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REVIEW ARTICLE

Intra-prosthetic dislocation of dual-mobility cups after total hip arthroplasty: potential causes from a clinical and biomechanical perspective

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Abstract
Introduction Recurrent dislocation of total hip arthroplasty is a frequent indication for revision surgery. Hip joint stability depends on implant design, cup position and crucially on femoral head diameter. Due to an effective ultra-large diameter femoral head, dual-mobility cups are considered an attractive solution to prevent dislocation in unstable conditions. Although patients obviously benefit for many years in terms of mobility and pain, an increase of intra-prosthetic dislocation reports using dual-mobility cups has been recently observed. However, the failure mechanism of this implant-specific complication, which is characterized by the loss of the positive-locking between the femoral head and the mobile liner, is not yet completely understood.
Methods A comprehensive search was performed with the PubMed database and a search engine to overview this topic and to identify potential causes for this implant-specific failure from a clinical and biomechanical perspective.
Results Peri-operative findings indicate extensive fibrosis at the large articulation as well as cup loosening as potential causes. In addition, current research has shown that the failure mechanism is affected by the surface topography of the femoral neck and in particular by the design of the mobile liner.
Discussion In clinical practice it is necessary to differentiate a classic dislocation between the mobile liner and the metallic shell from an intra-prosthetic dislocation between the femoral head and the liner.
Conclusion Due to the increasing popularity of dual-mobility cups in total hip arthroplasty, the understanding of which implant-specific features or tissue response may increase the risk of intra-prosthetic dislocation is of major importance for reduced revision rates by using optimized surgical techniques and implant designs.

Keywords Total hip arthroplasty · Wear · Dual mobility socket · Implant failure · Bousquet system · IPD

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Introduction

As a result of continuous progress in implant materials and surgical techniques, total hip arthroplasty has become a successful and established orthopaedic procedure. At present, almost 6 % of primary total hip arthroplasties fail within the first ten years post-operatively [1]. The most common reason for revision is aseptic loosening [1, 2], often resulting from osteolysis and inflammation of the surrounding tissue caused by wear debris [3]. Another indication for revision surgery is hip instability [1, 2, 4], where the femoral head is forced from its regular position due to an insufficient range of motion [5, 6] as well as due to surgical or patient factors [4]. The incidence for this serious and often painful complication is actually in the range of 3 % for primary [7] and 8 % after revision surgery [7, 8].

In the past, different constructive efforts were made in order to increase total hip stability. These included mainly larger femoral head sizes [9], a suitable ratio between head size and femoral neck diameter [10, 11] as well as the use of partly elevated acetabular liners [11].

As another treatment alternative for recurrent total hip dislocation, dual-mobility cups have been proposed. These systems use a mobile intermediate polyethylene liner in addition to a standard retentive femoral head. This creates a femoral head with an increased diameter and two main articulation surfaces: first, between the conventional femoral head and mobile liner and, second, between the outer side of the mobile liner and a metallic acetabular cup which is fixated in the acetabular bone (tripolar design). Another less regarded articulation surface is described between the mobile liner at the level of the retentive rim and the femoral neck.

The advantage of this implant configuration is that, first, most of the hip motions in daily life take place at the inner smaller bearing, producing lower friction torques and thus less wear and, second, only for larger ranges of motion, the outer bearing surface has to be used. Consequently, dual-mobility implant systems combine a small low friction bearing with an effective large femoral head diameter [12]. Currently, there are different dual-mobility designs available on the market, which principally differ from each other in terms of arrangement of the mobile liner with respect to the femoral head. Here, a distinction can be made between concentric and eccentric designs [13–15], whereby the concentric design represents the most common design used clinically. With concentric designs, the centre of rotation of the mobile liner coincides with the centre of the femoral head. In contrast, in eccentric mobile liners, there is a defined distance between both centres of rotation. This arrangement causes a torque under loading which may lead to a re-alignment of the mobile liner in the direction of the applied joint force [13, 16].

In clinical practice, the growing use of dual mobility cups has revealed promising results in primary as well as in revision total hip arthroplasty [4, 17–20]. Dislocation rates could be notably reduced in combination with dual-mobility systems at the ten-year follow-up [19–22]. However, in recent years, the number of studies concerning a dual-mobility specific complication called intra-prosthetic dislocation have increased [23–27]. This kind of failure can be described as the femoral head coming out of the mobile liner and then lodging itself in the metallic acetabular cup. Its incidence has been reported with rates from 0 % [20–22] up to 5.3 % [12, 17, 19, 25–31]. In order to reduce the revision rates of dual-mobility systems, potential causes of this implant-specific complication need to be analysed and understood.

