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TOPIC HIGHLIGHT

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Dual mobility cups in total hip arthroplasty

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Abstract

Total hip arthroplasty (THA) is considered one of the most successful surgical procedures in orthopaedics. With the increase in the number of THAs performed in the world in the next decades, reducing or preventing medical and mechanical complications such as post-operative THA instability will be of paramount importance, particularly in an emerging health care environment based on quality control and patient outcome. Dual mobility acetabular component (also known as unconstrained tripolar implant) was introduced in France at the end of the 1970s as an alternative to standard sockets, to reduce the risk of THA dislocation in patients undergoing primary THA in France. Dual mobility cups have recently gained wider attention in the United States as an alternative option in the prevention and treatment of instability in both primary and revision THA and offer the benefit of increased stability without compromising clinical outcomes and implant longevity. In this article, we review the use of dual mobility cup in total hip arthroplasty in terms of its history, biomechanics, outcomes and complications based on more than 20 years of medical literature.

Key words: Dual mobility; Total hip arthroplasty; Dislocation; Revision total hip arthroplasty; Instability

Core tip: Instability remains a significant issue after both primary and revision total hip arthroplasty. Dual mobility or tripolar unconstrained acetabular components can provide a viable alternative in preventing and treating instability. Reported outcomes of several European studies using dual mobility cups with mid- to long-term follow up support their effectiveness. Concerns such as intra-prosthetic dislocation and accelerated wear have been emphasized, although they seem to be less significant in older, low-demand patients. The use of dual mobility cups in younger patients should be viewed with caution based on a lack of current data concerning this high demand patient population.

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INTRODUCTION

Total hip arthroplasty (THA) is considered one of the most successful surgical procedures providing pain relief and improvement of function in patients with end-stage hip arthritis that is non-responsive to non-operative treatments[1,2]. As health care continues to improve and life expectancy increases, the demand for total joint replacement will grow to reflect this more active, aging population. The number of THAs performed in the United States is projected to reach 572000 by 2030, an increase of 174% compared to 2005[3].

Reducing or preventing medical and mechanical complications such as post-operative THA instability will be of paramount importance, particularly in an emerging health care environment based on quality control and patient outcome. The incidence of instability after THA in the primary and revision setting has been reported as high as 7% and 25% respectively[4]. Risk factors for instability after THA are multifactorial and may be patient-specific (gender, age, abductor deficiency) or related to operative variables (surgical approach, component malposition, femoral head diameter)[5]. Instability after THA remains one of the major causes of readmission and revision surgery accounting for 32.4% of THA readmissions and 22.5% of all THA revisions in the United States[6,7]. Readmission and revision surgery carry considerable economic cost as the surgical treatment of a dislocating THA can raise cost 148%[8]. Modifications in surgical technique (*e.g.*, anterior surgical approach, repair of posterior soft-tissues, increased offset and restoration of abductor tension) and the incorporation of larger femoral heads with greater inherent stability decrease the risk of instability after THA. Conversion to a bipolar arthroplasty and a constrained liner are salvage procedures for recurrent instability that provide stability but reduce functional outcome and implant longevity. Dual mobility acetabular components (also known as unconstrained tripolar implants) have recently gained wider attention in the United States as an alternative option in the prevention and treatment of instability in both primary and revision THA and offer the benefit of increased stability without compromising clinical outcomes and implant longevity.

HISTORY OF AND EVOLUTION OF DUAL MOBILITY CUPS

The dual articulation cup was developed by Professor Gilles Bousquet and André Rambert (engineer) in 1974 and combined the "low friction" principle of THA popularized by Charnley[9] with the McKee-Farrar concept of using a larger diameter femoral head to enhance implant stability[10]. The goal of the dual articulation was to achieve the greatest possible range of motion in a stable environment in addition to reducing wear. The original design (Novae-1®, Serf, Décines, France) incorporated a 22.2 mm metallic head articulating with a polyethylene liner, which in turn articulated with the acetabular shell. The shell was manufactured from stainless steel, coated with a porous plasma sprayed alumina (AL_2O_3) and had a cylindrical/spherical configuration. A three-point fixation system consisted of two Morse taper pegs, for impaction into the ischiopubic ramus and the ischium, and a bicortical iliac screw designed to enhance press-fit cup fixation. The liner was made from ultra-high molecular weight polyethylene (UHMWPE), gamma sterilized in air.

