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ORIGINAL PAPER

Intraprosthetic dislocation of dual mobility total hip arthroplasty: still occurring?

Thomas Neri [1,2] · Bertrand Boyer [1,3] · Jean Geringer [3] · Alexandre Di Iorio [1] · Jacques H. Caton [4] · Remi Philippot [1,2] · Frederic Farizon [1,2]

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Abstract

Purpose The objective was to identify predictive factors for intraprosthetic dislocation (IPD) and to understand how improvements in dual mobility cups (DMC) have helped to reduce dramatically the occurrence of this complication.

Methods DM mobile inserts retrieved from 93 hips were divided into three groups: first-generation DMC with IPD ("firstDMC-IPD"), first-generation DMC with over 15 years of implantation without IPD ("firstDMC-noIPD"), and latest-generation DMC ("newDMC"). The predictive factors for IPD based on clinical, prosthetic, radiological and intraoperative characteristics were analysed by multivariate analysis. The surface of each retrieved mobile insert was analysed using three-dimensional CT scan in order to compare their rim wear.

Results Three predictive factors for IPD were found: a high BMI, a wide rough stem neck and a large cup size. Wear of the firstDMC-noIPD inserts was significantly less than those of firstDMC-IPD inserts and significantly more than those of newDMC inserts. For the firstDMC-IPD inserts, the rim's outer surface wear was significantly greater than the rim's inner surface wear.

Conclusions IPD is a specific complication related to wear of the DM mobile insert due to failure of the liner's retaining rim, especially from the rim's outer surface. This long-term issue is different to the early traumatic complication, which can happen after an attempt at closed reduction of a DM THA dislocation. Recent modifications in the design and the coating of contemporary DMC and femoral stems, as well as improvements in the mobile insert itself, seem to corroborate our assumptions about the IPD mechanism and contribute to the quasi-disappearance of this complication.

Keywords Intraprosthetic dislocation · Dual mobility · Total hip arthroplasty

Introduction

The dual mobility (DM) concept was developed in the 1970s by Gilles Bousquet to decrease the postoperative dislocation rate and preserve the patient's original range of motion while also limiting the stresses on the mobile insert leading to wear [1, 2]. In order to fulfil these objectives, Bousquet combined the advantages of two biomechanical concepts: Charnley's low friction arthroplasty principle [3] and the McKee–Farrar principle [4]. The aim of the small articulation between the femoral head and mobile insert is to prevent multidirectional wear [3]. For the large articulation between the mobile insert and cup, the goal is to use the largest head possible to increase the range of motion and reduce the dislocation risk by increasing the jump distance [4].

One drawback of first-generation DM cups (DMC) (the original Bousquet DMC) was intraprosthetic dislocation (IPD), a rare but specific complication due to the retentive failure of the mobile insert that was first described by Lecuire et al. in 2004 [5, 6]. This complication occurs when the rim of the mobile insert that holds the femoral prosthetic head in the insert is worn, which leads the head to separate from the mobile insert. This is a long-term wear complication, not a traumatic dislocation [6, 7]. When this complication occurs, revision surgery is needed to change the mobile insert, at a minimum; the cup may need to be changed also if it was damaged by contact with the head [6].

✉ Thomas Neri
thomas.neri@chu-st-etienne.fr

1 Department of Orthopaedic Surgery, University Hospital Centre of Saint-Etienne, Saint-Etienne, France

2 EA 7424 - Inter-university Laboratory of Human Movement Science, University Lyon - University Jean Monnet, Saint Etienne, France

3 Ecole des mines de Saint-Etienne, Saint-Etienne, France

4 Institut orthopédique, 103 rue Coste, 69300 Caluire, France

Nevertheless, IPD is a rare event. With the first-generation DMC implanted from 1985 to 1990, the long-term incidence was reported to be 2 to 4% [8, 9]. In 2009, a multicentre study from Massin et al. reported a lower incidence of IPD (0.3% at 10 years' follow-up) [10]. The latest study with contemporary DMC (implanted after 2000) reported no IPD at all [4, 11–15]. However, the relationship between the decrease in the IPD rate and various mobile insert modifications remains unclear, partly due to a lack of clinical and biomechanical data. Several authors have defined the causes of IPD, such as peri-acetabular fibrosis and aseptic loosening of the acetabular cup [5, 16, 17]. However, these studies were purely descriptive or were literature reviews. Other than Fabry et al. [18], no study has attempted to identify predictors of IPD or has modelled how the evolution of implants has contributed to a near disappearance of IPD.