The present paper reports the most important clinical and biomechanical findings with respect to intra-prosthetic dislocation. Furthermore, we present several implant-specific characteristics which are deemed to decrease the risk of intra-prosthetic dislocation of dual-mobility cups. Finally, proposals concerning the surgical treatment in terms of this specific complication are discussed.

Search strategy

A comprehensive search was performed with the PubMed database and a search engine to identify relevant scientific articles. The following keywords were used for the search: 'intra-prosthetic dislocation', 'intra prosthetic dislocation', 'retentive failure', 'dual-mobility failure', 'dual mobility cups', 'dual mobility socket' and 'tripolar'. Any article that reported in vitro, in vivo or ex vivo findings or addressed the topic of intra-prosthetic dislocation was analysed. Studies were excluded if they met constrained dual-mobility systems. In addition, all data were summarized and differentiated into clinical and experimental or biomechanical findings.

Clinical findings

There are no conclusions from the present literature of whether this kind of implant failure is an early or late complication. In a clinical study of Vielpeau et al. [19], intra-prosthetic dislocations occurred between eight and 16 years after surgery. Much shorter failure rates were reported by Massin et al. [29] with 32 months as well as by Odland et al. [23] with a dislocated femoral head 24 months post-operatively.

The clinical expression of intra-prosthetic dislocation is often very poor and misleading. Patients often complain of a slight and progressive discomfort in the groin [28]. Others have reported a sharp pain near the hip joint [32]. In a case report by Odland et al. [23] the patient noticed a shortening of the extremity and weakness in the leg during weight bearing. As the clinical expression of intra-prosthetic dislocation seems to be highly variable, the patients should be advised to contact their surgeon if they feel something unusual or changes relating to their hip replacement.

Another indication provides a plain anterior-posterior and lateral radiograph of the patient for further clarification. Here, the surgeon has to differentiate between a classic dislocation where the dual-mobility cup dislocated from the metallic acetabular shell and an intra-prosthetic dislocation where the femoral head levered out of the mobile liner mainly due to wear. In the latter case, the implant-specific failure can mostly be recognized by a characteristic eccentricity of the neck of the femoral component (Fig. 1) [17, 23, 24, 26, 28, 33].

In case of a classic dislocation of the dual-mobility cup, a careful analysis of the radiograph may reveal a circular radiolucent area superior to the acetabular component ("bubble sign"), which represents the dislocated polyethylene liner [34].

At revision, peri-operative findings showed three types of intraprosthetic dislocation, which can be differentiated according to Philippot et al. [25]. Type 1 is characterized by the absence of arthrofibrosis and acetabular cup loosening. At this type no appreciable signs occurred that the bearing had ceased

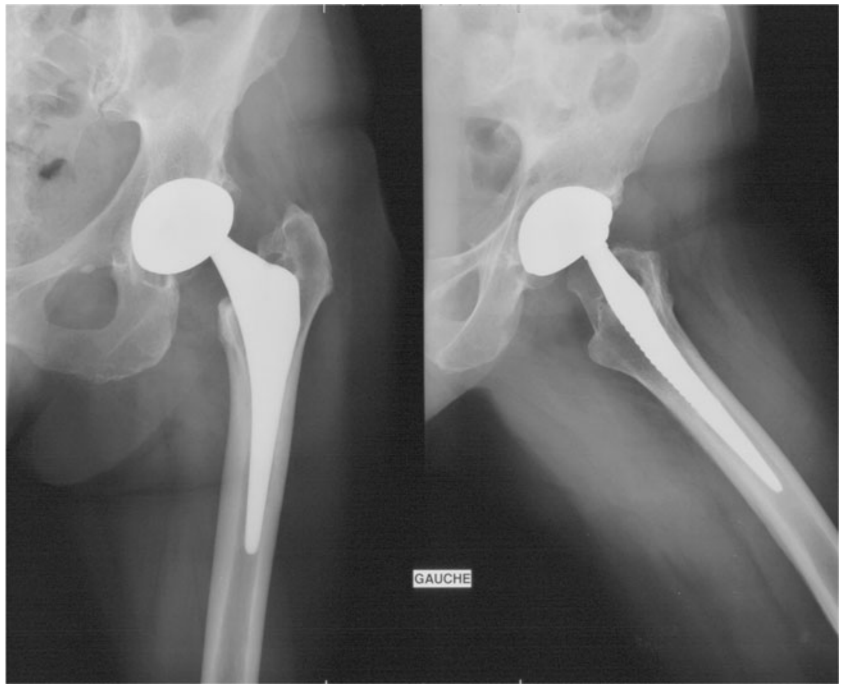

Fig. 1 Anterior-posterior and lateral radiograph shows a characteristic eccentric position of the femoral head on the left side, indicating an intra-prosthetic dislocation of a dual-mobility cup system