Modifications and improvements were made to the mechanics, metallurgy, and materials of the original design: titanium and hydroxyapatite replaced alumina coating[11], flanges and modular shells were added for screw fixation[12], highly cross-linked UHMWPE enriched with vitamin-E improved wear[13], larger femoral heads added stability[14], and anatomic designs decreased anterior overhang[15]. Advances in polyethylene manufacturing and sterilization decreased risk of catastrophic volumetric wear and allowed for the use of larger femoral heads and the use of a 10/12 Morse taper and a highly polished neck reduced liner impingement[16]. While the dual mobility was intended for primary and revision THA with minimal bone loss, cemented designs with concomitant impaction grafting were introduced for cases with more significant bone loss[17].

Dual mobility cups have been in clinical use for many years in Europe, but did not receive U.S. Food and Drug Administration approval until 2009. The designs currently available include the POLARCUP® (Smith and Nephew Orthopaedics AG, Rotkreuz, Switzerland), Anatomic Dual Mobility (ADM®) (Stryker, Mahwah, NJ), Active Articulation E1® (Biomet, Warsaw, IN) (Stick/K-Arm) and uncemented variations (SunFit TH, Coptos TH, Evolution TH) of the original Novae® cup (Serf, Décines, France). The POLARCUP® offers both cemented and press-fit options with the use of pegs and screws. The shell consists of a plasma sprayed titanium fixation surface and a stainless steel bearing surface. The Anatomic Dual Mobility (ADM®) (Stryker, Mahwah, NJ) also includes a titanium plasma sprayed fixation surface, but has a cobalt-chrome bearing surface and features an anatomic design with a recess in the shell to accommodate the iliopsoas tendon and reduce impingement symptoms. The Active Articulation E1® (Biomet, Warsaw, IN) integrates a vitamin-E impregnated polyethylene with a cobalt-chrome bearing surface. Again, fixation is promoted through osseointegration with a plasma sprayed titanium surface. The Modular Dual Mobility X3® (MDM®) (Stryker, Mahwah, NJ) uses a shell with screw holes for additional fixation and a modular highly polished cobalt-chrome liner which articulates with polyethylene. The MDM offers the advantage of screw fixation and the use of a standard shell which is available in hospital inventories and can be implanted with familiar instrumentation. The MDM acetabular shell can be converted to a dual mobility component by placing the metallic insert[18].

BIOMECHANICS

The dual mobility component increases hip range of motion (ROM) until impingement occurs through its two articulations design. In the first articulation the head is "engaged" but mobile within the polyethylene (PE) liner and follows the typical mechanical behavior of a hard-on-soft bearing in a standard THA. However, if the femoral neck and the rim of the PE liner come into contact, a second articulation begins to function and consists of the back of the PE liner and the metallic acetabular shell. As the PE liner articulates, effective ROM is increased until impingement of the femoral neck against the rim of the shell ultimately occurs (Figure 1). In this way, the head-

