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Dual mobility total hip arthroplasty in complex cases

Domenico Tigani, Emanuela Castiello, Alessandro Moghnie, Saverio Comitini, Marco Ganci, Alberto Consoli, Matteo Berti, Luca Amendola

Department of Orthopaedics, Maggiore Hospital, Bologna, Italy

Summary

Since their launch on the market in the late 1970s, Dual Mobility Cups (DMCs) have shown encouraging results both in terms of stability and of restoration of wide hip joint amplitude. Therefore, the use of DMCs is mainly indicated for patients at risk of dislocation, such as those with neuro-muscular diseases, femoral neck fractures, or complex situations like failed hip osteosynthesis, as well as being indicated in the setting of revisions.

The objective of this review is to provide indications and recommendations for orthopedic surgeons using DMCs in complex primary and revision settings. An overview of the technical and theoretical requirements necessary to achieve a successful DMC implantation is presented. According to the literature, indications have been expanded thanks to the constant improvement and development of materials and implants. Nowadays, the use of DMCs is no longer limited to revision surgery alone; on the contrary, increasingly complex cases may be approached. Long-term studies are needed before any formal conclusions can be drawn and before the promising results that have been obtained in difficult cases are consolidated.

Key words: total hip arthroplasty, dual mobility, complex primary hip, revision

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Correspondence
Domenico Tigani
Department of Orthopaedics, Maggiore Hospital, Largo Nigrisoli 2, 40100 Bologna, Italy
E-mail: d.tigani@ausl.bologna.it

Conflict of interest
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Introduction

The concept of dual mobility cup (DMC) in total hip arthroplasty (THA) was developed by Gilles Bousquet in the 1970s [1,2].

The implant combined three principles:

1. the "low friction" principle of THA popularized by Charnley thanks to the small femoral head diameter (22.2 mm), which articulates with an ultra-high molecular weight polyethylene (UHMWPE) liner [3];
2. the McKee-Farrar concept of using a larger femoral head diameter to enhance implant stability [4];
3. the Christiansen hip solution, which allows mobility of the head [5].

A dual mobility cup has two concentric joints: a large-diameter polyethylene (PE) articulation with a polished metal cup and a smaller constrained articulation between a modular femoral head and the PE liner. These two articulations allow for greater range of motion, a greater head-to-neck ratio, and a more physiologically effective head size that increases the jump distance and hence resistance to dislocation.

Since DMCs were initially conceived, their design has evolved on the basis of clinical experience and materials, which have improved with the knowledge and developments achieved over the past 40 years. What has not changed and, in fact, has become more established, is that surgeons from all over the world are confident regarding the use of DMCs in complex cases, i.e. situations presenting a higher risk of instability and dislocation as a common denominator, including patients aged over 75 years, as well as patients with a history of prior hip surgery, neuromuscular disease, a higher Charlson Comorbidity Index (CCI) or American Society of Anesthesiologists (ASA) score. Obesity, muscular problems, neurological diseases, or bone deformities are often associated with a high risk of instability. Finally, acute acetabular fractures or their sequelae and failed internal fixations or revisions are also conditions presenting a broadly recognised high risk of instability [6-9].

Biomechanical considerations

The management of THA instability remains a surgical challenge and many solutions have been reported with variable success rates. The use of bearings with a larger diameter has been advocated in order to increase range of motion without impingement or jump distance [10-13].

However, concerns were raised by Amstutz et al., who highlighted a recurrent dislocation rate of 13.7% with the use of femoral heads larger than 36 mm in a series of revision THAs [12]. All cases with recurrent instability had poor acetabular cup orientation and thus highlighted the fact that there are other mitigating factors that can lead to dislocation.

Constrained implants, which are characterized by a locking ring mechanism in order to secure the head within the socket, have been the most popular option to treat instability in the past, but are associated with mechanical failure and loosening due to high stress transmission at the prosthetic interface [14,15].

