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Stem length in revision total knee arthroplasty

Anay Rajendra Patel[1] · Brian Barlow[2] · Amar S. Ranawat[3]

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Abstract Stems are intramedullary extensions of either the femoral or tibial component of a total knee arthroplasty (TKA) designed to increase the mechanical stability to decrease the risk of aseptic loosening. Biomechanical studies have shown that TKA stems increase the mechanical stability by transferring load over a larger area and thereby reduce strain at the bone-component interface [1–4]. The length of a revision TKA stem is determined by the patient's anatomy and the intended fixation, namely fully cemented or press-fit cortical contact. The advantages and disadvantages of various stem lengths must be weighed against the needs of the patient to achieve an optimal outcome.

Keywords Revision · Fixation · Stem · Length · Uncemented · Cemented

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✉ Anay Rajendra Patel
AnayRPatel@gmail.com

Brian Barlow
BarlowB@HSS.edu

Amar S. Ranawat
RanawatAmar@HSS.edu

1 The Fondren Orthopaedic Group, 7401 Main St., Houston, TX 77030, USA

2 The Hospital for Special Surgery, 535 E 70th St., New York, NY 10021, USA

3 The Hospital for Special Surgery, 535 E 70th St, 6th Floor, New York, NY 10021, USA

Introduction

The evolution to the modern total knee arthroplasty began with initial interposition arthroplasty designs that had existed as early as the 1860s [5]. Knee arthroplasty then evolved to the Walldius hinge arthroplasty in the 1950s which utilized stems to combat the high torsional and bending stresses transmitted to the bone secondary to excessive constraint [6, 7]. The unacceptable early loosening and failure of the hinge designs led to future resurfacing designs with less need for stem fixation. Gunston applied design and surgical philosophies from his partner Sir John Charnley by utilizing a polyethylene bearing and polymethyl methacrylate for fixation [8]. These principles of soft tissue preservation, fixation with bone cement, and incorporation of polyethylene were critical to the development of modern primary knee replacements such as the total condylar prosthesis (TCP) [8]. The cemented TCP design and its uncemented contemporaries such as the Eftekhar Mark I did not utilize stems but rather metaphyseal-engaging posts to maintain stability [9].

Stems were gradually reintroduced as increasingly constrained designs were developed to manage more complex deformities and meet the increasing revision total knee arthroplasty (rTKA) burden [2, 10]. Revision TKA challenges included variable amounts of bone loss and soft tissue incompetence that necessitated improved fixation and increased constraint, respectively, to maintain joint stability. Stems can help bypass compromised articular and metaphyseal bone while also widely distributing the increased stress of a constrained articular fixation [2, 3].

Stem lengths are variable in rTKA but are crucial to the overall success of the reconstruction. Stem length is largely determined by the stem fixation technique. The major stem fixation techniques in modern rTKA are fully cemented and uncemented fixation. Fully cemented stems are generally shorter and metaphyseal engaging. Uncemented stems are predominantly used in a "hybrid" rTKA where the articular component is cemented to the remaining articular surface and the uncemented stem is press-fit to the diaphyseal portion of the bone [10]. Both techniques have advantages and disadvantages that influence their use in rTKA. Understanding the indication for stem use will help the surgeon determine the appropriate technique for stem fixation and length.

Definition of stem length

The contemporary literature on stem use in revision knee arthroplasty is limited to case series or lower quality comparative studies that feature a variety of stem lengths often with little explanation offered as to how stem length was chosen. Increased stability from increased length should not be assumed as one study demonstrated no clear mechanical advantage to stem length or fixation method when comparing 150-mm press-fit stems and 75-mm fully cemented stems [11]. The stem/bone engagement is a more critical concept than absolute stem length. Stem/bone engagement refers to the region of the bone that the stem achieves fixation and is generally divided into either metaphyseal- or diaphyseal-engaging stems. Stems engaging the metaphysis are generally cemented to fill the space between the stem and the bone to eliminate micromotion as this region is wider and consists of more cancellous bone. Stems engaging the diaphysis are generally press-fit as this region is narrower and consists of cortical bone. Diaphyseal engaging press-fit stems are often paired with a cemented articular component which is described as a hybrid technique [10]. Therefore, a more helpful definition of stem length should define stems as metaphyseal-engaging stems (MES) or diaphyseal-engaging stems (DES).

