Review Article

Treatment of femoral bone loss in revision total hip arthroplasty: a clinical practice review

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Abstract: Patient and implant selection is essential to optimize outcome. Femoral bone loss classifications such as the American Academy of Orthopaedic Surgeons, Gross, and Paprosky classifications permit surgeons to systematically manage bone stock deficiencies and guide implant selection. Here we provide a comprehensive report on the pitfalls and management of this reconstructive challenge. Preoperative planning remains vital to the treatment of femoral bone loss in revision hip arthroplasty and the authors believe it is essential and should include the entire femur. This commonly includes imaging for bone loss such as Judet views or computed tomography scan and must include the entire femur though additional radiographs such as Judet views apply more for acetabular bone loss as opposed to femoral bone loss. All patients should have pre-operative work up to exclude infection. If any of these results area elevated, an aspirate and sampling is required to guide microbiological management. Classically with regards femoral revision surgery, uncemented fixation has proven to give the best outcomes but surgeons must remain flexible and use cemented fixation when necessary. Adequate proximal bone stock permits the use of implants used in primary joint surgery. Implants with proximal modularity can be used in cases where bone stock allows for superb proximal bone support. The vast majority of femoral revisions have inadequate proximal bone stock, thus distally fixed stems should be used and have been shown to provide both axial and rotational stability provided there is an intact isthmus. Taper fluted stems can provide good outcomes even in cases of major bone loss. However, with severe bony loss, impaction grating or the use of a megaprotsthesis is sometimes necessary and is down to surgeon choice and preference. This article has been written as a guide for management and summarises the best evidence available.

Keywords: Hip revision; femoral revision surgery; femoral bone loss; femoral implants; cement on cement revision

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Introduction

Background

Total hip arthroplasty (THA) is a procedure that is used when the cartilage in the joint is damaged and leads to excessive pain and decreased function. The first successful modern day THA was performed by Sir John Charnley at Wrightington Hospital and it was designed as a low friction arthroplasty (1). Technology and surgical techniques have improved since that time and it has now been shown to be a successful procedure with adequate survivorship and excellent quality adjusted life years (QALYs) (2). It is no

longer a procedure reserved for a more elderly population and is increasingly used in more demanding, younger patients. In the USA, the numbers of THA are set to double by 2030 (3). It is therefore not surprising that with increased life expectancy and greater numbers of THA being performed in a younger, more active patient cohort, revision surgery is also increasing (4). Aseptic loosening, instability, and infection are common causes for revision (3,4), each presenting unique reconstructive challenges. Femoral bone loss is often seen in revision surgery and the quantity and quality of the bone dictates implant selection and reconstructive options (4). The etiology for revision and implant extraction contributes to variable degrees of femoral bone loss which must be addressed to produce durable and stable implant fixation.

Rationale and knowledge gap

Revision surgery aims to produce long-term implant survivorship with restoration of hip mechanics (5). Diaphyseal engaging stems are typically used with adequate isthmic bone stock with more severe loss at this site necessitating a megaprosthesis or cemented design (6). Stems that achieve diaphyseal fixation can be cylindrical and extensively porous coated or titanium fluted tapered components (5). Monobloc or modular components are available with proximal body modularity allowing for more accurate adjustment of version, leg length and offset (7-9). These have shown excellent results in the presence of damaged proximal bone (9).

Objective

Long term component fixation is essential and is reliant on axial and rotational stability. Uncemented components are reliant on adequate bone stock which can provide initial primary stability and biological ingrowth. High failure rates are associated with cemented stems and proximally coated cementless implants as host bone is unable to provide adequate cancellous-cement interlock or provide an environment for biological ingrowth (10). When the biological and mechanical properties of an implant are not adequately supported by host bone, the risk of failure is increased. In cases of salvage procedures, cemented stems with impaction grafting, segmental proximal femoral replacements or the use of allograft may be used to provide joint stability, implant fixation and adequate function. The purpose of this review is to summarise the existing evidence and present the best evidence available to aid surgeons with regards implant decision making in the challenging scenario of femoral bone loss.