Finally, results reported in literature for dual mobility implants compare favorably to the use of standard, large head diameter implants or constrained devices not only with regards to instability prevention or treatment, but also the risk of mechanical failure and aseptic loosening [16].

The jump distance, defined as the translation of the femoral head centre required for dislocation to occur, has been proposed as a predictive factor for dislocation [17]. Theoretically, the larger the distance, the lesser the chance of dislocation [18]. The jump distance of a DMC is greater than any standard cups; this is not only due to the size of the liner, which is very close to the diameter of the native femoral head, but also to the mobility of the liner itself, which helps prevent impingement. In fact, the interposition of a mobile polyethylene component between the prosthetic head and the highly polished inner surface of the outer metal shell provides two bearings and allows to increase the actual head size. Dual mobility designs present 2 different joints: a first, smaller joint is included in a second, larger one. The latter is captivated in a polyethylene liner that is in contact with the acetabular shell. The smaller articulation is engaged during most activities requiring a normal range of motion. The larger joint between the polyethylene liner and the acetabular shell is, instead, involved in activities that exceed normal range of motion, when the neck of the femoral stem enters in contact with the rim of the liner. Laboratory studies have shown an increased range of motion with dual mobility versus traditional implants. Calculations have shown that the range of movement determined by the smaller joint directly depends on the characteristics of the liner (refrain and chamfer) and on the femoral implant. With a Novae shell, an 11-mm femoral stem neck, and a 22.2-mm femoral head, the range is constantly of 51°. If a 28-mm head is used, a 76°range is reached with the same femoral neck. As for the large head, joint amplitude extension is related to shell size: with a 43-mm cup, it is 126°, whereas a 65-mm shell enables to reach 140°. According to these evaluations, the correct positioning of the cup and 11-mm femoral stem neck enables to achieve a 186° flexion/extension, a 126° abduction/adduction, and a 220° rotation using a 53-mm cup [19].

Indication and choice of implants

In Saint-Étienne, Gilles Bousquet recommended DM for all patients without limitations related to age or diagnosis [1,20,21].

On the contrary, outside of Saint-Étienne and Lyon, even in France, these implants were typically used for revisions or for patients with a high risk of instability [22]. Instability after THA is a multifactorial issue which can be linked with implant-related factors, surgery-related circumstances, as well as with the patient's inherent conditions. The patient-related factors that can cause hip instability are numerous: age over 75 years, history of prior hip surgery, neuromuscular diseases, higher Charlson Comorbidity Index or American Society of Anesthesiologists score. Finally, patients undergoing primary THA for a femoral neck fracture or other post-traumatic disorders, hip arthrodesis, or congenital/childhood deformities may also be at high risk of dislocation [23].

Through a short discussion, we will present an overview of DM indications in complex situations. Different types of DM implants have been used depending on etiological characteristics. Nowadays, a wide range of DM constructs is available: press-fit implants, tripod constructs, complex implants with extra fixation, modular solutions, and cemented cups. Monoblock press-fit implants can be used in case of normal anatomy and adequate bone quality. These implants usually have a cylindrical-spherical shape and consist of a half sphere augmented by a cylinder measuring 2 to 3 mm at the equator of the cup; in other constructs known as "hat designs", the presence of an inclined plane outside the hemispherical area increases coverage until 12° [24]. Finally, a cup with anatomical design can be adapted to the anatomy of the acetabulum, avoiding impingement with the iliopsoas tendon [25]. Tripod implants, which are the evolution of the original Bousquet design, provide the possibility to ensure additional fixation in all three planes through an iliac screw and two pegs inserted in the pubis and ischial areas. To achieve a more extensive fixation, complex implants have been produced. These constructs have additional plates and an obturator hook for extra-acetabular fixation. The last decade has seen the development of modular DM allowing to convert a standard cup in DM implants thanks to a separate chrome-cobalt modular component housed inside a titanium shell [26]. In this way it is possible to maintain the option of supplementary screw fixation.