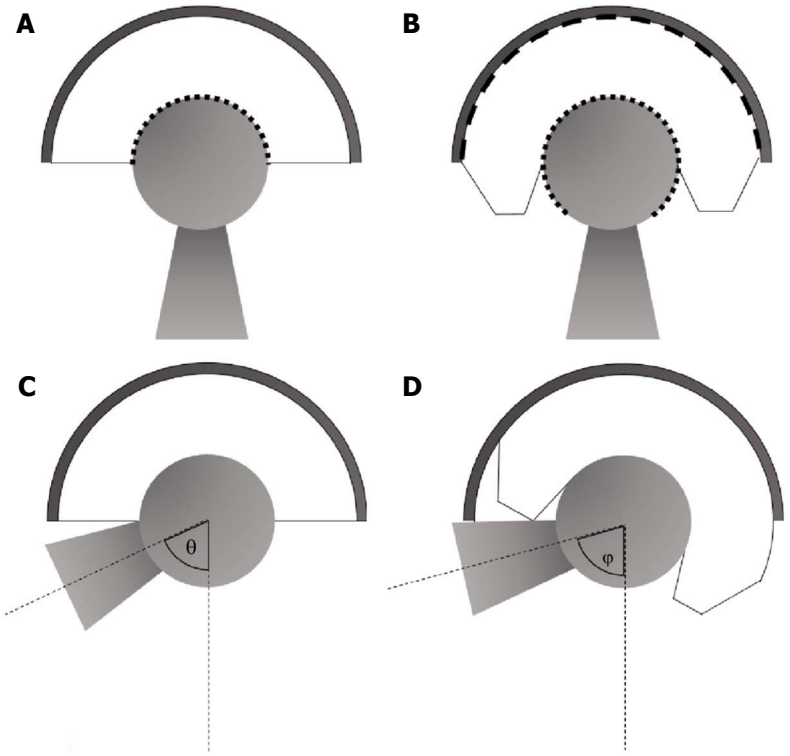

Figure 1 Standard cup *vs* dual mobility cup. Standard metal-on-polyethylene implants (A) include one articulation between the femoral head and the acetabular liner (dashed line). A dual mobility cup (B) consists of two distinct articulations, one between the femoral head and the liner, and another one between the liner and the shell. This configuration allows for greater range of motion before impingement of the femoral neck occurs (C and D, angle φ > angle θ).

liner complex theoretically functions as a large femoral head, increasing the head-neck ratio and subsequently the jump distance before dislocation. In an experimental setting, dual mobility cups with 22.2 mm and 28 mm femoral heads demonstrated significantly greater ROM compared to conventional implants with similar head sizes[19]. While there was no statistically significant difference between the two dual mobility head sizes and ROM, a larger head increases the range of motion before impingement of the neck against the PE liner, theoretically reducing the risk of intraprosthetic dislocation (IPD)[16].

OUTCOMES

Dual mobility in primary THA

Several studies on DM cups in primary THA have reported a low rate of postoperative implant instability[19-22]. Farizon[23], Philippot[12], Lautridou[24], Vielpau[21] and Boyer[25] reported their experience on the use of first generation Bousquet cups (Novae®, Serf, Décines, France) with a 22.2 mm metal head and conventional PE. At 15 years follow-up, survivorship ranged from 81.4% to 96.3% with a dislocation rate (with large articulation) between 0% and 1%. However, these authors did not include the dislocation rate of the femoral head and the mobile PE bearing (the small articulation) that ranged from 0% to 5.2%. Causes of cup failure included aseptic loosening (1.8%-3.4%), excessive PE wear (1%-2%) and acetabular screw fracture (1%). Guyen[19], Leclercq[20] and Vielpeau[21] published series of 167, 200, and 231 primary THA patients using current DM designs with a follow-up time period of 3 to 6 years and reported a 0% dislocation rate.

Dual mobility in revision THA

Dislocation rate after revision THA ranges from 5% to 30%[26-29]. Many factors have been implicated in postoperative instability including muscular insufficiency, aggressive capsulectomy, bone loss and implant positioning problems[30]. Leiber-Wackenheim[14], Hamadouche[31], Langlais[17] and Guyen[16] reported their results on the use of DM cups in patients revised for instability after primary THA. Survivorship of the cups at a mean follow-up period of 5 years was between 94.5% and 98% with a dislocation rate of 1.1% to 5.5%. These studies suggest DM cups are a reliable treatment option for patients revised for instability after primary THA.

Dual mobility in femoral neck fractures

Femoral neck fractures (FNF) treated with osteosynthesis have an increased risk of reoperation when compared to hip arthroplasty[32]. Although THA showed better functional results than osteosynthesis in FNF treatments[33], prosthetic dislocation remains a serious problem. In a recent meta-analysis by Iorio *et al*[34] the mean dislocation rate was 10.7% in patients with FNF treated with THA, five times higher than THA for osteoarthritis. Adam *et al*[35] reported 3 dislocations (1.4%) at 9 mo follow-up in a series of 214 patients with FNF treated with DM implants. Tarasevicius *et al*[36] compared dislocation rates of DM cups with that of conventional cups in patients with FNF treated with THA through a posterior approach. At 1 year follow-up, there were 8 dislocations (14.3%) in the conventional THA group and no dislocations in DM group. DM cups may also be considered as an option to prevent postoperative dislocation when treating FNFs in