Metaphyseal-engaging stems

Metaphyseal-engaging stems achieve fixation in the metaphysis or metadiaphyseal region of the bone. Both the articular component and stem are cemented into the metaphysis and proximal diaphysis. Uncemented MES constructs have been described; however, higher failure rates were noted [12–14]. Short cemented stems have long been considered the gold standard of revision fixation. These fully cemented stems were often 30–100 mm in length with longer stems reserved for femoral fixation and shorter stems for tibial fixation [13, 15–18].

There are several advantages to shorter stems employed in a cemented fashion (Table 1). A shorter MES allows freedom for medial/lateral and anterior/posterior placement. This flexibility can achieve a better fit for the femoral component in the coronal plane and also optimize the anterior/posterior position to manage the flexion gap. The risk of end-of-stem pain is lower with cemented metaphyseal stems than press-fit diaphyseal stems, however it has been reported with both fixation techniques [19–21]. Shorter cemented stems are more easily deployed in patients with diaphyseal bowing, deformity, or those with ipsilateral hardware. Diaphyseal deformity secondary to previous trauma, dysplasia, or inflammatory arthropathies may not be amenable to a longer DES stem. In these cases, isolating fixation to the metadiaphyseal portion of the bone can help simplify reconstruction.

Disadvantages of MES must also be considered when planning a revision TKA. In the revision setting, loss of articular bone can make component alignment difficult to gauge, a situation further complicated by the inability of a MES to reference the diaphysis for alignment. Furthermore, several authors have commented that removing a fully cemented stem in a re-revision often results in greater bone loss than uncemented DES [22–24].

Diaphyseal-engaging stems

Diaphyseal-engaging stems are generally uncemented and press-fit to the diaphysis. The articular component is often cemented to the cut surface of the metaphysis which is described as a hybrid fixation. This technique has been well described by Haas et al. among others where the articular and metaphyseal portions of the implant are cemented and the diaphyseal-engaging portion of the stem is uncemented [10]. These stems generally are a minimum of 75 mm in length and differ from shorter stems in several ways [25]. Longer stems are frequently slotted and made of titanium; both of these design features decrease stress at the stem tip in an effort to decrease end-of-stem pain.[19, 21] Longer stems with a length greater than 150 mm are available with curved or bent geometry to match the natural bows of the femur or tibia.

The length of a DES must be determined concurrently with the stem diameter. Longer stems that approach the isthmus of the bone will be narrower than wider stems that engage closer to the articular surface. No literature has clearly defined which is more important with regard to length vs. width; however, several principles have been determined which can help determine the ideal combination. Bistolfi recommended using a tibial stem no shorter than 75 mm when employing a rotating-platform hinge for rTKA [25]. A recent study by Gililland et al. suggested press-fit stem length is determined as the minimal length required to achieve 4 cm of diaphyseal fit [26•]. The ideal width of an uncemented stem has been described by the "canal-fill-ratio" (CFR), which is defined as the width of the stem divided by the width of the intramedullary canal. The authors recommended a minimal CFR of >0.85 to achieve a stable intramedullary fit [27].

There are several advantages of DES compared to a cemented MES (Table 1). Diaphyseal-engaging stems reference the diaphysis, which can be helpful for determining and

Table. 1 Advantages and disadvantages of short metaphyseal-engaging stems vs. longer diaphyseal-engaging stems

	Metaphyseal-engaging stems (MES)	Diaphyseal-engaging stems (DES)
Length	30–75 mm	>75 mm
Fixation	Generally cemented	Generally uncemented
Advantages	Small adjustments possible in medial/lateral and anterior/posterior directions	Diaphyseal referencing to help with component alignment
	Avoids limb deformity or ipsilateral hardware	Easier to remove if revision required
	Less end-of-stem pain	Applicable in patients with previous distal femoral or proximal tibial osteotomy
Disadvantages	Difficult to remove, can lead to more bone loss	End-of-stem pain
	Decreased references for proper component alignment	Without offset options can force articular components into suboptimal position
		Risk of periprosthetic fracture with canal preparation
		May not be applicable in setting of dysplasia or ipsilateral hardware

achieving the appropriate component alignment in the revision setting. Appropriate component alignment is crucial to the long-term success of revision TKA [28]. Parsley et. al showed improved alignment with uncemented stems compared to cemented stems as shorter cemented stems tended to have varus malalignment [27]. Uncemented stems are generally easier to remove than a large cement mantle that can accompany cemented stems, whether short or long [22, 24]. A hybrid construct theoretically provides stress transfer throughout the bone with no detrimental impact to bone mineral density [29, 30]. Patients with a previous distal femoral or proximal tibial osteotomy often have canal-epiphyseal mismatch that can be better managed with diaphyseal referencing and modular implants. [31, 32]

