Review Article

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Management of Severe Bone Defects in Femoral Revision following Total Hip Arthroplasty

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Treatment of femoral bone defects continues to be a challenge in revision total hip arthroplasty (THA); therefore, meticulous preoperative evaluation of patients and surgical planning are required. This review provides a concise synopsis of the etiology, classification, treatment strategy, and prosthesis selection in relation to femoral bone loss in revision THA. A search of literature was conducted for identification of research articles related to classification of bone loss, management of femoral revision, and comparison of different types of stems. Findings of a thorough review of the included articles were as follows: (1) the Paprosky classification system is used most often when defining femoral bone loss, (2) a primary-length fully coated monoblock femoral component is recommended for treatment of types I or II bone defects, (3) use of an extensively porous-coated stem and a modular fluted tapered stem is recommended for management of types III or IV bone defects, and (4) use of an impaction grafting technique is another option for improvement of bone stock, and allograft prosthesis composite and proximal femoral replacement can be applied by experienced surgeons, in selected cases, as a final salvage solution. Stems with a tapered design are gradually replacing components with a cylindrical design as the first choice for femoral revision; however, further confirmation regarding the advantages and disadvantages of modular and nonmodular stems will be required through conduct of higher-level comparative studies.

Keywords: Femur, Bone loss, Revision surgery, Total hip arthroplasty

INTRODUCTION

The number of revision total hip arthroplasty (THA) procedures has shown a rapid increase worldwide in the last two decades. According to projected estimates for the United States, by 2030 the demand for primary THA will have increased by 174% and by 137% for revision THA from the levels reported in 2005[1]. Findings from the analysis of data for England and Wales suggest that the volume of primary and revision THAs will have increased by 134% and 31%, respectively, between 2012 and 2030[2].

In economic terms, revision THA is estimated to account for 19% of expenditures for Medicare hip replacement between 1997 and 2003[3]. In 2012, the 9th National Joint Registry report for England, Wales, and Northern Ireland reported that the expenditure for revision total knee arthroplasty and THA performed under the National Health Service in 2000 exceeded £60 million[4]. Compared with primary arthroplasties, the cost of revision THA and use of hospital resources is substantially greater. Revision operations require more time, require more expensive prostheses, and the patients have a longer stay in hospital with higher associated complication rates and morbidity. In addition, the indication for revision surgery has a direct influence on cost, and the cost for cases of infection is significantly higher than that for aseptic revisions[2,5].

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In cases of femoral bone loss, which can vary in degree, particularly Paprosky III-IV[6], failure to provide adequate support for the prosthesis can lead to subsidence, loosening, and other serious complications. Despite development of numerous components for use in management of severe femoral bone loss, prosthesis-related complications have persisted, including fatigue fractures, corrosion, dislocation, and infection[7,8]. In addition, because patients are now undergoing revision at a younger age, these complications can be catastrophic due to failure of the residual bone mass to withstand future revisions. Therefore, treatment of femoral bone loss in the setting of revision THA remains a challenge. This review article focuses on the etiology of femoral bone loss, related classification systems, selection of prostheses for different bone defects, and clinical results from use of various treatment options.

ETIOLOGY OF FEMORAL BONE DEFECTS

Many factors are involved in development of femoral bone defects, including stress shielding, periprosthetic joint infection, aseptic osteolysis, periprosthetic fracture, iatrogenic bone loss, and metastatic lesions[6-10]. Among these, aseptic loosening, infection, and periprosthetic fracture are the main reasons for femoral stem revision[11]. Regardless of etiology, assessment of the pattern of bone loss and the degree of residual fixation of the femoral stems should be performed before surgery to ensure selection of an appropriate treatment option at the time of revision.