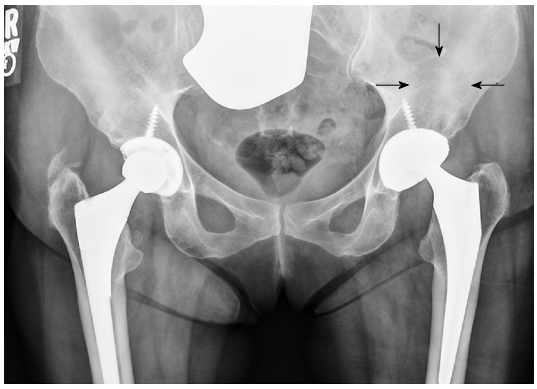

Figure 2 Bubble sign. AP pelvis radiograph of a patient with acute onset of left hip pain and limp. On the left, eccentric position of the femoral head within the dual mobility cup can be noted. Careful scrutiny reveals a circular radiolucent area superior to the acetabular component (arrows), which represents the dislocated polyethylene liner ("bubble sign").

elderly patients who are candidates for THA.

Dual mobility in tumor resection

THA after tumor resection has also been associated with a high risk of dislocation due to bone loss and soft tissue compromise. Philippeau *et al*[37] retrospectively analysed 71 patients with bony lesions of the hip treated with a THA and DM cups. They reported 7 postoperative dislocations (9.8%). Dislocation rate was lower when abductors were preserved (3.5%) and higher when abductors were sectioned/reattached (9.5%) and when the gluteus medius muscle or nerve were resected (18%). They also reported acetabular loosening in 4 cases (5.6%).

Dual mobility in spastic disorders

Several studies on THAs in patients with cerebral palsy (CP) showed good results on pain relief and function outcome; however the dislocation rate in this challenging patient group is reported to be as high as 14%[38-43]. Sanders *et al*[44] reported on 10 hips (8 patients) with CP treated[41-43,45] with THA and a DM cup and had no dislocations after a mean follow-up of 39 mo.

Indications and contraindications

The original goal of the DM cup, introduced at the end of the 1970s as an alternative to standard sockets, was to reduce the risk of THA dislocation in patients undergoing primary THA. Currently, DM cups are a well-accepted treatment option for any patient at an elevated risk for instability after primary or revision THA and in the treatment of recurrent dislocation[12,14,16,17,20,23-25,30,31,46-48]. Patients at higher risk of dislocation include patients with neuromuscular diseases, cognitive dysfunction, an American Society of Anesthesiologists score of 3 or more, and all patients older than 75 years with a history of prior hip surgery[28,49-53]. In addition, the use of DM cups is indicated in revision THA for any cause[17,30], primary THA after femoral neck fracture[35,36], and primary THA after tumor resection[37]. While several studies demonstrate a reduction in the dislocation rate in patients over 60 years, limited data is currently available on active patients younger than 50 years old and care should be taken when using DM cups in a population more prone to develop wear and osteolysis[20,21,24,48,54].