As for construction materials, the cementless cups are either in cobalt-chrome-molybdenum (CoCrMo) alloy or in 316L stainless steel; in modern generation implants, both solutions are covered by a double layer of titanium and hydroxyapatite.

A cemented version of dual mobility cups (DMCs), which are helpful in case of bone stock alteration, is also available in cobalt-chrome-molybdenum (CoCrMo) or stainless steel, depending on the manufacturer. The outer surface is characterized by concentric and radial groves in order to improve cement fixation.

DMCs in the setting of primary surgery

Femoral neck fracture is one of leading indications for DM. This is especially true in elderly patients due to the high dislocation rate in case of standard THA or hemiarthroplasty. According to the meta-analysis by Iorio et al., the median incidence of dislocation for patients treated for FNF with THA is 10.7%, that is five times more than corresponding data for osteoarthritis. A possible explanation for this may be given by the greater tendency to fall, less muscular control, and increased ligament laxity that present in hip fractures [7]. In effect, elderly patients are fragile and may have several comorbidities that can increase the risk of post-operative instability (Fig. 1A-C).

The current literature suggests that these patients might benefit from press-fit implants without supplemental fixation. The titanium and hydroxyapatite bilayer finishing surface that provides surface roughness in latest-generation implants has significantly contributed to bone integration and cup fixation. Press-fit implants belong to a second generation of DM implants. These were mainly introduced for THA procedures in the 2000s and have shown excellent results, replacing the "tripod" construct in most cases.

The use of cemented dual mobility cups may be an option in case of severe osteoporosis, especially in elderly patients, in whom there is a potential concern regarding the quality of fixation. At intermediate follow-up, cemented implants have shown similar results to those of contemporary press-fit DMCs [27,28].

The wide use of dual mobility cups in the treatment of displaced femoral neck fractures has highlighted a low dislocation rate in many prospective studies, regardless of the variable experience of operators adopting this approach.

In addition to neck fractures, hip fractures also increase the risk of dislocation when they require hip arthroplasty. Although acetabular fracture is certainly not a leading indication for acute hip arthroplasty, there is a limited subset of patients that can benefit from this treatment, especially at an advanced age. Open reduction followed by internal fixation is widely considered the treatment of choice for the vast majority of patients; at the same time, in case of failure, THA should be considered to restore function and resolve pain. Beyond these indications, primary total hip arthroplasty, which is often combined with internal fixation, can be an effective procedure in the presence of hip arthritis or when the following conditions are present: combined femoral head and/or neck fracture for which satisfactory outcomes cannot be achieved with internal fixation; wide comminution in osteoporotic bone; less predictable results with ORIF due to the impossibility of achieving anatomical reduction; superior antero-medial dome impaction; posterior wall fracture with comminution. The impact of these conditions is obviously higher in elderly patients due to poor bone quality and the need for early recovery. As the dislocation rate of acetabular fractures treated by acute THA can reach 23%, dual mobility is preferred when treating acetabular fractures with the procedure [29,30]. From a general point of view, THA in acetabular fractures should lead to a stable fixation of the fracture fragments and to the implantation of a stable acetabular component with correct positioning. Although anatomical reduction is not