CLASSIFICATION

In 1993, the American Academy of Orthopedic Surgeons proposed a system for classification of femoral bone loss based on detection of segmental, cavitary, or combined bone defects[12]. A segmental defect is defined as a loss of support from femoral cortical bone. This may occur at level I (above the lower end of the lesser trochanter), level II (within 10 cm of the lower edge of the lesser trochanter), or level III (distal to 10 cm below the lower edge of the lesser trochanter). A cavitary defect is defined as a loss of cancellous or endosteal cortical bone without violation of the outer cortical shell, which is often observed in combination with ectasia of the femoral medullary cavity. Combined bone defects are the result of a combination of segmental and cavitary bone loss in the femur, which can be caused by osteolysis, stem movement, or iatrogenic conditions. The usefulness of this classification system for providing practical guidance during treatment is limited due to its simplicity.

The classification system developed by Paprosky et al.[6] was introduced in 1999. This system is based on the location of femoral bone loss (metaphyseal or diaphyseal), degree of residual proximal femoral bone stock (i.e., amount of cancellous bone loss), and the amount of residual isthmus available for diaphyseal fixation. The classifications are: type I, minimal metaphyseal bone loss with an intact diaphysis; type II, extensive metaphyseal bone loss with an intact diaphysis; type IIIA, metadiaphyseal bone loss, 4-cm scratch-fit can be obtained at the isthmus; type IIIB, metadiaphyseal bone loss, 4-cm scratch-fit cannot be obtained; and type IV, extensive metadiaphyseal damage, thin cortices, and widened canals. This classification system can be helpful in guiding the surgeon in selection of the appropriate femoral stems according to the degree of bone defect, thus it has become a widely used "gold standard".

TREATMENT STRATEGY

1. Paprosky Types I-II

Promising clinical outcomes have been achieved with typical management of mild to moderate proximal bone loss with a primary-length fully coated monoblock femoral component[13-15]. Despite the suggestion made by many surgeons that revision stems should bypass femoral defects by at least two cortical diameters, navigation of the femoral bow is required with use of longer stems[16], which compounds the complexity of the surgery and the risk of intraoperative fracture[17], and leads to reduction of bone stock for future reconstructions[18]. Tetreault et al.[13] reported that the tip of the previous stem or cement mantle was not bypassed in the majority of revisions (78%), and that a high rate of osseointegration could still be achieved with use of a primary-length monoblock stem so long as 4 cm of distal fixation was obtained. Pinaroli et al.[18] shared their perspective on "conservative femoral stem revision" using a primary stem with a double-taper and quadrangular cross-section shape, supported by an absence of revision and 100% osseous integration. In addition, the advantages of using a primary stem include a more simplified surgical technique,

the potential for a lower risk of complications, and preservation of femoral bone stock for future revisions if required. The findings of a comparative study of primary and revision stems indicated that there was no difference in subsidence, leg length discrepancy, and Hip disability and Osteoarthritis Outcome Score Joint Replacement (HOOS JR)[19]. The findings of a systematic review also indicated that use of primary cementless stems in femoral revision surgery can be regarded as a feasible option, supported by a mean stem-related survival rate of 95.6%±3.8% at a mean follow-up of 4.7±1.3 years[20].

2. Paprosky Types III-IV

Treatment of severe bone defects remains a major challenge. Extensively porous-coated stems and modular fluted tapered stems have been developed for management of Paprosky III and IV femoral defects.

In a study that followed 51 patients with types III or IV defects who were treated with an extensively porous-coated stem for 4.2 years, Sporer and Paprosky[21] reported that a canal >19 mm in diameter was a limiting condition for extensively porous-coated stems because of a failure rate of 18%. However, good results have been achieved with use of this stem in patients with type III defects. Chung et al.[22] performed 96 revisions for 89 type IIIA defects and seven type IIIB defects; in these cases, the mean diameter of the canal was 16.5 mm. The resulting rate of bony ingrowth was 98.8% (92/96) at a mean follow-up of 65.7 months[22]. Ding et al.[23], who evaluated 31 revisions diagnosed with 28 type III defects and three type IV defects, reported that only one case was radiologically unstable and the survival rate was 96.2% at 10 years.