The objective of this study was twofold: to determine predictive factors for IPD and to understand how improvements in DM implants have helped to reduce the occurrence of IPD. Through an implant retrieval study, we hypothesised that identifying the parameters responsible for this complication in first generation of mobile inserts and analysing the modifications made in contemporary mobile inserts would help us understand why the IPD rate has decreased.

Material and methods

Population

To identify predictive factors for IPD, we needed to compare two groups who received first-generation DMC, one with IPD and one without IPD. A third group with contemporary DM implants was required to understand why the IPD risk has decreased. The study flowchart is shown in Fig. 1.

The first group ("firstDMC-IPD") was composed of first-generation mobile inserts (1995 to 1998) with IPD. The second group ("firstDMC-noIPD") consisted of first-generation mobile inserts without IPD (1995 to 1998), with an implantation time of at least 15 years [19]. In this control group, the function of the mobile insert was considered optimal or at least as optimal as a removed implant could be, having lasted a relatively long period of time without being revised. The third group ("newDMC") included only latest generation mobile inserts, i.e. implants between 2001 and 2008 ($n = 25$).

The inclusion criteria were (1) an implantation period between 1985 and 1998 for the first generation of mobile inserts and between 2002 and 2005 for the contemporary generation of mobile inserts, (2) patients receiving the same type of implants during the same implantation period and (3) mobile inserts explanted from a primary THA. Indications for the primary THA procedure were primary hip osteoarthritis (OA), post-traumatic OA, avascular necrosis of the femoral head and congenital hip dislocation. All the demographics data and reasons for the mobile insert removal are reported in Table 1.

The exclusion criteria were (1) revision surgery, (2) incomplete clinical and radiological data, (3) patient lost to follow-up, (4) unknown explantation reason, (5) mobile inserts associated with different femoral and acetabular implants than those described in the next section, (6) an implantation time under 15 years for the first-generation DMC with no IPD and (7) implantation between 1998 and 2001. We did not include mobile inserts implanted between 1998 and 2001 because the mobile insert had been modified during this period, i.e. changes were made to polyethylene characteristics, the sterilisation process and the retaining rim design.

Consequently, among 1960 primary total hip arthroplasty (THA), procedures performed with a DMC in our department, 450 mobile inserts were explanted and 93 were selected and divided into the three groups described above: firstDMC-IPD ($n = 40$), firstDMC-noIPD ($n = 28$) and newDMC ($n = 25$).

Materials

The patient records were consulted to determine the characteristics of the implants used during the initial THA procedure: size and type of dual mobility cup, prosthetic neck and femoral stem.

For both first-generation groups, the implants were the same. All the cups were cementless Bousquet-type DMC (NOVAE®, SERF, Décines, France). These cups consisted of a metal-back shell coated on the outside with porous alumina (Al_2O_3). Two different types of cup materials were used: The metal-back shell was either made of stainless steel (316 L) or anodized titanium. Fixation was ensured by press-fit and a tripod system of two impacted anchoring pegs and one superior fixation screw through a flange. Two types of femoral stems were used (SERF, Décines, France). These were conical threaded stems with an alumina coating, differing in material and neck diameter. The PF® was a modular femoral stem, with modularity between the threaded intramedullary stem and the one-piece head–neck piece. The entire implant made of stainless steel (316 L) with a 16-mm neck diameter and 22-mm head. The PROFIL® was a dual modular stem with modularity both between the threaded stem and neck and between the neck and head; the entire implant was made of titanium with a 13-mm diameter neck. Its modular femoral head was secured through a Morse taper. The femoral heads were made of stainless steel (316 L) or cobalt-chrome and were 22.2, 26, or 28 mm in diameter. The polyethylene mobile insert was five-eighths of a sphere and featured a narrowed opening in which the head was secured using a bearing press. The mobile inserts were manufactured from ultra high molecular weight polyethylene (UHMWPE), had a molar weight of 4.5 g/mol and were sterilised in air.

