR [6]. With implantation of ceramic components specific risks have to be considered such as intra-operative handling, implant orientation and post-operative patient behaviour [6, 22, 25].

In the presented study the maximum resisting moment and the ROM until impingement and dislocation were mostly influenced by the implant position. In addition, the stability of THR against dislocation was clearly affected by design parameters of the insert like chamfer angle and inset of the head centre, whereas the use of different wear couples, that is metal-on-polyethylene *vs.* ceramic-on-ceramic, had less impact in the case of adequate implant position. As shown by the tests under lubricant conditions, however, the ceramic-on-ceramic couple provides less dislocation stability in an unfavourable implant position, for example steep position and retroversion of the cup, in comparison to the metal-on-polyethylene wear couple. Due to less failure tolerance compared to PE, ceramic-on-ceramic wear couples should only be applied in the case of an optimised implant position in order to prevent impingement and dislocation with subsequent material failure like enhanced wear, chipping off or brittle fracture.

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Notes

1. ESKA Implants GmbH, Lübeck, Germany.
2. UHMW-PE: Ultra High Molecular Weight Polyethylene.
3. CeramTec AG, Plochingen, Germany.
4. Aesculap AG, Tuttlingen, Germany.
5. Vantico, Quillan, France.
6. Biochrom KG, Berlin, Germany.
7. HEM Data Corporation, Southfield, MI.

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