Pre-operative planning

Careful preoperative planning is essential in these cases. While remaining bone stock post implant removal cannot be predicted with 100% accuracy, the pattern of pre-operative bone loss is critical to surgical planning. A full history and examination is taken prior to surgery with particular attention paid to duration of symptoms and other associated symptoms. Laboratory tests including erythrocyte sedimentation rate (normal, <30 mm/s) and C-reactive protein level (normal, <10 mg/dL) are useful when excluding infection. If elevated, then a joint aspiration is indicated. Synovial fluid obtained with a hip aspirate should be sent for differential cell analysis and both aerobic and anaerobic cultures. A white cell count of 2,000–3,600 and a differential of >80% polymorphnuclear (PMN) leukocytes is suspicious for infection (11,12). Jandl *et al.* (12) demonstrated an absolute PMN cell count of less than 2,000/μL as adequate for ruling out periprosthetic joint infection. In the presence of metal-on-metal components, or an adverse reaction to metal debris in metal on polyethylene implants, metal ions including cobalt and chrome should also be tested. The requested cell counts and differentials should be done using manual instruments, as automated cell counts, in the presence of metal ions, may be inaccurate. Radiographs are used to detect stress shielding, deformity, cortical deficiency, and the cement mantle if present (13). Although radiographs can underestimate the degree of bone loss, further 3-dimensional imaging with a computed tomography with metal artefact reduction is rarely necessary for the femoral side (14). The surgeon should obtain the operation note and implant stickers for any previous surgical intervention, and ensure that the correct equipment is obtained for implant removal. The removal of well-fixed implants is beyond the scope of this chapter.

Surgical options for femoral implants

Several authors have summarized femoral stem options (15-17). Each of these options are reliant on existing bone stock. Treatment strategies and implant choice is therefore selected pre-operatively and based on the classification systems available.

Classification of bone loss

Several classification systems exist for quantifying femoral bone loss and they include D'Antonio (American Academy of Orthopaedic Surgeons, AAOS) (18), Gross (19) and Paprosky (16). The AAOS classification is largely based on the presence of segmental, cavitary or combined defects. This is a simple and easily understandable classification system however it does not quantify the amount of bone loss and does not allow for implant selection. The Paprosky classification is the most used to describe femoral bone loss and plan for surgery. It describes the site of femoral bone loss—metaphyseal versus diaphyseal, a description of the proximal bone stock and the quantity of isthmic bone available for diaphyseal fixation. Type II bone loss can involve extensive metaphyseal damage with an intact diaphysis where in type III bone loss, the metaphysis is not supported and has a varying degree of diaphyseal bone. Type IV is the most severe and femurs with this classification are described as 'stove-pipe'. Although this is accepted as the most popular classification, it was designed for the purpose of cylindrical porous-coated stems, hence the importance of the isthmus. With the more versatile "cone within a cone" fixation of tapered fluted stems, fixation distal to the isthmus is possible. As such, when using taper fluted stems, the only two types of femoral bone loss that need to be distinguished are ones with an intact metaphysis and ones without.