Special considerations and complications

Dual mobility acetabular components are associated with some specific complications secondary to its dual articulating design. For example, intra-prosthetic dislocation or retentive failure is a complication observed exclusively with this type of implant and involves failure of the articulation between the femoral head and the PE liner. The proposed mechanism for dissociation is a result of wear of the PE liner's retentive chamfer[25]. After dissociation, the head articulates directly with the metallic bearing surface of the acetabular shell, producing acute limb shortening and limp. Furthermore, as the shell is not designed for a metal-on-metal articulation, friction between its bearing surface and the femoral head results in rapid wear, metal ion release and surrounding soft-tissue metallosis[55]. In plain X-rays, the asymmetric position of the femoral head within the cup can be visualized which may be mistakenly attributed to "polyethylene wear". However, the characteristic "bubble sign" which corresponds to the dislocated liner is pathognomonic of retentive failure (Figure 2). Management is dependent on the time interval from dislocation to diagnosis. If IPD is diagnosed early, before significant wear of the femoral head and acetabular shell occurs, it can be treated with simple liner exchange. In cases of late diagnosis, revision of the acetabular component, as well as femoral head exchange may be necessary due to femoral head and acetabular shell damage. Boyer *et al*[25] in a series of 240 hips followed for 9 years and 11 months reported a 4.1% incidence of IPD. A similar incidence (4%) was reported by Philippot *et al*[15] among 1960 primary THAs with a mean follow-up of 14 years. The authors recognized three distinct types of IPD: type 1, which was typically due to liner wear; type 2, which was related with arthrofibrosis blocking the liner; and type 3, which was associated with cup loosening. When comparing the two stems with different neck diameters and incidence of retentive failure, no statistically significant difference was observed. The authors note that the narrower neck was unpolished titanium (which is rougher than stainless steel used in the larger neck diameter stem) and could have counteracted the positive effects of the smaller neck size. In their series of 231 primary THAs where a second generation dual mobility cup was used, Vielpeau *et al*[21] reported 0% retentive failure rate at 5.2 years. In 437 hips using the original Bousquet implant design, intra-prosthetic dislocation after a mean of 16.2 years was observed in 3 hips. The authors attributed the low incidence of intra-prosthetic dislocation to the smooth, polished, and narrow femoral neck. In other studies with mid- to long-term follow-up, the incidence of retentive failure ranges from 0% to 5.2%[12,14,19,20,47,48,56]. Table 1 summarizes reported retentive failure rates in the literature.

The configuration of the dual mobility cup with its

Table 1 Main published results of dual mobility cups in total hip arthroplasty

Ref.	N. of hips	Indication	Mean FU	Implant design (cup)	Head size (mm)	Intraprosthetic dislocation (%)	Dislocation rate (%)
Boyer *et al*[25], 2012	240	Primary THA	22 yr	Novae®[1]	22.2	4.1	0
Farizon *et al*[23], 1998	135	Primary THA	12 yr	Novae®[1]	22.2	2	0
Lautridou *et al*[24], 2008	437	Primary THA	16.5 yr	Novae-1®[1]	22.2	0.7	1.1
Philippot *et al*[47], 2006	106	Primary THA	10 yr	Novae-1®[1]	22.2	1.9	0
Philippot *et al*[12], 2009	384	Primary THA	15.3 yr	Novae-1®[1]	22.2	3.6	0
Philippot *et al*[48], 2008	438	Primary THA	17 yr	Novae-1®[1]	22.2	5.2	0
Guyen *et al*[19], 2007	167	Primary THA	3 yr	Saturne®[2]	n/a	0	0
Leclercq *et al*[20], 2008	200	Primary THA	6 yr	Evora®[3]	22.2 (n = 175) 26 (n = 18) 28 (n = 7)	0	0
Hamadouche *et al*[56], 2012	168	Primary THA	6 yr	Tregor®[4]	22.2	2.4	0
Vielpeau *et al*[21], 2011	437 (Group A) 231 (Group B)	Primary THA	16.5 yr 5.2 yr	Original Bousquet Novae-E®[1]	22.2	0.7 0	0 0
Bouchet *et al*[54], 2011	105	Primary THA	2.3 yr	Novae®[1], Statfit®[5], Avantage®[6], Gyros®[7]	28	n/a	0
Bauchu *et al*[60], 2008	150	Primary THA	6.2 yr	Polarcup®[8] 3rd gen	n/a	0	0
Combes *et al*[22], 2013	2480	Primary THA	7 yr	Novae®[1], Avantage®[6], Collegia®[9], EOL®[10], Gyros®[7], Tregor®[4], Polarcup®[8], Saturne®[2], Evora®[3]	28 (n = 1484) 22 (n = 956)	0.1 0.6	0.7 0.5
Tarasevicius *et al*[36], 2010	42	Neck Fractures	1 yr	Avantage®[6]	28	n/a	0
Adam *et al*[35], 2012	214	Neck Fractures	3-9 mo	Saturne®[2]	28 (n = 182) 22.2 (n = 32)	0	1.4
Sanders *et al*[44], 2013	10	Spastic disorders	3.2 yr	Avantage®[6]	n/a	0	0
Philippeau *et al*[37], 2010	71	Tumor resection	3.3 yr	Avantage®[6], Saturn®[2], Novae®[1], other	n/a	n/a	9.8
Langlais *et al*[17], 2008	85	Revision THA	3.2 yr	Tregor®[4]	22	n/a	1.1
Leiber-Wackenheim *et al*[14], 2011	59	Revision THA	8 yr	Novae-1®[1] Novae-E®[1]	28	0	1.7
Hamadouche *et al*[31], 2010	51	Revision THA	4.3 yr	Tregor®[4]	22.2	2	2
Guyen *et al*[16], 2009	54	Revision THA	3.9 yr	Saturne®[2]	n/a	3.7	1.8
Hailer *et al*[61], 2012	228	Revision THA	2 yr	Avantage®[6]	n/a	n/a	2
Philippot *et al*[30], 2009	163	Revision THA	5 yr	Novae®[1]	22.2	0	3.7