For the newDMC group, the acetabular component was a "second-generation" cementless DMC. This was a 316-L stainless steel acetabular cup with a double coating of alumina and

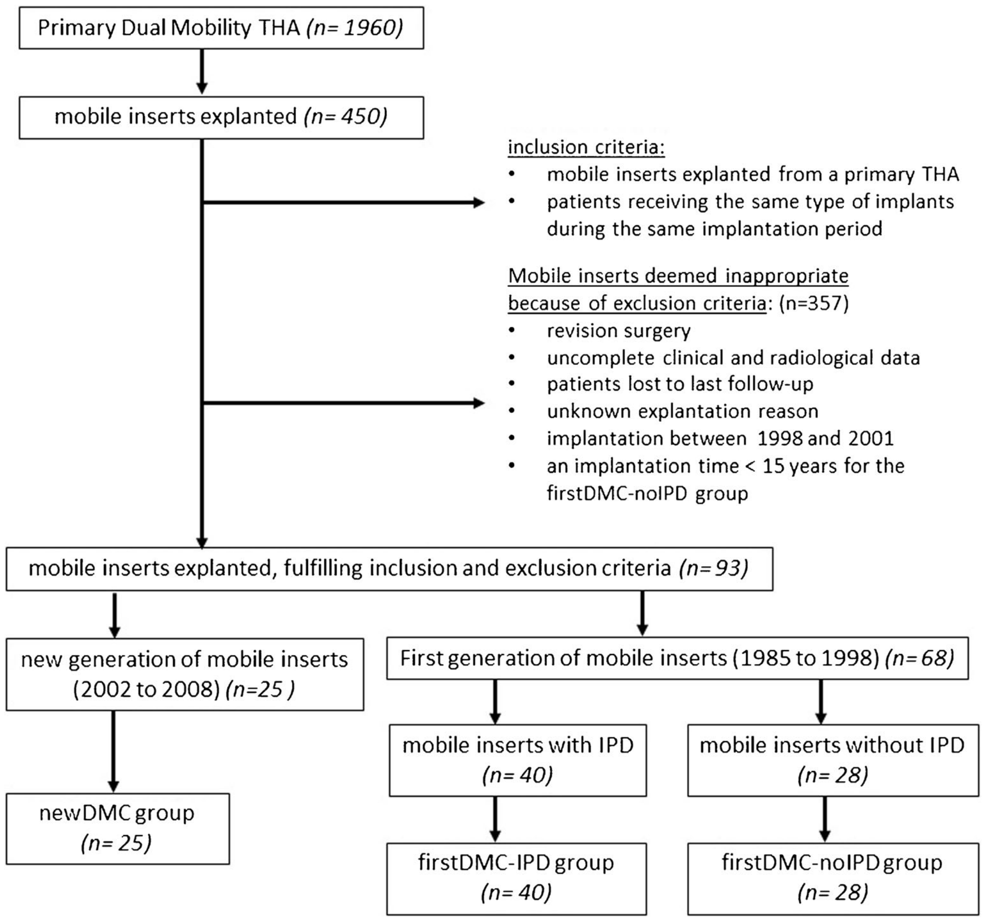

Fig. 1 Study flowchart. THA total hip arthroplasty, IPD intraprosthetic dislocation

hydroxyapatite. Fixation was either press fit only (Sunfit™, Serf, Décines, France) or press fit associated with tripod fixation (Novae-E™, Serf, Décines, France). A cementless Corail® femoral stem (DePuy Synthes, Warsaw, IN, USA) was used in all cases. This was a straight, cementless stem made of forged titanium alloy (Ti6Al4V) with a 13-mm diameter, trapezoid cylindrical neck. The prosthetic head was made of stainless steel (316 L) or cobalt-chrome with a diameter of 22.2 or 28 mm. The mobile insert was made of UHMWPE with a molar weight around 7.3 g/mol and was vacuum-sterilised. This new mobile insert had a larger retaining rim (about 45% more material) than the first-generation insert, and its design was improved to prevent mobile insert blocking and to better distribute the impaction and extraction forces.

Table 1 Demographic data and reasons of mobile insert removal

	Reasons for mobile insert removal						Mean age at surgery	Mean Devane score	Mean BMI	Mean duration of implantation
	IPD	IPD + AL	AL	Wear without IPD	Infection	Peri-prosthetic fracture				
firstDMC-IPD (n = 40)	32	8	0	0	0	0	50 ± 14 [13–74]	2.9 ± 1 [1–5]	24.4 ± 5 [16–33]	10 ± 4 [1–25]
firstDMC-noIPD (*n* = 28)	0	0	17	7	2	2	45 ± 15 [14–71]	2.6 ± 1 [1–4]	20.7 ± 4 [15–31]	18 ± 5 [15–35]
newDMC (*n* = 25)	0	0	6	0	9	10	72 ± 10 [53–87]	1.9 ± 1 [1–3]	22.2 ± 7 [14–45]	9 ± 3 [7–15]
Mean							54 ± 17 [13–88]	2.6 ± 1 [1–5]	22.4 ± 6 [14–45]	11 ± 7 [1–36]