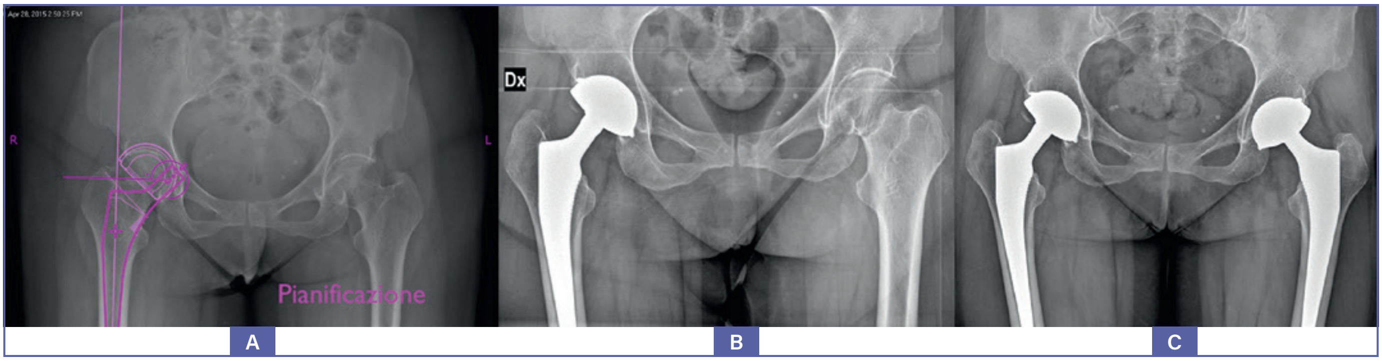

Figure 1. AP view pelvic X-rays. A) Right femoral neck fracture. Pre-operative planning; B) 1-year after DM implant on the right side + left femoral neck fracture; C) 2-years after DM implant on the right side + 1-year after DM implant on the left side.

necessary, the continuity and stabilization of the column should be restored using the standard technique and instrumentation for acetabular fractures. Autografts from the femoral head are essential for filling bone defects. Several studies have reported good results for geriatric acetabular fractures; however, there are theoretical concerns in relation to prosthetic cup fixation and the risk of instability. Regarding the first issue, the study of Marmor et al., which mapped the acetabular fracture in elderly patients, is particularly interesting. The authors classified fractures based on available stable articular surface and intact bone corridors for acetabular cup fixation. They found that the dome is the most common stable articular surface, followed by the posterior one; the sciatic buttress corridor was available in all fracture patterns, while the gluteal pillar corridor was the second, most frequently available corridor. Regarding the issue of instability, dislocation is also minimized through the use of larger femoral heads and dual-mobility cups [29-31].

When a DMC is preferred, different options are possible. A modular dual mobility implant with a cluster hole cup can be an option in less complex cases if a minimum of 4 screws with good purchase can be used to fix the cup in at least two Marmor's corridors and in the available stable articular surface [32,33]. Based on this principle, Gautam et al. recommend to associate at least one screw, placed inferiorly in the superior pubic ramus or ischium (preferably one in each), to avoid cup failure in abduction [33].

In the event of more complex cases or in presence of pelvic discontinuity, the standard cup is not recommended, whereas cage reconstruction is a possible option. In these scenarios, definitive fixation of the acetabular fracture with a plate and screws can be performed before reaming. The femoral head can be used to obtain a morselized bone graft that will be placed in the residual fracture gaps, or as a structural graft for larger acetabular defects. The available cages that bridge the defect are characterized by the presence of extra-acetabular plate(s) placed over the ilium and distal anchorage using an obturator hook, as well as a plate screwed over or buried into the ischium. The cage helps protect the graft from incorporation and remodelling. These constructs can accept a cemented dual mobility implant or are built around a cup with a double surface of titanium/hydroxyapatite-coating or trabecular cup in titanium alloy for secondary osteointegration (Fig. 2A-E).