Reconstructive options according to bone loss using the Paprosky classification

Type I defects can be treated with either cemented or uncemented implants as with this type of bone loss, the proximal metaphyseal bone is maintained, and proximal femoral remodeling is not seen. In revision scenarios, some have seen more improved results with uncemented designs (20). This type of bone loss, however, rare, and if cementless fixation is used, a modular stem with a metaphyseal sleeve is ideal in order to get optimized metaphyseal fixation, though non modular fully coated systems are also used with encouraging results (6). In most of these cases cancellous bone is missing, and therefore cemented fixation is not reliable, and should only be used in the very elderly with a limited life expectancy (21). The most commonly seen defects are type II, with an intact diaphysis but absent proximal metaphysis and only some proximal varus femoral remodeling. Extensively porous-coated implants have yielded good results (16,21) with more modern tapered fluted stems gaining popularity due to excellent results (22). With type III defects, options include extensively porous-coated cylindrical stems, tapered stems with circumferential fluted projections and cemented stems with impaction bone grafting. Type III defects have been seen to perform well with both extensively porous-coated stems and with a modular tapered stem with anti-rotational flutes which provide rotational stability. With type IV defects, it used to be thought that it is difficult to obtain biological fixation so reconstruction would often take the form of a long cemented stem, allograft-prosthetic composite (APC), impaction grafting with a long cemented stem or a megaprosthesis (16,21). However, with long fluted tapered titanium stem fixation is possible and the use of impaction grafting with a long-cemented stem or a megaprosthesis is becoming much less common than in the 1990's and early 2000's (22).

Historical implant options

The use of a cemented stem was more commonly seen in earlier revision scenarios but due to the improvement in uncemented technology, their use is less frequent. Some biomechanical tests have found a cemented revision stem to have 80% less shear strength that a primary cemented stem (23). The use of this technique therefore saw a high rate of early failure and loosening (24-27). In the modern era, one of the indications for a cemented stem are low demand patients or those with a high fracture risk. Due to the high failure rate of cemented designs, uncemented proximal porous components were designed to get over the problems associated with cementing into poor quality metaphyseal bone. However, it was noticed that poor quality metaphyseal bone was not capable of providing primary stability and a biological environment for bony ingrowth so early failure was seen with these early designs (28). A study by these authors showed an average survivorship of 52% at 8 years of follow-up with aseptic loosening as an end point. Their study looked at 375 uncemented stems with 6 different designs. The most significant predictors of failure were pre-operative bone loss and quality of the metaphyseal bone.

More contemporary treatment options

Cement within cement revision

This technique sees the surgeon recementing a new implant into an existing cement mantle. This only applies for slip taper cemented designs and not for composite stem designs. The removal of cement during revision surgery can lead

to significant complications (29,30). These complications include cortical perforation, fracture, loss of bone, bleeding and operative complications. If the cement mantle is intact, and the stem has to be removed to improve offset, version or leg lengths, or simply for enhanced acetabular exposure a cement within cement revision can be used. With this technique, a smaller femoral component is cemented into an existing stable cement mantle. Some surgeons have cemented the same component if it is not damaged and is compatible with the use of other revision components. In that case, a tap-in-tap-out technique may be used, and an identical implant can simply be tapped into the existing cement mantle, if it is a collarless, polished, tapered stem though it is important to adequately prepare the old cement mantle by ensuring it is dry and roughened. This allows a greater surface area for cement interdigitation during the liquid phase which reduces lamination (31). However, roughening is not always possible especially if the cement mantle is thin. Since cement bonding to cement is chemical, interdigitation is not necessary, and the senior author does not use power tools to roughen the cement to avoid damaging the existing mantle. Indications for a cement within cement revision include a malpositioned stem with an adequate cement mantle or when stem revision is needed to impart greater implant stability, which is not possible to be achieved by modifications of the cup and/or the liner (32), as in using a higher offset stem, or cementing the stem prouder within the mantle to correct a shortened leg. One of the benefits of a cement within cement revision is that an extended trochanteric osteotomy is not needed to remove distally placed excess cement (33,34). A study by Duncan *et al.* (35) with a series of 135 hips with cement within cement revision at an average of 8 years follow up, showed no signs of aseptic loosening.

Cemented versus uncemented revision surgery

It has been shown that cemented femoral revisions have failure rates as high as 19% compared with 4–6% for uncemented components (6,25,36). Uncemented implants typically need 4–6 cm of diaphyseal fixation and when possible, uncemented biological fixation is preferred (37,38) though, it is widely acceptable that cemented fixation may still have a role and may be needed in certain cases (39-41), although these indications are becoming less and less over the years.