"Wear without IPD" corresponds to patients with pain and audible snapping while walking who had the mobile insert only changed during surgery. "Infection" corresponds to late implant-related infection

IPD intraprosthetic dislocation, *AL* aseptic loosening

Data analysis

Pre-operatively, patient characteristics (gender, age), body mass index (BMI) and activity level (Devane activity score) were collected (Table 1). The preoperative X-rays were analysed. All THA in which the insert had more than 4-mm eccentric displacement of the head from the cup were considered an IPD. The diagnosis of IPD was confirmed by the intra-operative findings. The inclination of the acetabular cup was determined on anteroposterior radiographs [20]. We also sought to determine whether certain parameters, by inhibiting the function of the large articulation, could have caused the retaining rim wear. The presence of heterotopic ossifications was determined using Brooker classification system [21]. Evidence for stem and/or cup aseptic loosening or implant malposition was evaluated. Operative reports were systematically reviewed to evaluate the potential for third body wear (e.g. wear particles, metallosis) that may have contributed to aseptic loosening, along with factors that may have contributed to blocking of the large articulation (lack of motion between the mobile insert and the metal-back shell) such as fibrosis or presence of a cam effect.

Wear analysis

As previously described, a 3D surface scan of the mobile insert enabled us to quantify the wear of the retaining rim [19, 22]. This coordinate measuring machine is considered the gold standard to measure the wear [23, 24]. The mobile inserts were entirely mapped with a fully automatic stripe light scanner that uses green LED light (Fig. 2). After modelling the mobile inserts, the analysis focused on the area of interest—the retaining rim. The rim was divided in two areas: inner side (concavity, small articulation, head side) and outer side (femoral stem neck side) (Fig. 3). To determine the wear volumes of the explanted mobile inserts, the native mobile insert volumes for each corresponding size (same internal and external diameters) were quantified. The volume of the native mobile insert was calculated from 3D perfect theoretical models, based on the original industrial drawings of the mobile inserts provided by the manufacturer. Thus, by subtraction from the native mobile insert, we could determine inner, outer and total (inner + outer) rim wear for each explant, expressed in cubic millimetre.

Statistical analysis

The comparison between the first-generation groups was done to understand the IPD mechanism. Univariate and multivariate logistic regression analyses were used to determine factors that influence IPD occurrence. These included patient-related factors (age, sex, BMI, Devane score), implant-related factors (stem type, femoral head type, femoral head diameter, DMC type, DMC diameter), radiological factors (cup inclination, Brooker stage) and intra-operative findings (fibrosis). A univariate analysis was carried out first. Normality tests were performed before using parametric tests. The chi-square test was used to compare the variable of interest (with or without IPD) for qualitative parameters and Student's *t* test for quantitative parameters. All variables that had a significant relationship in the univariate analysis were then included in the multivariate analysis. A multiple binomial logistic regression analysis was performed to identify significant independent predictors of IPD that could be either continuous or categorical. The dependent variable was the occurrence of an IPD. Odds ratios (OR) and the corresponding 95% confidence intervals for each of these independent variables and their impact on IPD were determined.

The comparison between firstDMC-noIPD and newDMC groups was done to understand why the IPD incidence has decreased. To compare retaining rims between different groups, parametric Student's *t* tests were performed if the data followed a normal distribution. Otherwise, non-parametric Mann-Whitney tests were used. Statistical tests were carried out with SPSS Statistics software (version 21, SPSS Inc., Chicago, IL, USA). The significance threshold was set at < 0.05.

Results

IPD predictors

All the findings are presented in Table 2. For the patient-related factors, only BMI significantly affected the occurrence of an IPD ($P = 0.008$). Patients with a higher BMI had a higher rate of IPD. For the implant-related factors, the type of stem had a significant effect on the occurrence of an IPD ($P = 0.007$). The use of PROFIL® stems was correlated with a higher rate of IPD. The delay in IPD occurrence only was statistically different for the type of stem parameter ($P = 0.02$). The mean time before the IPD occurrence was 12 ± 5.3 years (range 5–25) for the PF® stems and 9.8 ± 3.9 years (range 1–16) for the PROFIL® stems. A larger DMC diameter was also a predictor of IPD ($P = 0.028$). The type of head had an effect; however, this parameter was not significant in the multivariate analysis as it was a confounding factor: all the PF® stems had a stainless-steel one-piece head and neck. Conversely, the type of cup (stainless steel or titanium) ($P = 0.117$) and the diameter of the femoral head had no significant effect on the risk of IPD ($P = 0.118$). For the preoperative radiographic factors, the cup's inclination ($P = 0.746$) and the Brooker stage ($P = 0.866$) did not affect the occurrence of an IPD. For the intra-operative factors, fibrosis was not predictive of the occurrence of an IPD ($P = 0.343$).