its moving [23]. Type 2 is defined by a blockage of the outer articulation as a result of an extrinsic process [25, 28]. Several reasons for the blockage of the outer articulating surface have been discussed in the literature. These include periprosthetic ossifications [27] and major intra-articular fibrosis [25, 27], impingement as a result of trochanteric nonunion [23], lack of forces at the joint capsule [14], as well as insufficient clearances between the liner and the metal back [25]. The last type of peri-operative findings, Type 3, is associated with metal back loosening due to high friction torques or insufficient osseointegration [25].

However, almost all clinical studies addressing the topic of intra-prosthetic dislocation reported on gross wear and plastic deformation of the retentive rim when analysing the retrievals [17, 18, 23, 26, 32, 33]. This often symmetrically arranged kind of wear pattern is located in the capture area of the femoral stem and indicates a frequented impingement between the neck and the retentive rim [23, 28]. Another wear pattern seen on retrievals is an asymmetric degradation of the retentive rim due to liner tipping under gravity or varus tilting, respectively [35]. Furthermore, in some cases, dislocated polyethylene liners showed eccentric wear at the inner sliding surface [22, 23]. These various intra-operative findings clearly indicate that more than one mechanism can lead to intra-prosthetic dislocation.

Biomechanical findings

The analyses of the wear patterns at the retrievals indicate different mechanisms of damage. In order to understand these mechanisms, Fabry et al. performed motion analyses with concentric and eccentric dual-mobility systems as part of an experimental study [36]. For this purpose, an industrial robot was used, which simulated different activities of daily living in consideration of realistic hip joint motion and load. Additionally, the dynamic motion analysis was supplemented with commonly used bovine serum in order to take the influence of lubrication into account.

The evaluation of analysis showed that the spatial position of a concentrically arranged intermediate component (Fig. 2a) is independent of the direction of the applied resulting force. Moreover, its position was influenced by its own weight, the lubrication conditions, as well as the movements of the femoral stem. Already after a short period of physiological loading, the intermediate component tended to tilt in a characteristic varus position (Fig. 2b) [36]. As long as the range of motion of the inner bearing was sufficient, the component remained at this position; otherwise, the mobile component followed the motion of the femoral stem. However, in the long term the component tilted back into the varus position due to its design features.

If there is no radiographic marker in the rim of the concentric mobile liner made of polyethylene, the critical varus position cannot be determined in situ by X-ray techniques. This specific kinematic behaviour causes a highly-frequented impingement situation between the intermediate component and the femoral neck during the activities of daily living. Thus, the permanent varus position and the recurrent prosthetic impingement may lead to uneven wear at the inner sliding surface and at the inferior side of the retentive rim of the mobile liner (Fig. 2c).

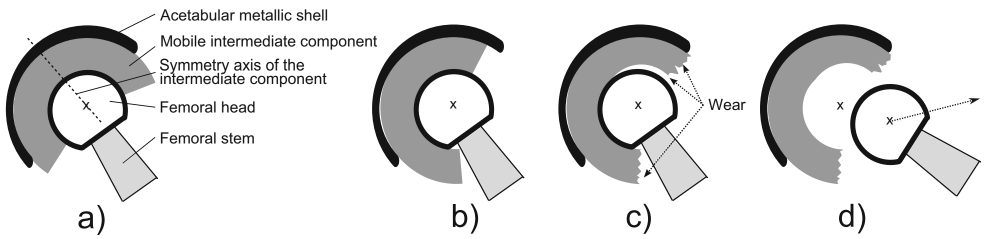

Fig. 2 Schematic sequence of intra-prosthetic dislocation. **a** Implantation situation. **b** Resulting post-operative tilting of the intermediate component in varus position. **c** Irregular polyethylene wear at the rim and at the internal contour of the intermediate component. **d** Loss of the positive locking between the intermediate component and the femoral head leading to intra-prosthetic dislocation

As a consequence of the polyethylene wear at the rim and at the internal contour, we hypothesize that the positive locking between the intermediate component and the femoral head can no longer be achieved (Fig. 2d). Over time, the femoral head would be levered out of the mobile liner and a direct undesired articulation occurs between the acetabular shell and the head-neck complex. This situation can lead to major metallosis, with severe periprosthetic bone and soft tissues damage, and therefore requires prompt surgical revision.