Uncemented revision

Proximally porous coated stems

These uncemented implants can be used with minimal proximal bone loss or type I Paprosky revisions. These defects can be seen after removal of a cementless implant with a narrow shape or one with minimal proximal bony ingrowth. The metaphyseal bone is often sufficient to allow osteointegration and further bony ingrowth (42). Again, when the proximal bone stock is preserved, cemented stem revision has shown good results (43,44). This has also been successfully achieved in cases of revisions such as hip resurfacings.

Proximal modular components

It is difficult to obtain initial implant stability with proximally coated monobloc stems, hence this led to the use of modular implants, e.g., the S-ROM prosthesis (DePuy). A study by Cameron *et al.* (37) specifically looked at revision surgery using the S-ROM in 320 cases. They had a mean follow up of 7 years and included 109 cases with short stems and 211 cases with long stems. With regards to aseptic loosening, there were no reported revisions in the short stem group and 3 revisions (1.4%) in the long stem group. With these implants, a diaphyseal section is connected to a press-fit metaphyseal sleeve. Its modularity allows the metaphyseal bone to exactly match that of the proximal sleeve and this combines with a versatile diaphyseal stem which itself can vary in diameter and length. The modularity also gives the surgeon more improved control over stem version.

Uncemented diaphyseal fixation

Extensively porous-coated cylindrical stems

Early failures with both uncemented and cemented femoral implants led to the need for diaphyseal fixation. This led to the development of extensively porous coated cylindrical stems which were popularized in North America (45,46). With this technique, femoral preparation is performed line to line for bowed 8–10" stems or undersized by 0.5 mm for 6, 7 or 8" straight stems, and stability is achieved with the diaphyseal scratch fit. While these are collared stems, if primary stability is not achieved with a good

scratch fit (47), collar contact will be insufficient, in the senior author's experience, for durable fixation. The porous coating allows biological fixation via bony ingrowth after the initial interference fit. These stems have shown excellent long-term survivorship in the revision setting in large studies with long term follow up. Engh *et al.* (47) looked at 2,854 femoral stems with three different but identical distal fixation designs (Anatomic Medullary Locking, Prodigy, and Solution, DePuy, Warsaw, IN) and saw only a 1.1% loosening rate at 15 years. Others have seen similar results with excellent outcomes with this type of component (45). Weeden *et al.* (48), reported on 170 revisions over a mean period of 14.2 years. Over this period, the percentage of stems that required revision surgery was 4.1%. Femoral defects were classified according to the Paprosky classification system with 11% as type I, 30% type II, 48% type IIIA, and 11% type IIIB. Evidence of bony ingrowth was seen radiographically in 82% and 14% had stable fibrous fixation. A high rate of failure (21%) was seen with more significant bone loss (type IIIB), and the intraoperative fracture rate with stem insertion was 8.8%.

This component is associated with perioperative fracture. The tight interface fit is achieved via significant force and a study by Egan *et al.* (49) showed an intraoperative fracture rate as high as 20%. Increased fracture risk was associated with poor bone quality, increased stem length and increased stem diameter. Stress shielding is also seen with these stems and can be seen in as many as 33% of cases (50) though the authors from this study noted that its incidence was not observed in stems less than 12 mm. Garcia-Cimbrelo *et al.* (51) showed an overall stem survivorship of 97% in 114 cases with 5–17 years of follow up where stress shielding did not influence survivorship. Whilst the significance of stress shielding is yet to be clarified in the elderly population, in a younger patient cohort the clinical significance is likely to be greater as a lack of femoral bone stock would make additional revision surgery challenging.