Rim wear analysis

When comparing both first-generation cup groups, total, outer and inner rim wear of the firstDMC-IPD group was

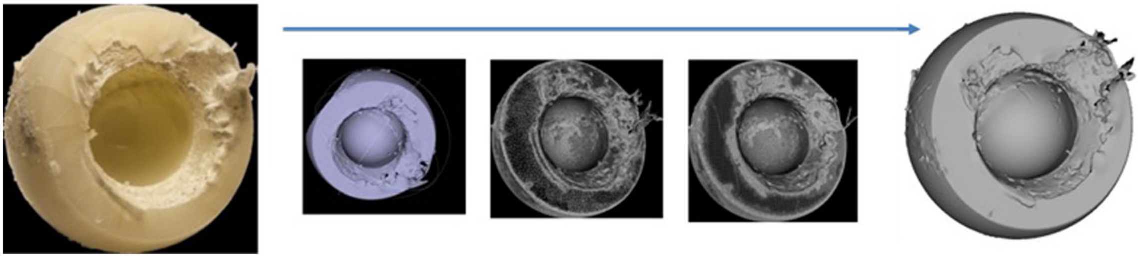

Fig. 2 Process of 3D mobile insert modelling: example of a mobile insert that was removed because of an IPD with asymmetric wear of the retaining rim

significantly higher than that of firstDMC-noIPD group ($P <$ 0.001, Fig. 4a). Total, outer and inner rim wear of the firstDMC-noIPD group was significantly greater than that of the newDMC group ($P < 0.001$, Fig. 4b). For the firstDMC-IPD group, the outer rim wear was significantly greater than the inner rim wear ($P < 0.001$, Fig. 4c). A predictive model of the probability of IPD in terms of total rim wear was created (Fig. 5). Three areas were defined: the first one between 0 and 15% of wear, in which the wear was not very discriminating; the second between 15 and 40% of wear was an area of critical transition and very discriminating; and the third, after 40% wear, in which the increase had less of an impact on the risk of developing IPD. In other words, the impact of rim wear became critical at 15% and not before. At 32% of total rim wear, this model predicted a 100% risk of an IPD.

Discussion

The most important finding of this implant retrieval study was that IPD is a wear complication from mainly the outer side of the retaining rim. Three predictors of IPD for DMC were identified: a high BMI, the type of stem and the size of the acetabular cup. Improvements in implant design and construction have reduced retaining rim wear and can explain why IPD has been nearly eliminated.

To understand why this complication no longer occurs, it was first necessary to identify its causes. We found that IPD is due to retaining rim wear and not to a traumatic phenomenon with hip dislocation. The traumatic mechanism is an early complication that occurs during the closed reduction of a DM THA dislocation. This rare phenomenon is nevertheless the most described in the literature [25, 26]. During closed reduction of a posterior THA dislocation, impingement between the posterior edge of the prosthetic cup and the DM mobile insert may happen, which could lead to blocking of the mobile insert. In this position, the mobile insert is subject to excessive mechanical loads induced by the external reduction manoeuvre. This overloading could lead to the femoral head separating from the mobile insert. To avoid this complication, we recommend always reducing a DM THA dislocation under general anaesthesia to ensure complete muscular relaxation and to carry out the reduction manoeuvre gradually, without excessive loads. Therefore, dislocation is an early traumatic complication, which is very different from the long-term wear complication described by Lecuire et al. [6].

As demonstrated by D'Appuzzo et al., although motion occurs at both articulations, the motion of the small articulation dominates with higher wear [27]. We demonstrated that an IPD can occur when the retaining rim is worn, with wear mainly due to contact between the femoral neck and the outside of the rim. This interface has been described as the "third articulation" by some authors [2].