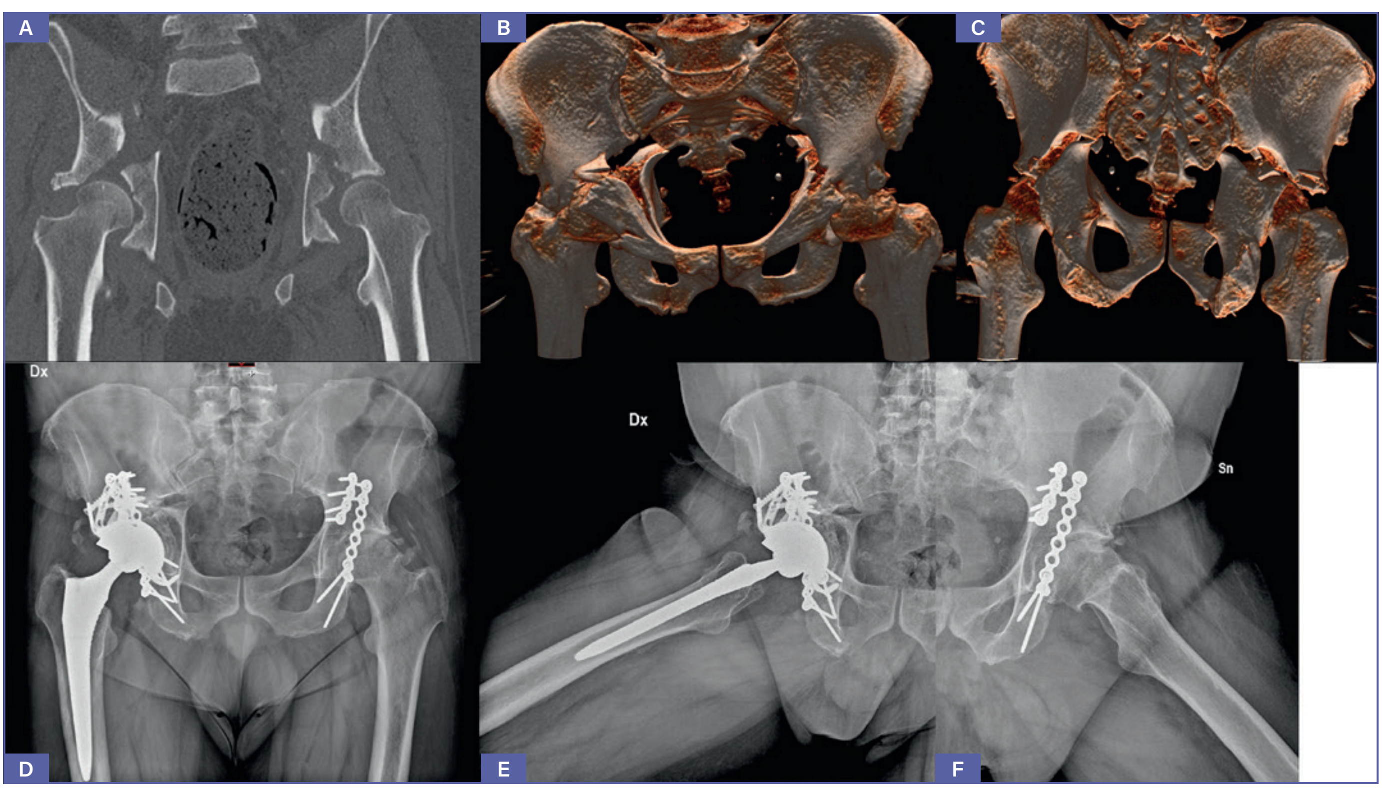

Figure 2. Bilateral acetabular fracture. A) Pre-operative frontal plane CT scan; B) Pre-operative 3D CT scan – anterior view; C) Pre-operative 3D CT scan – posterior view; D) Post-operative AP view X-rays showing posterior ORIF on the left side and posterior ORIF + Kerboull-plate + DM implant on the right side; E) Post-operative frog-leg view X-rays showing posterior acetabular ORIF + Kerboull-plate + DM implant on the right side; F) Post-operative frog-leg view X-rays showing posterior left acetabular ORIF.

The failure of internal fixation for proximal femur fractures has a variable incidence rate. In this setting, the option of total hip arthroplasty is often the solution. The issues inherent to this procedure are connected with the need to remove the fixation hardware and the potential presence of mal- or non-union, which can lead to modified landmarks and increase the risk of implant mispositioning, especially in case of previous extracapsular fractures. Several papers have focused on this topic, highlighting a high incidence of dislocations and numerous technical difficulties [34].