Monoblock systems are often used in favour of modular implants to mitigate stem fracture risk though this complication is also seen in monoblock constructs. Busch *et al.* (52). Showed a fracture rate of 2.3% in 219 extensively porous-coated stems. This occurs when the proximal stem segment remains unsupported above a well-fixed diaphyseal stem and undergoes cantilever bending. The stem undergoes fatigue failure and fractures. They stated that stem diameters less than 13.5 mm and previous extended trochanteric osteotomies were both risk factures for stem fracture.

The use of fully coated stems must also be done cautiously in the presence of significant bone loss. Sporer (53) showed a failure rate of 19% in type IIIB femurs and 38% in type IV femurs with a canal diameter greater than 19 mm. They hypothesised that larger diameter and longer femoral components prevented adequate scratch fit fixation.

Tapered fluted titanium femoral implants

As cylindrical porous-coated stems do not function well when there is diaphyseal bone loss, tapered fluted titanium femoral stems have become more popular. In addition, femoral stress shielding is of concern when cylindrical porous-coated stems, and this is not the case with fluted titanium femoral stems, which adds to their attractiveness for most femoral revision, even with an intact diaphysis. These stems were initially introduced by Wagner in 1986, and were in use in Europe in the 1980's and 1990's before their introduction in North America (13,54). The original Wagner stem suffered from poor offset as the neck was quite vertical. This concept was re-designed initially as a modular design, and more recently as a monobloc design. The philosophy behind the modular design is that the distal segment can fix within the bone, then leg lengths, offset and anteversion can be fine-tuned with proximal components that attach to the stem using a Morse taper and locking bolts from the top. However, modular components are associated with a greater fracture risk of fracture at the Morse taper interface. Because of the risk of fracture, nonmodular implants may be used, but the surgeon has to be careful to make sure that the implant is adequately sized to ensure immediate stability, with a reduced risk of fracture or failure (38,55).

Modular fluted tapered stems

As stated, modular stems can restore hip mechanics more readily independent of distal stem position (54). Restoration of hip mechanics can prove difficult in the presence of periprosthetic fractures or varus remodelling when using a monoblock system (7), although the senior author routinely uses monoblock stems for periprosthetic fractures without difficulty.

Desai *et al.* (56) showed a survivorship of 97% at 5 years in 52 patients treated with modular fluted tapered stems. In their study, the degree of bone loss was not correlated with an increased risk of loosening, subsidence, nor infection. With more significant bone loss, Palumbo *et al.* (57) showed

no cases of stem failures due to aseptic loosening in their study of 18 cases with types IIB or IV of femoral bone loss. Other studies also looking at femoral revisions with more significant bone loss have advocated the use of this stem design (58,59). The incidence of stress shielding has been seen to be reduced as the conical design leads to a more even load distribution and has even been seen to improve and restore bone stock (60). Though this has not been seen universally (61), as the authors of this study saw a 21% rate of stress shielding only in stems greater than 18 mm in diameter with a mean follow up of 10 years. Amanatullah *et al.* (58) showed a similar stress shielding rate of 22% in 92 patients with modular components.

Earlier designs have been more associated with modularity fracture with rates being reported as high as 18% and as low as 1% (62,63). The high failure rate was explained by a small diameter taper junction in one of the stem designs, though inadequate proximal support and excessive body weight are risk factors for cantilever bending and hence further failure much like the cases seen in monoblock cylindrical stems. Manufacturers have reduced the incidence of this complication by increasing the taper size though patients must still be closely observed for this complication and counselled accordingly. One risk of fracture is having dissimilar metal at the junction, as in the Revitan stem (Zimmer, Warsaw, IN) (64).

The benefits of modularity have been to better restore hip mechanics. While they have been shown to improve accuracy in leg lengths (65), they have not improved the rates of instability when compared with monoblock or cylindrical systems. Dislocation rates have varied between 3% and 19% (66,67) and others have shown instability as the highest complication with these stem types (67,68). In a series including 70 type IIIB and IV Paprosky femurs treated with modular fluted tapered stems, Brown *et al.* (69) showed dislocation to be the most common complication with a reoperation rate of 17% and a complication rate of 26%. It was abductor function that led to the higher association of dislocation so it is thought that these options should be used with other components such as dual mobility, constrained liners, or large femoral heads in at risk groups.