Identification of stem type as an IPD risk factor confirms the importance of the neck characteristics when dealing with a DM system. The impact of the stem type can be explained by the differences in neck composition between the PF® and PROFIL® stems. PF® stems had a polished stainless-steel neck, while PROFIL® stems had a non-polished anodized titanium neck. While the diameter of the neck on the PROFIL® stem was smaller than that of the PF® stem, it does not appear to be small enough to counteract the roughness of its neck. Nevertheless, although we could not demonstrate it, it seems

Fig. 3 Section through a polyethylene mobile insert showing the retaining rim, divided into two parts: the inner side (the small articulation side) in green and the outer side (the femoral stem neck side) in blue

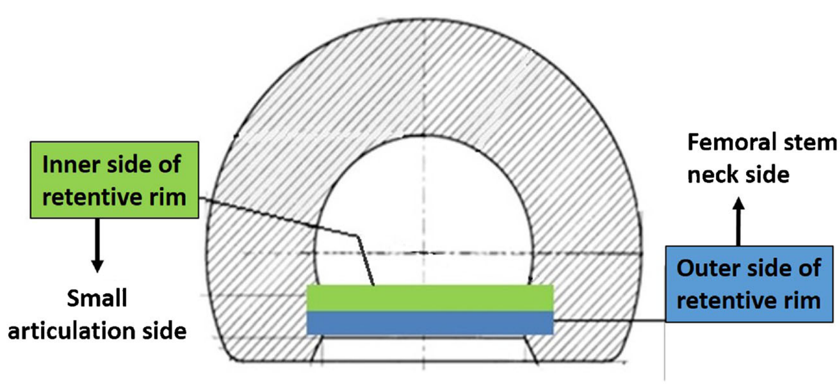

Table 2 Predictors of intraprosthetic dislocation established from the comparison between firstDMC-IPD and firstDMC-noIPD groups

		Univariate analysis		Multivariate analysis		
		P value		*P* value		OR (95% CI)
Patient-related factors	Age	0.262				
	Sex	0.492				
	BMI	0.01	*	0.008	*	0.831 (0.724–0.954)
	Devane score	0.174				
Implant-related factors	Stem type	< 0.001	*	0.007	*	0.040 (0.004–0.418)
	Head type	0.001	*	0.473		0.415 (0.038–4.589)
	Head diameter	0.118				
	Cup type	0.117				
	Cup diameter	< 0.001	*	0.028	*	0.808 (0.668–0.977)
Radiological factors	Cup inclination	0.746				
	Brooker stage	0.866				
Intra-operative factors	Fibrosis	0.343				

*$P < 0.05$

logical to think that large-diameter femoral necks will make earlier contact with the insert and will more quickly wear the outside of the rim.

For the BMI risk factor, the relationship between increased wear and increased BMI, probably due to excessive mechanical loading of the mobile insert, appears trivial and confirms the rim hypothesis [28, 29]. For the last IPD predictor, larger diameter acetabular cups were associated with a greater risk of IPD. The cup diameter is directly related to the mobile insert's outer diameter. At first glance, this may appear paradoxical, as the contact between the neck and mobile insert occurs later in large-diameter mobile inserts than in small-diameter mobile inserts. But, a larger contact area between the mobile insert and the cup also implies a bigger load to move this larger area. Since it is harder to get the large articulation moving, the small articulation is likely more solicited and the neck–mobile insert contact could occur more often and with a greater stress on the rim. The large articulation starts moving only once the neck and mobile insert have made contact, which may explain the continued outside wear in these large inserts. For smaller