Analysis of the literature shows that the dislocation rate with standard cups can reach 20%, whereas the use of DM allows to reduce the risk of dislocation [34-38].

As the chances of other complications are in any case high, great attention should be paid when choosing the approach and selecting the stem. With regards to the former, in selected cases, the transtrochanteric approach with coronal osteotomy of the great trochanter seems interesting, as it can facilitate the implant removal and thus enhance joint exposure and preserve the extensor mechanism, posterior capsule, and vascularization [39]. Normally, stable trochanteric fixation can be easily achieved by means of cerclage or dedicated plates. As for the second issue, i.e. appropriate implant selection, the use of a cementless revision stem with locking device in order to bypass the metaphyseal or subtrochanteric fracture lines through of previous screws may be appropriate. In case of major osteoporosis and absence of distal fracture lines, cemented stem should be preferred.

Beyond fractures, contemporary DMCs have shown excellent results in high-risk patient populations with degenerative arthritis. Hernigou et al. have reported low dislocation rates in obese patients (defined as a BMI exceeding 30 kg/m^2) undergoing primary THA with either DM. At 7-year follow-up, a statistically significant reduction in dislocation was observed in obese patients who had used DM rather than the standard bearing cup (9%). Furthermore, in terms of reducing dislocation rates, using DM was more effective than performing bariatric surgery prior to THA (14% dislocation rate at 7 years follow-up) [40].

Based on literature data, DM cups can be recommended for patients with a higher risk of dislocation due to cerebral palsy or other neurologic diseases. Indeed, DM cups may provide an answer to instability issues in patients with weaker neuromuscular control (Parkinson's disease, dementia, palsy, etc.), who are at high risk of dislocation. DM cups can also be considered in patients with residual poliomyelitis; however, smaller sizes are required for these patients as their hips do not grow completely as a result of the early onset of the pathologic insult.

Other conditions that could be dealt with in the above setting include persistent coxa valga, increased femoral anteversion, and the associated imbalanced forces generated by the adductor, internal rotator, and hip flexor muscles [41]. There is no general rule for the choice of the implant in these conditions, as the decision often depends on the secondary deformity or on the quality of bone [22].

Osteonecrosis of the femoral head is a therapeutic challenge due to the young age and high functional demand that most patients with this disease present. In fact, patients with ONFH are reported at highest risk of revision surgery [42,43]. The use of dual mobility cups in patients with ONFH has shown excellent results with no episodes of dislocation or revision in several series.

From a technical point of view, there are no particular recommendations regarding the use of DM implants for this type of lesion, other than underlining a potential rapid evolution in elderly patients leading to the appearance of acetabular wear, in which case cemented or peripherally anchored implants can be beneficial.

In case of dysplasia or sequelae of congenital dislocation, the use of an implant with extra-acetabular fixation is recommended. According to what was suggested in Saint-Étienne, tripod implants that reinforce press-fit fixation in all three planes could be a solution for most of these situations. The small diameter of tripod implants, which preserve bone stock and maximize bone coverage around the implant, is the 41-mm diameter (SERF communication). Implants with obturator hooks and screwed flanges are also an option in these types of cases.

DMCs in revision surgery

Dislocation is one of the most common complications after revision THA. According to different series, reported incidence of dislocation after revision THA varies between 10 and 28% [44,45]. Patients undergoing revision THA often present a compromised abductor mechanism and/or cup mispositioning, which both increase the risk of postoperative instability.

Dual mobility constructs and large femoral heads are two contemporary, non-constrained bearing options used in revision THA to minimize the risk of dislocation. Viste et al. considered 334 revision THAs performed between 2006 and 2011 using a dual mobility cup; the authors found a 2.9% cumulative incidence of dislocation at the latest follow-up. Better results have been reported by Wegrzyn et al. in 980 patients using dual-mobility constructs with an incidence of dislocation of 1.5% at seven years [46].