Monoblock tapered systems

The risk of stem fracture, metallosis and osteolysis are reduced with nonmodular stems though restoration of hip mechanics has been seen to be more difficult with the use of these stems. Subsidence requiring stem revision was seen 3 out of 38 hips (8%) at a mean follow up of 47 months in a study by Grünig *et al.* (70), although the stem used in that study has a 2° taper with a higher chance of subsidence, and the indications for revision in that series were for severe bone loss, periprosthetic fractures, and reimplantation after Girdlestone procedures, all of which are demanding indications. 16 other stems had subsided by <1 cm by 3 months follow up but this did not affect clinical outcome. In a study looking at 43 hips, Isacson *et al.* (71) showed that 5 patients had subsided by >2 cm and 22 patients by <5 mm. Nine cases had dislocated with 8 requiring re-revision for instability, but in that series the original Wagner stem was used, and it is now obsolete.

More modern designs such as the Redapt stem (Smith and Nephew, Memphis, TN) have been utilized with encouraging results. A recent study by Gabor *et al.* (22) in their retrospective cohort looked at both THA and revision THA and showed mean total subsidence was 1.64 mm (SD 2.47) in 157 cases where a monolithic, tapered, fluted grit blasted revision femoral stem was used. They showed that overall, 17 of 144 stems had subsided >5 mm and 3 out of 144 >10 mm within one year. They concluded that improved designs and trials with a greater variety of stem lengths and offset options had mitigated the concerns of subsidence and instability with monoblock systems.

Subsidence occurs less commonly with modular stems (72) though the evidence suggests it occurs more commonly in patients greater than 80 kg in weight and with less than 2 cm of stem-cortex contact (73).

Impaction grafting and cemented revision

With this technique, the old stem is removed, and the canal removed of debris, old cement, fibrous tissue and endosteal membrane. The concept is to convert smooth and sclerotic bone into a surface that is more amenable to cementation and hence stem fixation. This is done by tight packing of cancellous allograft chips of variable size. A plug is placed distal to the bone defect in intact bone, and cancellous bone is tightly packed into the canal initially with cylindrical tamps to pack the bone in the defect. The bone around the anticipated stem is then packed with cannulated phantoms similar to broaches over a guide wire. A highly polished, tapered, collarless stem is then cemented into the reconstructed femur which permits further controlled subsidence into an open centralized for optimal implant stability (74). Success with this technique varies with

departments, with those of less experience performing less well. Long term construct survivorship has been shown as beneficial (75,76). A large study by Ornstein *et al.* (39) saw 15-year survivorship at 94.0% for woman and 94.7% for men with any reason for revision as an end point. They evaluated 1,188 revision performed with impaction grafting and a polished Exeter Stem (Stryker, Mahwah, NJ, USA). Overall survivorship at 15 years was 99.1% for aseptic loosening, 98.6% for infection, 99% for subsidence and 98.7% for fracture. Follow up ranged from 5–18 years where only 70 cases needed re-revision.

The concerns with this technique remain fracture, stem subsidence, extensive use of allograft, and surgical time. Fracture can be related to poor quality bone and hence impaction of cancellous bone into cortical defects (77,78) with intraoperative fractures recorded as high as 12%. Subsidence of greater than 5 mm is commonly seen (77,78) and has been reported to occur in up to 38% of cases. This again is likely down to technique and due to inadequate impaction grafting, inadequate cement mantle, fracture or resorption of the graft (79). It is a difficult procedure and outcomes are good when performed in centers with adequate experience of this technique.

