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Stem Fixation in Revision Total Knee Arthroplasty: Indications, Stem Dimensions, and Fixation Methods

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Although stems improve initial mechanical stability in revision total knee arthroplasty (TKA), ideal indications, proper lengths and diameters, and appropriate fixation methods remain controversial. The topics of the present article include the indications, selection of lengths and diameters, and fixation methods of stems in revision TKA. The use of a stem in revision TKA can protect the juxta-articular bone. A stem cannot be a substitute for optimal component fixation; it plays an adjunctive role in transferring the loads from the compromised metaphysis to the stronger diaphysis. Proper bone surface preparation and appropriate use of the stem based on a great store of knowledge are required to support the stemmed components effectively in revision TKA. The balance between overshielding and overloading the juxta-articular bone would provide excellent structural protection. The stem length and diameter should be tailored according to patients' anatomical characteristics and determined fixation strategy. There are two traditional methods of stem fixation including the total cementation technique and the hybrid technique with a cementless press-fit stem. Selection of a cementation technique should be based on thorough consideration of advantages and disadvantages of each technique.

Keywords: **Knee, Arthroplasty, Revision, Stem**

Introduction

One of the primary goals of total knee arthroplasty (TKA) is to recreate a stable joint with accurate position and orientation of prostheses, mimicking the normal knee kinematics. However, it would be a more difficult task in the revision setting due to combined severe bone defects and soft tissue insufficiency. Stems are required in most revision TKAs to help transfer loads from the compromised articular and metaphyseal bone to the remaining tibial cortical rim and to widely distribute the increased stress of a constrained articulation.

They improve the mechanical stability at the cost of stress shielding. Mechanical stability can be improved by resistance to shear, reduced lift-off, and decreased micromotion[1)]. However, long stems may have disadvantages including end-of-stem pain and stress shielding along their length with associated reduction in bone density, a theoretical risk of subsidence, loosening, and periprosthetic fracture[1,2)]. It is known that the axial load can be reduced by 23% to 39% when a stem length reaches 70 mm[3)]. With a stem up to 150 mm in length, marked stress shielding of the proximal tibial cortex and doubling of the strain are noted at the stem tip[3)].

Although the need for stem to improve initial mechanical stability and ultimate component survival is well accepted, the ideal indications, proper lengths and diameters, and fixation methods remain controversial. No evidence-based guidelines are available to help determine when to use a stem, which length and diameter are ideal, and whether or not to use cement fixation[4)]. Such decisions should be based on a great store of knowledge rather than on presumption. In this review article, we will discuss the indications, selection of stem lengths and diameters, and fixation methods in revision TKA.

1. Indications

Stems should be used in revision TKA when the remaining

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bone stock is insufficient to support the prosthesis. Bone grafting for large volume defects may require the use of a stem to protect the graft from excessive load. The knee joint bears loads that are several times the body weight. If a stem fails to transfer the load, then the remaining cancellous bone will experience load beyond its ultimate strength, which will lead to a loss in component fixation in the initial phase[5]. Modular metal augments (blocks or wedges), cones, or sleeves can be used when the cortical rim or either the distal femur or proximal tibia is breached. The selection of metal augments typically mandates the use of a stem. Brand et al.[6] reported the results of 22 TKAs with modular metal wedges and small tibial cemented stems: no tibial tray was considered loose at an average of 37 months of follow-up.

Wolff's Law states that bone remodels in response to applied stress and strain in the chronic phase. The strain for normal remodeling of the proximal tibia should be within a physiological range of 50 to 1,500 με[1]. Below 50 με, stress shielding is likely to occur and bone resorption takes place[1]. On the contrary, the risk of damage within the cancellous bone with microfractures increase above 1,500 με, and the risk of collapse with pathological overloading increases above 3,000 με[1]. The stiffer the material, the greater the stress shielding effect. Also, the greater the difference in Young's modulus of elasticity between the material and surrounding bone, the greater the stress shielding. Greater shielding is therefore expected in cobalt-chrome components than in titanium components. Accordingly, factors affecting the selection of a stem include not only bone stock and the type of bone defect but also component material. However, recent studies with finite element analysis have shown no difference in stress shielding between long stems made of titanium and cobalt-chrome[1]. The development of metaphyseal cones or sleeves and porous trabecular metals have provided an alternative to stems although biomechanical studies are warranted[7]. More research on various stem lengths, surface finishes, and different stem fixation techniques are needed under different circumstances to optimize the strain environment.

The increased constraint of polyethylene insert in patients with soft tissue insufficiency can result in increased stress between the components and cement or between cement and host bone. Therefore, more stable fixation of components would be required in patients with severe soft tissue insufficiency and constrained prostheses[8]. Anderson et al.[9] reported good results of 55 TKAs using a constrained condylar prosthesis without stem extension: there were one case of femoral loosening and one case of tibial fracture at 44.5 months of follow-up. Sabatini et al.[10] reported favorable clinical and radiographic results with use of the second generation semi-constrained prosthesis with stem extension. Although the use of the stem remains controversial in constrained TKA, the stem should be used routinely if there is inadequate bony surface.