In recent years the modular tapered fluted stem has gradually been accepted as the preferred treatment for severe bone defects. Use of this stem enables independent sizing in the metaphyseal/diaphyseal component, variable stem-to-neck length options, and the option of change in the version and offset. Otero et al.[7] reported on evaluation of 82 patients with types III or IV defects and 47 patients with Vancouver B2 and B3 femoral fractures that were revised using this stem for a mean of 3.75 years. They reported 1.4 mm (range, 0-21 mm) of median subsidence, a bone integration rate of 94.6%, and 98.4% survival with aseptic loosening as the end point[7]. Palumbo et al.[24], who evaluated 18 revisions, reported a 6% rate of re-revision resulting from a chronic periprosthetic infection and symptomatic subsidence with a mean follow-up period of 4.5 years. Desai et al.[25] reported on evaluation of 52 hips treated with a modular femoral implant at a mean follow-up of 3.8 years; despite a 5-year survival rate of 100%, there were eight intraoperative periprosthetic fractures, two deep infections, and three dislocations.

Considering that patients are undergoing revision at a younger age, residual bone stock cannot provide any additional support for a new implant, thus severe post-revision complications can be discouraging. In such cases, conservative femoral revision using short cementless stems with a tapered rectangular cross-sectional shape as an alternative has been reported[26-29]. The rectangular cross-sectional shape provides four-point fixation along the four corners within the femoral canal, supporting rotational stability without impairing the endosseous blood supply, thus facilitating bony ingrowth and long-term stability[26]. In addition, the dual-tapered shape enables further endosteal engagement, greater stem-diaphyseal diametric mismatch, and a resultant increase in circumferential compression of the implant, ensuring axial stability. According to Chang et al.[26], owing to the above-mentioned characteristics, use of this type of stem could initially ensure exceptional stability in any morphologic shape of the femur. Uriarte et al.[27] reported that, at seven years, the estimated stem survival was 95.5% for revision for any reason and 100% for revision for aseptic loosening. Korovessis and Repantis[28] and Wang et al.[29] also reported a 10-year survival rate of 95% and survivorship of 98% at an average follow-up of 5.6 years, respectively.

In addition, impaction bone grafting, reconstruction of allograft prosthesis composite (APC), and the use of a proximal femoral replacement (PFR) megaprosthesis have also been applied for management of types IIIB and IV femoral bone defects.

The technique of femoral impaction bone grafting, which was developed in 1987, uses morselised cancellous bone graft impacted into the femoral canal in combination with a cemented, tapered, and polished stem[30]. With the development of instruments with a specific design and reconstruction meshes, the acceptable clinical efficacy of this technique has been confirmed. A systematic review and meta-analysis that included 16 studies (498 patients) with a mean follow-up period of 8.1 years reported a pooled success rate of 81%, pooled structural failure of 15%, and a pooled infection rate of 8%[31]. From the microscopic point of

view the graft is now organised according to three zones. The surface layer consists of regenerated cortical bone; the interface between cement and living tissue is located beneath, and the deepest layer consists of bony trabeculae within cement[32]. In addition, release of bone morphogenetic protein-7 from the impacted allograft can occur; this release occurs in proportion to the strain applied to the bone, which indicates that the impaction is favorable to the process of remodelling and incorporation of bone[33].

APC and PFR techniques are an attractive option; however, these techniques should be applied by experienced surgeons as a final salvage solution. Hadley et al.[34] conducted a retrospective analysis of the midterm clinical results of 46 revision THAs using proximal femoral telescoping APC. They reported that, at 10 years, the overall patient survival was 58%, reoperation-free survival was 76%, and construct survival was 95%, and there were no cases of radiographic femoral stem loosening, a union rate of 86% at the APC-host site, 23% with signs of some allograft resorption, and a trochanteric union of 54%[34]. Viste et al.[35] reported on evaluation of PFR for Paprosky IIIB or IV bone loss. During an average follow-up period of six years, revision of two PFRs was required due to infection and aseptic loosening, and survivorship free of any revision or removal of an implant was 86% at five years and 66% at 10 years. Although good efficacy has been achieved in the early stage with use of APC and PFR, further validation of the long-term results is still needed.