[1]Serf, Décines, France; [2]Amplitude, Valence, France; [3]Science et Médecine, Créteil, France; [4]Aston, St Etienne, France; [5]Zimmer, Etupes, France; [6]Biomet, Valence, France; [7]DePuy, St Priest, France; [8]Smith and Nephew Orthopaedics AG, Rotkreuz, Switzerland; [9]Cremascoli-Wright, Paris, France; [10]Norton-Ceramconcept, Paris, France. n/a: Not available.

two articulations and thinner liner has raised concern for accelerated PE wear and associated osteolysis. In a retrieval study of liners removed after revision surgery for infection or aseptic loosening, no difference in total volumetric polyethylene wear was noted between tripolar unconstrained cups and conventional cups with 22.2 mm heads[57]. However, greater wear was noted at the convex bearing surface of the liner. Failure rate due to accelerated polyethylene wear was 2% in a series of patients with first generation PE[25]. In the same series, age < 50 years was associated with significantly greater wear rates, apparently due to the higher activity level of these patients. Similarly, in a series of Philippot *et al*[48] revision rate due to PE wear was 1.6%. Combes *et al*[22] reported a 7% rate of osteolysis (with first-generation PE), especially in patients of younger age and those treated for sequelae of childhood hip disease.

Radiographic evaluation of PE wear can be difficult in the setting of a dual mobility component, because of the deep position of the head within the cup and the cylindrical-spherical shape of the shell itself. An eccentric femoral head implies concomitant wear of both the concave and the convex bearing surface of the liner[58]. Highly cross-linked UHMWPE and vitamin-E impregnated polyethylene has reduced volumetric wear in standard implants[13,59] and have been integrated into dual mobility implants in an effort to deal with accelerated wear issues. Bauchu *et al*[60] in a retrospective series of primary THAs with the POLARCUP® component (Smith and Nephew Orthopaedics AG, Rotkreuz, Switzerland), which incorporates a highly cross-linked UHMWPE liner, reported no incidents of wear-related osteolysis. However, there are currently no independent studies of tripolar cups further supporting these findings. For all these reasons, the use of dual mobility cups should be used with caution in younger patients with high demands and increased risk of wear-related osteolysis.

Another issue with the DM cup is aseptic loosening. Loss of fixation of the original design was attributed to delamination of the plasma sprayed alumina layer[23]

which led to design modifications. Some authors propose that fixation of tripolar cups, particularly second-generation implants, should always be supplemented with screws[11]. Nonetheless, as noted earlier, current shell options include monoblock cups, which take advantage of modern porous coated surfaces for enhanced osseointegration. A potential drawback of these monoblock cups is the difficulty assessing proper seating of the cup within the acetabulum which may contribute to the reported rates of aseptic loosening ranging from 0% to 8.3%[12,14,19-22,47,48,56] (Table 1).

CONCLUSION

Instability remains a significant issue after both primary and revision THA. Dual mobility or tripolar unconstrained acetabular components can provide a viable alternative in preventing and treating instability. Reported outcomes of studies using DM cups with mid- to long-term follow up support their effectiveness. Concerns such as intra-prosthetic dislocation and accelerated wear have been emphasized, although they seem to be less significant in older, low-demand patients. The use of dual mobility cups in younger patients should be viewed with caution based on a lack of current data concerning this high demand patient population.

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