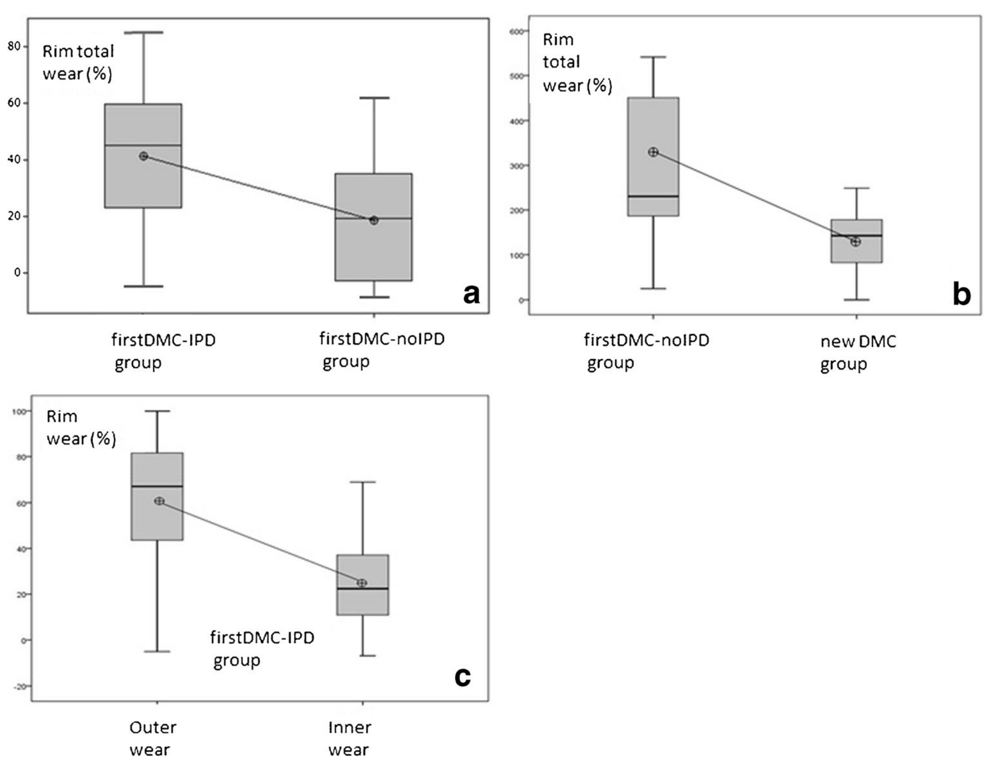

Fig. 4 **a** Comparison of rim total wear between firstDMC-IPD and firstDMC-noIPD groups. **b** Comparison of rim total wear between firstDMC-noIPD and newDMC groups. **c** Comparison of outer and inner rim wear for inserts with IPD (firstDMC-IPD group)

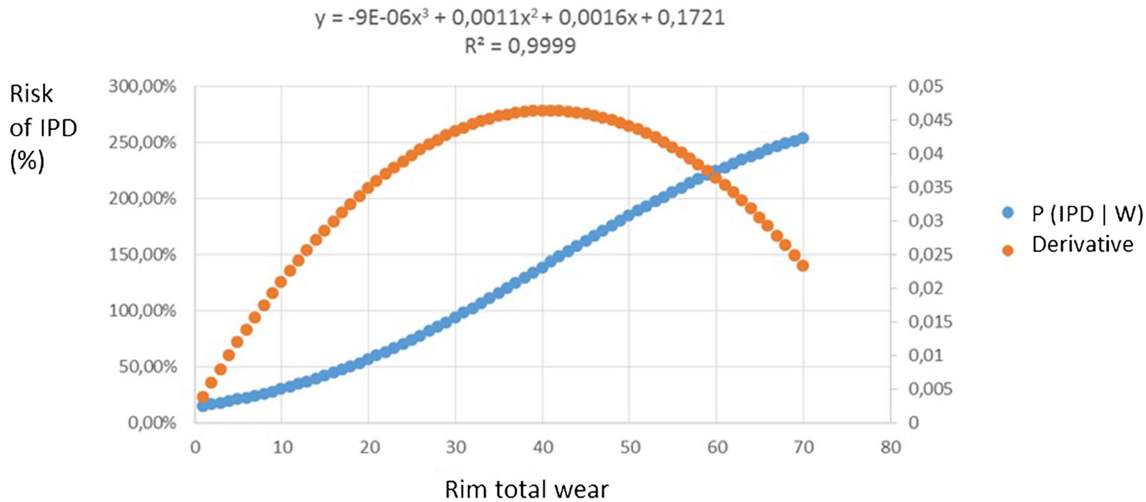

Fig. 5 Predictive model of the probability of an IPD in terms of total rim wear. IPD intraprosthetic dislocation

mobile inserts, less neck–mobile insert energy is needed to trigger movement of the large articulation, allowing it to act as a motion reserve, as intended in its original design.

Fabry et al. [16] and then Philippot et al. [5] hypothesised that an IPD can also occur when the large articulation is blocked. However, our analysis found no relationship between fibrosis, heterotopic ossification and the occurrence of IPD. Loving et al. reported in an in vitro analysis that DMC components had wear rates similar to when the small articulation was the only articulation, while there was a statistically significant increase in wear rate when the larger articulation was the only articulation [30].

