Complications of Acetabular Modularity

a report by
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Uncemented modular cups are the preferred implants for primary total hip arthroplasty (PTHA). Cemented all-polyethylene cups are still popular in Europe; however, the high prevalence of radiographic loosening observed after the first decade of implantation in young patients\(^1\) and the concept of ‘cement disease’\(^2\) collaborated to generate skepticism about the use of cement for acetabular fixation. Since their introduction in the mid 1980s, uncemented modular cups gradually displaced cemented cups, particularly in North America.

The radiographic fixation of uncemented cups five years after implantation exceeded 98% in two studies performed at the Hospital for Special Surgery. One of these studies evaluated cups implanted with line-to-line acetabular preparation and screws,\(^3\) and the second study utilized the press-fit technique and cups with a limited number of holes or no holes.\(^4\) Moreover, in some studies, uncemented fixation outperformed cemented acetabular fixation. In a matched paired analysis, Clohisy et al. compared the survivorship of all-polyethylene cemented components with uncemented modular cups at a follow-up of nine to 12 years. The prevalence of aseptic loosening was 31% and 0% respectively (p<0.001).\(^5\)

In addition to biologic fixation, acetabular modularity offers numerous advantages during surgery, including the possibility of enhancing initial fixation to bone with screws, combining different bearing materials and head sizes, and utilizing liners with different elevation and offset. If revision surgery for wear is necessary, the polyethylene liner can be exchanged without disturbing the bone-implant interface and, in the case of recurrent dislocation, a constrained liner can be used.

However, the development of uncemented modular cups was not without complications. Technological and manufacturing deficiencies, poorly understood design-related aspects of modularity, sub-optimal sintering of the ingrowth surface to the shell,\(^6\) and the use of shells with multiple holes resulted in unforeseen modes of failure that are now understood two decades after their initial use. Recent long-term studies suggest that when all mechanical and biological-related revisions are considered, the clinical performance of first-generation uncemented cups may be similar to that of cemented cups.\(^7\)

An understanding of the modes of failure of first-generation modular cups discussed in this article led to the design of modern modular and non-modular cups.

Backside Wear and Conformity

Polyethylene and metallic debris generated at the non-articulating surfaces of modular acetabular components, so-called ‘backside wear’, has been implicated in the development of peri-prosthetic

osteolysis. This complication was predominantly observed in first-generation modular acetabular components, which had a poor locking mechanism allowing micro-motion of the polyethylene liner. Micro-motion was compounded by the poor conformity between the liner and the shell and the rough inner surface finish. In addition, shells with multiple holes reduced polyethylene support and allowed polyethylene particles to access the iliac bone. Incongruities or lack of conformity between the liner and the metal shell were generated during the manufacturing process, or after implantation due to load-dependant deformation of the liner, which compressed in the direction of the load generating gaps in non-weight-bearing areas or due to backside wear. Incongruities by design are virtually impossible to avoid as a minimum clearance between the liner and the shell should exist to allow complete sitting of the liner in the shell and engagement of the locking mechanism. An additional disadvantage of non-modular cups has been the need for a locking mechanism (e.g. C-ring) that can generate metallic debris.

Over a decade ago, an investigation performed at the Hospital for Special Surgery demonstrated that the liner–metal interfaces of modular uncemented acetabular components are a source of polyethylene and metallic debris, present in peri-acetabular osteolytic lesions. It is now well-known that non-articular modular junctions create new interfaces for the generation of particulate debris, which cause a granulomatous reaction. These changes are design-dependant.

Synovial fluid containing debris particles occupy the space between the liner and the shell either by design or as a consequence of polyethylene deformation or backside wear. The authors have recently shown that during the gait cycle, or standing up, loading and deformation of the liner forces the backside content into the iliac bone through the screw holes. This phenomenon explains the presence of ballooning osteolytic lesions, which compromise long-term fixation in vivo. In fact, when osteolysis is severe and the strong supportive iliac bone is lost, stresses transmitted to the interface between the ingrowth surface of the well fixed cup and the titanium shell substrate can lead to fatigue-separation of the ingrowth surface from the shell; the authors have recently observed this in four patients with a titanium fiber metal cup.