The stem can also be used for the treatment of periprosthetic fractures after TKA. Fractures around a loose prosthesis are classified as Rorabeck type III[11]; the exchange for a prosthesis with a longer stem for diaphyseal fixation is the treatment of choice in this type of periprosthetic fractures. As in the case of fractures around the femoral component, the stability of the prosthesis is important in the treatment of periprosthetic tibial fractures. In fractures with subtype B according to Felix classification, a loose prosthesis has to be exchanged for a revision prosthesis with diaphyseal stem fixation[12].

Stems can be used depending on the extent of offset. Hicks et al.[13] noted significant variability in the location of the tibial canal relative to the tibial plateau. They found that the intramedullary canal center was usually anterior and medial to the tibial plateau. Tang et al.[14] described that the axis of the tibial shaft is located anterolateral to the center of the tibial plateau in Asian population. These studies highlighted the feasibility of offset stems of the tibial component in revision TKA.

2. Dimensions (Length and Diameter)

Micromotion of knee prostheses can be significantly reduced by increasing the stem length, diameter, and canal filling ratio (CFR) in revision TKA using press-fit stems[1]. Biomechanical studies also demonstrated significant improvement in joint stability with use of a press-fit stem with an increased length and diameter[15,16].

When a short stem (25 to 30 mm in length) is used, it should be cemented for stability. However, the use of long modular stem extensions, which are canal filling and diaphyseal engaging, can provide the stability in a press-fit method without the use of cement. Wood et al.[17] reported the results of 135 revision TKAs using press-fit diaphyseal fixation and cemented metaphyseal fixation: the 12-year survival analysis showed 98% probability of survival free of revision for aseptic loosening.

However, the literature review failed to identify the "ideal" length[18]. It is unlikely that an ideal length can be determined because of the heterogeneity of patients' anatomical characteristics and revision circumstances. Patient-specific tailoring of reconstruction strategy will be needed to match the patient's anatomy, bone loss, and constraint requirements.

Although some authors have recommended at least 4 cm of diaphyseal engagement for press-fit stems[19], longer stems that approach the confined diaphyseal isthmus may need to be narrower[20]. The length of a diaphyseal engaging stem must be determined concurrently with the stem diameter[20]. No clinical evidence has effectively reconciled this relative influence of stem length and diameter. The ideal composite of stem length and diameter may be better expressed as the CFR, which is defined as the width of the stem divided by the width of the intramedullary canal. The canal filling stems permit considerable diaphyseal cortical contact, which may enhance component stability and improve mechanical alignment[20,21]. Fleischman et al.[22] reported that the risk for mechanical failure was reduced by 41.2% for every 10% increase in CFR. Parsley et al.[23] recommended a CFR of >0.85 to achieve stable intramedullary fit.

A long stem can force articular components into suboptimal position (Table 1). Gobba et al.[24] demonstrated that a 120 mm tibial stem will force the tibial component into an excessively valgus position, and a 200 mm tibial stem will often force the tibial component into a posteromedial position above the tibial surface. Therefore, proper surgical strategies are required to prepare a cut surface that facilitates the entry of the long stem. We will describe such strategies in the next section.

A preoperative estimate along with the intraoperative assessment of stem length and diameter is required to determine the extent of press-fit. The preoperatively templated stem diameter has to be confirmed intraoperatively to the point at which cortical chatter is felt or heard with a reamer at the preset stem length. A greater degree of press-fit is required when there are severe bone defect and soft tissue insufficiency[3]. Reaming to a greater diameter and removal of more endosteal bone induce more robust support for the stemmed component; it facilitates the insertion of a stem of larger diameter and provides an enlarged stem-to-bone contact associated with positive effects on stability[25]. The press-fit stem length and diameter have to be tailored to optimize the canal filling with the consideration of patients' anatomical characteristics and degree of bone defect and prosthesis constraint. Manufacturers provide various press-fit or cemented stems with different lengths and diameters (Table 1), which need to be prepared to match various patients' anatomical characteristics (Fig. 1).