Salvage scenarios

Allograft prosthetic component (APC)

When met with significant femoral bone loss +/− an enlarged femoral diaphysis poor in quality, proximal bone is osteotomized and a long stem prosthesis is cemented into bulk proximal femoral allograft and inserted in a press fit manner into the distal canal. If the stem is inserted in a press fit way then the APC is shaped to dock into the canal and fixation between the allograft and host bone is done using a step cut. Rigid distal fixation into the host bone is to be avoided in order to reduce the risk of non-union and graft resorption (80).

One of the advantages of this salvage procedure over a proximal femoral replacement is the ability to preserve bone stock and soft tissues such as the abductors. As with all allograft, disease transmission is a risk though the chances are small (81) and other disadvantages include the non-union risk or resorption of the graft (82). The chances of success are maximized when the APC host bone contact ensures rotational and axial stability.

Overall survivorship has been seen as high as 69% at 10 years by Babis *et al.* (83) in their study of 57 hips treated with an APC. They had an average follow up of 12 years with 33.3% (20) of hips undergoing revision surgery at an average follow-up of 44.5 months. Bone loss was seen to significantly affect survivorship (P=0.019) as was greater than two previous operations (P=0.047), and APC length (P=0.005).

Complications associated with this procedure have seen to be dislocation (13%), infection (8%) and aseptic loosening (11%) (84). This study was a systematic review of 498 hips with a survivorship of 81% at 8 years follow up. Nonunion is also a frequently encountered complication and has been reported as high as 25% and fracture ranges from 2–5% in various studies (85-87). Blackley *et al.* (40) showed that allograft resorption was as high as 27% in 63 cases of APC revisions at 9 years with 4 dislocations, 5 deep infections and 3 cases of aseptic loosening at the implant cement interface. With the modern use of tapered fluted titanium stems, the senior author has not used this technique in almost 20 years.

Megaprosthesis

In cases of significant proximal bone loss where resection arthroplasty is considered, this type of prosthesis can be used and is often reserved for the elderly, low demand patients. Survivorship is a concern with these implants and has been reported at 72% at 5 years (88) and 64% at 11 years (89). Though an additional study by Parvezi *et al.* (90) showed significant improvements in the Harris Hip Score (P<0.05) achieving excellent or good functional outcomes in 22 of 43 hips.

Longevity is a problem with these prostheses due to inadequate fixation and subsequent early loosening (91-93). Though, the more recent evidence suggests a higher survival rate due to improved technology and techniques. Instability is also seen with these designs owing to poor soft tissue quality (94,95) with other complications also seen such as limb length discrepancy and nerve palsy (96,97). Though, an added advantage with this device is that implantation is timely and is an option when few other implants can be used.

Strengths and limitations

We believe this is a robust analysis of the current evidence available on the topic. A wide variety of subject matter is presented with inclusion of seminal papers and more novel approaches. The evidence presented here represents

the best current practice and it has been condensed to help shape opinion and decision making. Though, we appreciate there are limitations. There does appear to be some heterogeneity in the literature which makes direct comparisons more challenging. There is a paucity of randomized controlled trials and studies would ideally increase samples sizes in order to reduce type II errors on statistical analyses. We suggest greater work on the subject in order to drive the gold standard.

Conclusions

Hip revision surgery is a challenging procedure and its management is dictated largely by patient factors and the availability of bone stock. Accurate pre-operative planning is essential, and the authors advocate for grading the degree of bony loss as per the Paprosky classification. Implant choice is dictated by surgical preference and expertise. Pre-operative work up includes imaging and investigation to exclude infection such as CRP or aspiration if necessary. In cases of significant cortical loss, strut grafts can also be used to provide stability (98,99) and presence of a femoral isthmus will drive decision making with regards implant choice. Modular and monoblock tapered systems are available and indications for both have been discussed. The development of porous coating has improved distal stem fixation methods but we advocate surgeons planning for several reconstructive options as bone quality can be worse than expected and complications such as peri-operative fracture can necessitate a change of implant choice.

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