The planning of the implant to use depends on the type of defect that is present, defined according to the GIR classification of acetabular bone loss (Tab. I).

In case of GIR grade I defect and good bone quality, the press-fit implant is theoretically possible alone; however, solutions such as cemented cups are largely used in Northern Europe [42], whereas modular DM implants with the possibility of fixation with supplement screws are preferred in the US. Some companies allow the possibility for tripod fixation; this solution is the most followed in France. In general, there is no need for additional bone graft.

In grade II bone defects, the enlargement and deformation of the acetabular cavity are combined with the disruption in one

Table I. GIR classification of acetabular bone loss.

Grade I: loosening and/or enlargement and deformation of the acetabulum. No wall defect
Grade II: loosening and/or enlargement and deformation of acetabulum. Defect in one wall
Grade III: loosening and/or enlargement and deformation of acetabulum. Defect in > 2 walls
Grade IV: massive and overall periacetabular bone loss

of the bony walls. The surgical strategy is based on the reconstruction of the disrupted wall by means of an implant with an obturator hook and screwed flanges on the top, combined with morselized or structural bone grafts. Modular DM implants may still represent a good choice in these cases; augments or structural bone grafts can also be used.

Acetabular bone defects classified as grade III are characterized by the disruption of two or more walls (anterior or posterior pillar and medial wall). Both cemented and cementless solutions are viable. Cemented solutions are generally preferred in elderly patients. Over the past decade, some reports have focused on the use of the Kerboull cross-plate as a frame in THA with dual mobility cups (DMCs), with excellent mid-term survivorship results [47,48]. The Kerboull cross-plate surgical technique has recently been upgraded in the SICOT-J journal [49]. The authors highlighted the necessity of a correct version in the coronal plane with the use of bone graft below the superior plate in order to ensure a correct inclination of 45° in the coronal plane. To avoid extrusion of flanges and consequently diminish the risk of impingement, they suggest downsizing the Kerboull cross-plate in relation to the bony cavity. Finally, DMC implants may also be downsized by two sizes according to the inner diameter of the cage. Monolithic cup-cage constructs with obturator hook and iliac plates have recently been popularized for cementless acetabular reconstruction. They differ in the characteristics of the metal composition, macrostructure, and surface coating (Lima e Coptos).

Stemmed cups with modular DM (Integra) can be beneficial for this type of defect. The same is possible for grade IV defects, where there is a massive bone loss involving the entire acetabular rim and walls. A discontinuity of the tuber ischiadicum may also be associated. In most of these cases, however, a custom-made tri-flange construct is required.

Discussion

Herein, we provide indications and recommendations relative to the use of DMCs in complex primary and revision settings, giving an overview of the technical and theoretical requirements that are necessary to achieve successful DMC implantation. Since their launch on the market in late 1970s, DMCs have shown encouraging results both in terms of stability and of restoration of wide hip joint amplitude. Therefore, the major indication for the use of DMCs is in patients at risk of dislocation, such as those with neuro-muscular diseases and fractures around the hip. The use of DM became particularly important when patients with neurological or muscular problems suffered femoral neck fractures. Even though quantifying the cumulative risk of dislocation is difficult, it is important for the surgeon to take all the possible precautions to reduce this possibility. According to the literature, patients with neurological conditions such as neuromuscular weakness present a higher incidence of gait disturbance, falls, functional disturbance, and post-THA dislocation rates. In case of Parkinson's disease, the incidence of instability can reach 37% [50,51]. No cases of dislocation have been reported by Bassiony for hip fractures in Parkinson's disease [52].