3. Fixation Methods

Two traditional methods of stem fixation have been used: total cementation technique and hybrid technique with a cementless press-fit stem. Both techniques have their own advantages and disadvantages (Table 2)[20,26]. Based on the available literature, no superiority of any type of stem fixation has been found[26]. Due to the inhomogeneity of failure mechanism, bone stock, implant design, and comorbidities, a strictly randomized controlled trial (RCT) for revision TKA is nearly impossible to compare the outcomes according to the cementation technique[26]. A recent RCT[27] performed radiostereometric analysis with (1) constructs of the same length, (2) the same Anderson Orthopaedic Research Institute type of bone defect, (3) implants with the same level of constraint, and (4) exclusion of re-revision TKAs. No difference was reported in median migration or the number of migrating components between total and hybrid cementation techniques in revision TKAs. However, another study[28] showed that cemented stems were significantly more likely to have radiographic loosening compared to uncemented stems (4.9% vs. 1.6%, p=0.02). It suggested that the reamed diaphysis was a poor surface for cement interdigitation, leading to higher rates of radiolucency (32% vs. 17%, p=0.006).

Some surgeons favor the use of a specific technique, but others select them on an ad hoc basis. Most surgeons prefer the hybrid technique with a press-fit stem in ordinary revision TKA (Table 3)[20]. However, the total cementation technique is occasionally required when the metaphyseal bone is severely destructed and the inner cortex is too poor in patients with severe osteoporosis. We will describe the hybrid cementation technique first and then

Table 1. Length and Diameter of Stem according to Providers in Korea

Variable	Depuy PFC Sigma	Zimmer NexGen LCCK	Biomet Vanguard 360	Stryker Triathlon TS	Smith & Nephew Legion revision
Cemented	(Tibia) 30 or 60×13	30×15	No	50×9, 12, 15	20×10, 12, 14
	(Femur) 90 or 130×13	100×10–16		100×9, 12, 15	60×10, 12, 14
		155×10, 12, 14, 16		150×9,12,15	100×10, 12, 14
Cementless	(Tibia) 75×10, 12, 14, 16, 18	No	40×10–16	No	60×9–16, 18
	115×10, 12, 14, 16, 18		80×10–16		100×9–16, 18
	(Femur) 95×10, 12, 14, 16, 18		120×10–16		
	135×10, 12, 14, 16, 18				

Values are presented as length×diameter (mm).

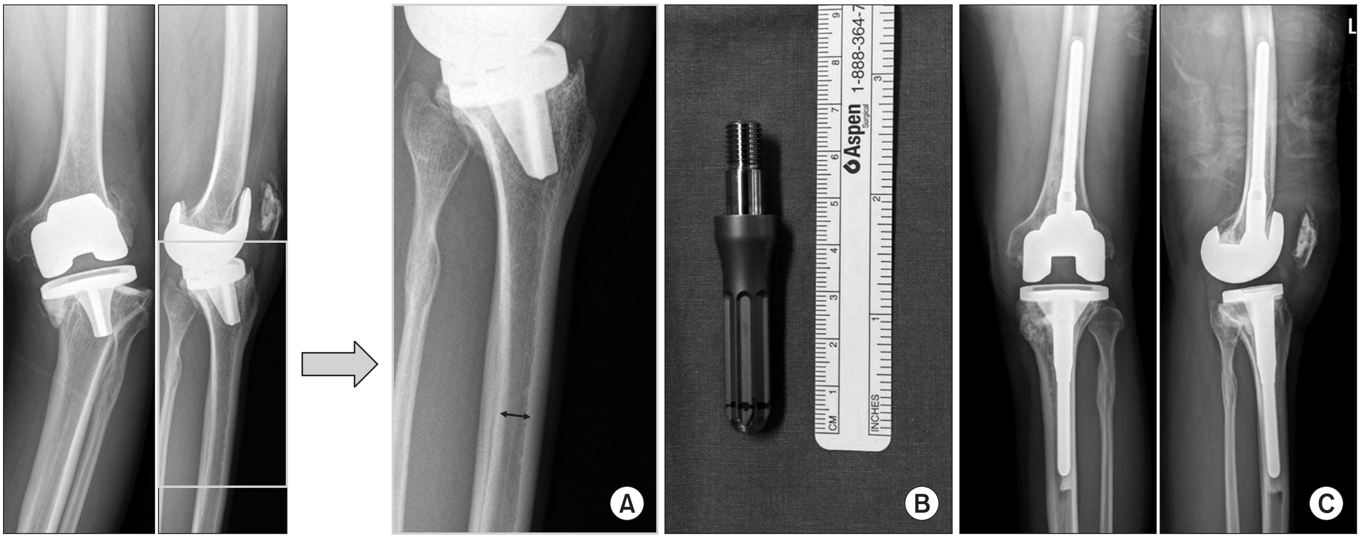

Fig. 1. Preoperative planning on the diameter and length of a stem. (A) Tibial component loosening required stable fixation of the tibial component using a stem in revision total knee arthroplasty, but the narrow intramedullary canal made the use of a stem difficult (double-headed arrow). (B) The 75×10 mm press-fit stem was altered to be 45×10 mm to prevent an insertion failure. (C) Fortunately, the ordinary 75×10 mm stem could be inserted with modification of the stem insertion point.