STEM DESIGN

1. Tapered vs. Cylindrical

Currently, the stem has two main geometric forms: cylindrical stem and tapered stem. An increasing number of studies comparing the efficacy of the two stems in regard to various aspects have been reported. Although one study reported that no differences in mean subsidence rates, HOOS JR scores, or aseptic re-revision rates were observed between the two types of stems[36], an increasing number of surgeons now consider the tapered design component as their first choice. Russell et al.[37] reported on a study comparing the initial fixation stability between a tapered stem design and a fully porous-coated cylindrical stem design in cadaveric models. Higher average loads for production of 150-μm displacement or failure (>4 mm subsidence) were observed for tapered stems than for cylindrical stems (393 N vs. 221 N; 1,574 N vs. 500 N, respectively). Zhang et al.[38] reported that the average subsidence was 2.17 mm (range, 0-8 mm) in the tapered group, which showed significant improvement compared with that in the cylindrical group, which was 4.17 mm (range, 0-15 mm). When the diameter of the proximal end of the tapered stem is increased, the fixed strength of the tapered stem will be greater, and a higher load is required to produce settlement using the tapered stem compared with the cylindrical stem[38]. A tapered design component can be wedged into the femur to ensure stability, which can be effective in reducing the stiffness and stress shielding of the stem compared with the cylindrical stem fixed by backbone rubbing[38,39]. Richards et al.[8], who conducted a retrospective study for comparison of a tapered, fluted, modular titanium (TFMT) stem and a cylindrical nonmodular stem, reported that higher outcome scores (Western Ontario and McMaster Universities [WOMAC] pain, WOMAC stiffness, Oxford-12, and Satisfaction), fewer intraoperative fractures, and better restoration of the proximal femur host bone were observed in the TFMT cohort.

2. Modular vs. Nonmodular

There is controversy regarding the use of modular and nonmodular stems. Some scholars have reported that the modular component enables easy adjustment of lower limb length, forward inclination, and eccentricity[40,41], whereas there are several disadvantages associated with the nonmodular component, including postoperative dislocation and a high incidence of prosthesis sinking[42]. However, other authors have suggested that there are some disadvantages associated with use of the modular stem, including a high incidence of intraoperative fracture, corrosion, and fracture at the proximal and distal parts of the prosthesis[43], whereas use of the nonmodular component involves a relatively simple surgical procedure without severe postoperative complications. In two retrospective studies, Huang et al.[11,44] reported that no significant differences in the postoperative Harris hip score, the level of overall satisfaction, the 8-year cumulative survival, the rate of infection, dislocation, and postoperative periprosthetic fractures were observed between the two types of stems[44]; however, use of modular stems resulted in reduced restoration of proximal osseous in residual osteolytic areas and more severe femoral stress shielding,

stem tip spot-welds, and radiolucent lines around the stems[11].

CONCLUSION

Treatment of femoral bone loss in revision THA continues to be problematic. Accurate evaluation of the degree of bone defect before surgery can facilitate selection of a suitable femoral stem, which is essential for achieving clinical success. Treatment with a primary-length fully coated monoblock femoral component is recommended for limited bone defects (Paprosky types I and II), and management with an extensively porous-coated stem and a modular fluted tapered stem is recommended for complex bone defects (Paprosky types III and IV). An impaction grafting technique is another potential option for improvement of the bone stock. APC and PFR can be used by experienced surgeons, in selected cases, as a final salvage solution. In addition, conduct of comparative studies demonstrating a higher level of evidence will be required in order to verify the clinical efficacy of different types of stems.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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