After determining the IPD mechanisms, we identified which implant changes have contributed to greatly reducing the IPD rate (Fig. 6). The main changes were an improvement of the rim's bearing surface. These assumptions were the basis for industry-wide changes in femoral stem neck designs, which now are thinner, trapezoid cylindrical, with smooth edges and highly polished [11, 15]. With the improvements in the mobile insert design, higher UHMWPE molar weight, a larger and an improved design of the rim to avoid blocking of the mobile insert, our study found less rim wear [30]. The last parameter is better DMC coatings. The new generation of coatings reduces wear particles and the third body effect on the rim [11]. Therefore, to avoid IPD with DMC, we recommend using a femoral stem with a cylindrical, polished and thin neck along with a new generation of mobile insert and coating. Recently, highly cross-linked polyethylene (XLPE) has been proposed for DMC. Although the use of XLPE can induce component fracture in the retaining area related to the femoral head snap-fit, Malatray et al. demonstrated in vitro that the generation of cracks remains similar to conventional UHMWPE. However, clinical studies are required to evaluate the in vivo potential for crack propagation.

Our study has several limitations. First, three explants were excluded from the newDMC group before the statistical analysis because they had abnormal wear levels. Our method of quantifying wear with a surface scan seems to find its limits when analysing mobile inserts without measurable wear.

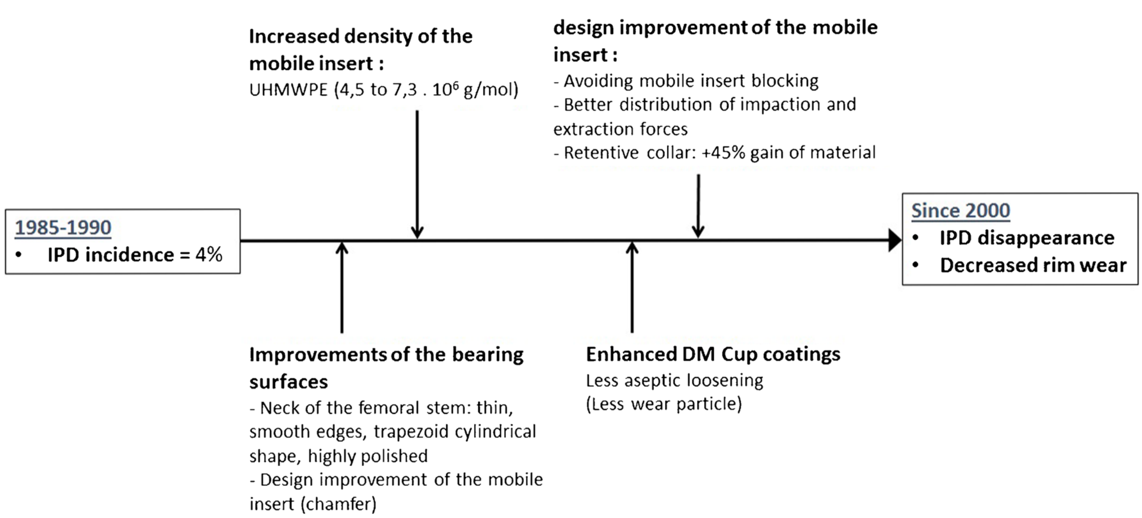

Fig. 6 Factors that may explain the quasi-disappearance of IPD. IPD intraprosthetic dislocation

There is still work to be done to determine the causes of these limitations. Second, the mean implantation time was different between the firstDMC-noIPD group and the newDMC group. For this reason, even if the IPD incidence now appears to be lower or even non-existent, only a longer follow-up with the new-generation DMC will allow us to conclude whether the improvement of DM implants has truly eliminated the risk of IPD, or whether they simply shifted their appearance in time. A third limitation is the implants themselves. For reasons of implant availability, we only used new implants of a specific brand. Consequently, our findings should be extrapolated with caution.

Conclusion

IPD is a specific complication related to wear of the DM mobile insert due to failure of the insert's retaining rim, especially from the rim's outer surface. This long-term issue is different to the early traumatic complication, which can happen after an attempt at closed reduction of a DM THA dislocation. Three factors predicting the occurrence of IPD were identified: BMI, the type of femoral stem and the diameter of the acetabular cup.

Recent modifications in the design and the coating of contemporary DMC and femoral stems with a cylindrical, thin and high polished neck, as well as improvements in the mobile insert itself, seem to corroborate our assumptions about the IPD mechanism and contribute to the quasi-disappearance of IPD. This analysis of failure mechanisms should be taken into account to prevent IPD, and the implants used with DMC, including femoral stems, should be adapted.

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We also thank Clement Neri, for his help to create the IPD predicting model.

Compliance with ethical standards

Conflict of interest Thomas Neri, Bertrand Boyer and Jean Geringer are consultants for SERF (Décines, France).

Rémi Philippot and Frédéric Farizon receive royalties from SERF (Décines, France).

Jacques Caton is consultant for Group Lepine (Genay France).

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