In contrast, eccentric mobile liners showed a self-centred anti-varus behaviour under physiological in vitro loading with moderate valgus-positions independent from the activity [36].

In conclusion, the experimental results confirm the clinical findings seen at retrievals [22, 35], which indicate that concentric dual-mobility cups are more prone to intra-prosthetic dislocation.

Recommendations for implant design

Several implant-specific characteristics are attributed to an increased risk of intra-prosthetic dislocation. First, from a biomechanical point of view, it would be advisable to use an eccentric design of the mobile liner, which might realign itself into an anti-varus position under different in vivo conditions [15, 36]. Thus, the motion of the mobile liner remains active and the risk of major intra-articular fibrosis as well as irregular wear at the retentive rim decreased. Furthermore, the number of recurrent prosthetic impingement can be also reduced.

Second, in order to minimize the wear at the rim of the mobile liner, attention should be paid concerning a suitable design and surface topography at the impingement area of the femoral stem. Femoral necks with an aggressive unpolished surface and large diameters should be avoided [23]. In addition, if a long-neck option is required, care should be taken to ensure that the base of the Morse taper is fully covered by the femoral head, otherwise the risk of rim fatigue would be increased [26]. The use of non-skirted femoral heads enlarges the range of motion of the inner bearing and thus reduces the probability of a recurrent impingement between the intermediate component and the femoral neck [23]. Furthermore, it is important to know the geometry of the dual-mobility cup with regard to the femoral head diameter and the diameter of the retentive rim to assess the risk for intra-prosthetic dislocation.

In terms of wear reduction, reduced polyethylene wear has clearly been demonstrated with highly cross-linked polyethylene (HX-PE). However, first generation annealed HX-PE oxidizes, whereas melted HX-PE has reduced mechanical properties, especially in terms of fatigue and lack of elasticity. Knowing that dual mobility works mainly in fatigue situations when the large articulation is moving due to femoral neck contact with the insert, we believe that both first generations of annealed and re-melted HX-PE should be avoided in dual mobility sockets. Second generation HX-PE, which have been demonstrated in vitro to be wear-resistant with preserved mechanical properties, seem to be more appropriate in dual mobility cups. However, to the best of the author's knowledge, no clinical results have been reported so far.

Surgical treatment

When recognizing intra-prosthetic dislocation, which is a dislocation between the femoral head and the mobile liner, an urgent treatment is required. The attempt with a closed reduction is rarely successful. Indeed, forcing the femoral head inside the polyethylene liner can usually be achieved if the positive-locking fit is damaged. However, this will be highly unstable and results in a recurrent intra-prosthetic dislocation. The best treatment option is surgical. If revision is performed within a few days of intra-prosthetic dislocation, femoral head and polyethylene liner revision is sufficient if the bearing surface of the acetabular metallic cup is free of macroscopic scratches. In terms of longer periods with intra-prosthetic dislocation, major scratches will be visible at the articulation surface of the shell which may be associated with intra-articular metallosis. In those cases, the metal shell should also be revised in addition to the femoral head and the polyethylene liner. Furthermore, a complete synovectomy should be performed. When recognizing a classic dislocation between the mobile liner and the metallic shell a closed reduction can be successful. However, care should be taken as the outer bearing surface of the mobile liner can be damaged during reduction resulting from friction against the edge of the metallic shell. Furthermore, an objective analysis of the current state of wear at the retentive rim is difficult.

Conclusion

Due to the gaining popularity of dual-mobility cups in recent years the number of studies depicting dual-mobility specific complications have also increased. However, it should be noted that the complication of intra-prosthetic dislocation is more associated with the older design of dual-mobility cups (first generation). At present, the incidence of this specific complication tends to decrease using new generations of dual-mobility cups associated with very few or no intra-prosthetic dislocations occurring at ten-years follow up [20, 21].

Peri-operative findings indicate extensive fibrosis at the large articulation as well as cup loosening as potential causes for the intra-prosthetic dislocation. In addition, the failure mechanism is affected by the surface topography of the femoral neck and in particular by the design of the dual-mobility system. Due to the gaining popularity of dual-mobility cups in total hip arthroplasty, the understanding of implant-specific features and risk factors for intraprosthetic dislocation is of major importance for reduced revision rates by using optimised surgical techniques and implant designs.

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