Several papers report excellent results in terms of the risk of instability with the use of DM THA for FNF. Tarasevicius et al. described a significant reduction in the dislocation rate for THA procedures performed using DM in 105 patients: no cases of dislocation occurred in the DM group compared to the standard cup group, in which dislocation was reported for 10.4% of cases within the first postoperative year [53]. Likewise, in a cohort of 214 FNF treated with DM THA, Adam et al. reported a dislocation rate of only 1.4% at 9-months [54]. Many surgeons prefer hemiarthroplasty instead of THA to treat displaced femoral neck fractures because THA with a conventional cup seems to involve a higher dislocation rate. Furthermore, hemiarthroplasty is a less invasive procedure. In 2014, a study conducted at the Regional Hospital in Denmark indicated that THA with DMC is superior to bipolar hemiarthroplasty following treatment for displaced femoral neck fractures in terms dislocation and re-operation rates [55]. DM has shown better results compared to hemiarthroplasty even in patients with dementia and femoral FNF, as reported by Iorio et al. in a recent RTC [56]. Sanders et al. reported no dislocations using the AVANTAGE DMC in eight patients (10 hips) with cerebral palsy and painful osteoarthritis of the hip at a mean follow-up of 39 months [57].

Recently, Bouche et al. reported a higher frequency of misalignment when THA was achieved for an acute proximal femur fracture. Several explanations can be proposed: poorer bone quality, incomplete removal of upper acetabular osteophytes, and surgical procedures performed by younger surgeons. These misalignments do not cause more mechanical complications in the first months after surgery. The possible explanation of this apparent paradox could be correlated with the study by Ohmori T et al., where a model of pelvis and femur developed from computed tomography images was used.

The study provided evidence of the therapeutic benefit of DMC in terms of a 10°-15° increase along the anterior, posterior, and vertical planes of the cup safe zone.
The risk of dislocation is particularly high in revision surgery or post-traumatic arthritis, as well as in any condition involving a subversion of the normal anatomy. In these situations, the surgeon has to deal with several problems linked to both poor bone quality and the presence of bone loss. For these reasons, very specific solutions should be planned, using DMCs for tripod fixation, modular constructs, or reconstruction procedures with supplemental fixation. When these measures are correctly applied, the dislocation rate is lower than that reported with standard cups. DMCs have shown to be the superior anti-dislocation devices; at the same time, aseptic loosening rate with DMCs does not appear to be higher when appropriate acetabular reconstruction is performed [58,59].
Since its introduction, the DMC has shown advantages and drawbacks. The main drawbacks of the first-generation implants were acetabular loosening and intraprosthetic dislocation. The original Bosquet implant was a cementless, 316L stainless-steel DMC, impacted in press-fit. Its fixation was supplemented by tripod anchoring with two pegs (one impacted in the ischium and the other in the pubis) and one superior screw inserted into the iliac wing. The surface of the cup was covered with an alumina coating. Long-term studies of first-generation DMCs have confirmed that they are an excellent solution against dislocation. Boyer et al. observed no dislocations at a 22-year follow-up on 240 DMCs [60]. However, the same paper highlighted an 8.3% rate of aseptic cup loosening after 11 years, and a 4.1% retentive failure rate after 10 years. These failures were due to cup imperfections related to the inert non-bioactive alumina coating on the surface.
The survival of the latest-generation implants has improved due to changes made to the liners (increased molecular weight polyethylene, better design to improve clearance) and to the coating (bilayer of hydroxyapatite and plasma-sprayed titanium) [61,62]. With latest-generation DM implants, survivorship at 10 years is reached in 100% of cases [63]. Longer-term studies are needed to confirm these encouraging findings.

Conclusions

In conclusion, the revision rates for aseptic loosening with DMCs are similar to those achieved with standard cups, whereas DMCs have demonstrated efficiency in decreasing dislocation risk even in complex situations, in both primary and revision cases. Planning surgery accurately and choosing the right implant is paramount to obtaining adequate results and limiting the risk of dislocation. The main limitations that DMCs presented in the past were poor osteointegration and liner wear, which led to aseptic loosening and IPD. The improvements made over time have greatly reduced these complications.

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