Locking Mechanism Failure

The mechanical properties of the locking mechanism are dictated by design. Tradonsky et al. examined the in vitro push-out and lever-out strength necessary to dissociate the liner from the metal shell in eight unused modular acetabular components with five different locking mechanisms.20–24 Push-out and lever-out forces required to dissociate Harris-Galante components were lower than those required to dissociate other cups, suggesting that the original locking mechanism was deficient. In cups with a weak locking mechanism by design, or debilitated due to shell-liner micro-motion, complete failure of the locking mechanism was evident. In cups with a weak locking mechanism due to design, or debilitated due to shell-liner micro-motion, complete failure of the locking mechanism resulted in dislodgement of the liner from the metallic shell.20–24

At the Hospital for Special Surgery, the authors studied the clinical findings and retrieved the implants of 11 patients who suffered a dislodgement of a Harris-Galante cup.24 The major contributors to the dislodgement were three time-dependent variables—the fatigue-associated deformation or breakage of the locking mechanism, the increased micro-motion in the shell-liner interface due to polyethylene degradation, deformation and backside wear, and impingement of the neck and the liner rim that increases as wear progresses.

Modern Modular and Non-modular Cups

In an attempt to address the previously mentioned problems, modern modular cups have improved locking mechanisms and11,12 maximized shell-liner conformity, smooth inner metallic surface,25 and a limited number of holes or no holes.4 These modifications reduce shell-liner micro-motion and backside wear in in vitro studies.26 In addition, introduction of the press-fit technique allowed implantation of cups without holes, limiting the access of particles to the iliac bone.4,27

Increased shell-liner conformity in modular cups maximizes the area of supported polyethylene, diminishes micro-motion between the liner and the shell, and distributes stress and load more evenly. Such advantages should result in less stress transmitted to the locking mechanism and less micro-motion and backside wear.11,12 Plaxton et al. quantified the cup-liner conformity and contact area in seven unloaded metal back acetabular cup designs. The area of unsupported polyethylene was 9% in the Impplex cup, and 12% in the Trilogy cup without holes. The contact area of supported polyethylene was 30cm² and 22cm², respectively, which are among the highest of the seven designs tested.26

The Trilogy cup has been broadly implanted at the Hospital for Special Surgery. The authors have evaluated 297 patients who underwent 335 consecutive PTHAs with the Trilogy cup carried out by Dr. Eduardo Salvati. All cups were implanted using the press-fit technique. Ten patients were lost to follow-up, and 16 died from unrelated causes. The remaining 271 patients (308 hips) were followed clinically and radiographically for four to seven years. Only one cup was revised because of aseptic loosening. Among the 271 patients who were alive at the time of the last follow-up, 266 (98%) still had...
retention of the shell and 264 (97%) had retention of the liner and the shell with a good or excellent clinical result. In the group of 229 patients (262 hips) with complete radiographic follow-up, 259 cups were well fixed and the average wear rate was 0.09mm/year. Osteolysis was detected in only 12 hips (5%) and was associated with male gender (p=0.001) and the annual wear rate (p=0.004). The extent of calcar resorption was also associated with the annual wear rate (p<0.001) indicating that though particles cannot access the iliac bone in shells without holes, they are capable of producing osteolysis in the proximal femur.4,9

Another approach for reducing the complications of modularity is the use of non-modular cups in which the liner is pre-assembled by the manufacturer in a shell without holes.28,29 Non-modular components should have no motion between the liner and the shell and therefore no backside wear.29,30 In order to assess backside wear of second-generation modular cups and non-modular cups had not been yet demonstrated in vivo, the authors recently performed the following study. They compared the backside wear of retrieved Implex non-modular cups with that of modular cups of first- and second-generation designs.31 They match-paired for time in situ, patient age and weight, nine retrieved Harris-Galante type 1 liners, nine received Harris Galante type 2, nine were given the Trilogy, and nine received liners from a modern two-piece pre-assembled cup (Implex). The average time in situ was 2.5 years. The backside was divided in quadrants and each examined and rated with a validated semi-quantitative score ranging from zero (absence of wear in all quadrants) to 12 (severe backside wear in all quadrants). The average total backside wear score was 8.4, 7.3, 3.7, and 2.3 respectively. The HG1 and HG2 cups demonstrated more severe backside wear than the Trilogy and Implex (HG1 versus Trilogy and HG1 versus Implex; p<0.001, HG2 versus Trilogy and HG2 versus Implex; p<0.02). There was a tendency toward less backside wear in the Implex cup when compared with the Trilogy (p=0.04). The authors’ study demonstrated a significant reduction in vivo in the backside wear of modern modular and non-modular acetabular cups, when compared with first-generation modular designs, with a trend toward less backside wear in a non-modular design.31

In summary, understanding the mode of failure of first-generation uncemented modular cups, together with refinements in manufacturing and implantation techniques, allowed the design and use of modern modular and non-modular uncemented cups that demonstrated a low rate of peri-prosthetic osteolysis and backside wear in vivo. These advancements should result in a low rate of peri-prosthetic osteolysis and mechanical failure in the long term.

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