Table 2. Advantages and Disadvantages of Total Cementation versus Hybrid Cementation Techniques in Revision Total Knee Arthroplasty

Variable	Total cementation with fully cemented stem	Hybrid cementation with press fit stem
Advantage	Easy to implant	Potential for bone stock preservation
	Better initial stability	Less stress shielding
	Potential benefit of intramedullary elution of antibiotics	Optimizing mechanical alignment by diaphyseal referencing
	More variability in component positioning and sizing	Easy to remove
	Useful especially in diaphyseal bowing	Applicable in patients with previous DFO or HTO
Disadvantage	Difficult to remove	Potential for end-of-stem pain
	Decreased references for proper alignment	Potential forcing of component into suboptimal position without offset stem
		Risk of periprosthetic fractures with canal preparation

DFO: distal femoral osteotomy, HTO: high tibial osteotomy.

Table 3. Comparison of Indication and Concept between Total Cementation and Hybrid Cementation Techniques in Revision Total Knee Arthroplasty

Parameter	Total cementation with fully cemented stem	Hybrid cementation with press fit stem
Indication	Huge bone defect	Ordinary revision setting
	Poor bone quality	
Concept	Metaphyseal engaging	Diaphyseal engaging
Length	Short	Long
Characteristic	Smooth, small range of diameter option	Fluted, wide range of diameter option
Material	Co-Cr	Titanium

introduce the use of cement plugs in the total cementation technique.

Preoperative radiographic planning includes assessment of the intramedullary canal to ensure that stem insertion is possible without ipsilateral hardware and deformity or that the intramedullary canal axis conforms to the mechanical axis orientation.

Eccentric joint surfaces may require the use of offset stems[29]. The stem length and diameter are estimated to obtain adequate endosteal press-fit. Preparation of at least two possible stem lengths with correspondingly different stem diameters would allow optimal application and prevent cortical impingement.

Intraoperatively, technical efforts should be focused on exposing the good inner cortex to achieve a sufficient press-fit and matching the cut surface and stem orientation, when using an extramedullary alignment guide. Alternatively, preparation of the cut surface can be easily performed using a broad intramedullary guide rod or a reamer. The initial reaming removes ectatic and sclerotic inner cortex which can lever the reamers away from the true intramedullary canal axis[3]. Then, the intramedullary canal is sequentially reamed to the appropriate length and diameter to accept the press-fit stems. Traditionally, reaming is performed approximately 1 cm past the tip of the stem to ensure that there is no tip impingement with the possibility of cortical erosion. It is continued in millimeter increments until minimal endosteal cortical contact is felt at the preoperatively determined stem length. For structural-bulk allografts, reaming should be continued at least 1mm wider beyond the point at which cortical chatter is felt and heard to improve initial stability.

The position of components is dictated by the position of the press-fit stem. If the canal is eccentric, an offset stem should be considered. In particular, the femoral component position in the sagittal plane with a straight stem is also dictated by the stem and therefore determines the flexion gap. Because posterior shifting of the femoral component's position or addition of posterior femoral augments to alter the flexion gap cannot be accomplished with a straight stem, a posterior offset stem or a femoral component with a different housing junction point can be a good viable option[3].

When components are easily seated without a stem but failure of seating occurs with the stem, the surgeon should consider the following causes: (1) improper stem size; (2) occurrence of endosteal impingement; and (3) mismatch between the prepared bone surface and the intramedullary position of the stem. The use of an offset stem and adjustment of stem position with intramedullary widening should be considered as a solution.

After sufficient reaming and confirmation of the match between the canal and prepared bone surface, cement is mixed and packed along the cut surfaces with component undersurface and metaphyseal keel, but not around the stem tip.

For the total cementation technique with a fully-cemented stem, impingement of stem or mismatch between the prepared bone surface and stem orientation is uncommon (Table 2). However, optimization of mechanical alignment by diaphyseal referencing cannot be expected. Care should be taken to achieve accurate positioning of components and alignment during the bone preparation and cementation. With a cement plug placed above the expected level of the stem tip, cement is pressure injected into the intramedullary canal. Additional cement is mixed and packed along the prepared bone surfaces with undersurface of the articular components, surfaces of the metaphyseal keel, and around the stem.

Conclusions

Use of a stem in revision TKA can protect the juxta-articular bone and transfer the load to the stronger diaphyseal bone. The balance between overshielding and overloading of the juxta-articular bone is crucial for excellent structural protection. Proper bone surface preparation and appropriate use of stems based on a great store of knowledge are required to support the stemmed components effectively in revision TKA. The stem length and diameter should be tailored according to the patients' anatomical characteristics and selected fixation strategy. Two traditional methods of stem fixation (total cementation technique and hybrid technique with cementless press-fit stem) have their own advantages and disadvantages, which should be carefully taken into consideration in the selection of a cementation technique.

Conflict of Interest

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

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