There are also several disadvantages of longer stems that the surgeon must consider when planning a revision TKA. Historically, a major concern was the restriction of diaphyseal referencing to component placement. If the stem and articular portion of the construct were mated in a linear fashion, diaphyseal referencing may force the articular component into a less than optimal position. Using computer modeling, Gobba et al. demonstrated that a 120-mm tibial stem will force the tibial tray into an excessively valgus position, whereas a 200-mm tibial stem will often force the tray into a posteromedial position [33]. Modern revision TKA implants now have offset couplers between the articular and diaphyseal portions of the implant which improve alignment and reduce implant overhang [34]. Anterior/posterior femoral offset options are crucial for managing the flexion gap in the revision TKA. Any surgeon attempting revision with a DES should be fully aware of the offset and modular capabilities and limitations of their system [35].

Unfortunately, patients with diaphyseal bowing, deformity, or previous implants are still at risk of canal perforation or abutment regardless of modularity options. Patients with previous ipsilateral total hip arthroplasty also will have the femoral stems to consider. The meeting of a hip stem and a knee stem can lead to a stress riser between the two implants, and surgeons should be aware of this prior to implanting a DES [36]. As long-stem preparation requires reaming of the IM canal, there is a small risk of fracture. Cipriano et al. reported a 3 % fracture rate in 634 stemmed TKA which occurred more commonly on the tibia; as such, surgeons should be prepared to manage such a complication [37].

Clinical outcomes

Evidence suggesting an ideal stem length with regard to clinical outcome in rTKA is lacking. The outcomes of cemented compared to uncemented stems in rTKA have been more common. Both cemented and uncemented stems have shown excellent outcomes in various series. With regard to cemented stems, a recent series identified no revisions for aseptic loosening in a series of 58 rTKA with 30-mm cemented tibial stems and an average follow-up of 5 years [38•]. The authors noted that using tantalum cones within metaphyseal defects resulted in fewer radiolucent lines. A separate series by Meneghini et al. using cemented 30-mm stems and metaphyseal cones for rTKA also demonstrated excellent outcomes [39]. These recent series reinforce that appropriate metaphyseal reconstruction with a cemented stem can produce satisfactory outcomes.

Similarly, hybrid fixation with uncemented diaphyseal engaging stem has shown excellent outcomes and survivorship. In a classic article by Haas et al., the survivorship of a hybrid rTKA with both tibial and femoral stems was 84 % with a mean follow-up of 42 months.[10] More recently, a series by Sah et al. confirmed the previous series with 92 % survivorship at 5 years with no revisions for aseptic loosening.[35] In a comparative study of cemented vs. uncemented stems for aseptic rTKA, only 22 and 24 % of the cemented stems had 4 cm of diaphyseal fit whereas all uncemented stems had ≥4 cm of diaphyseal fit [26•].

Although stem length is not specifically delineated, it can be assumed that the cemented stems were shorter than the uncemented stems. Clinical and radiographic survivorship was not statistically different. A similar study comparing 102 cemented vs. 126 uncemented stems for a two-stage infection revision found similar survivorship, reinfection, and clinical outcomes between the two techniques at an average of 52 months of follow-up. However, cemented stems were significantly more likely to have radiographic loosening compared to uncemented stems (32 vs. 17 %, respectively, p=0.006) [40•]. The authors suggested that the reamed diaphysis was a poor surface for cement interdigitation leading to higher rates of radiographic lucency. In summary, survivorship and clinical outcomes of cemented vs. uncemented stems are similar, and the relatively low-quality evidence available does not suggest superiority of one technique.

The role of metaphyseal fixation

While stem length continues to be debated, there appears to be a strong trend in the recent literature highlighting the importance of metaphyseal fixation for reconstruction survivorship [38•, 39]. The current generation of revision TKA implants improved on earlier generations by addition of ingrowth metaphyseal sleeves and porous metal cones for metaphyseal reconstruction. Previously, the predominant form of metaphyseal reconstruction was bulk allograft, but the high rate of resorption with large allografts led to the development of modern sleeves and cones [41].

The recent studies by Meneghini, Gililland, Edwards, and others noted excellent short- to mid-term outcomes using porous metal metaphyseal components as part of the reconstruction [26•, 39, 40•]. Modern revision TKA should focus on not only articular reconstruction mated to stems but also include careful evaluation of the metaphysis. Previous concerns that metaphyseal reconstruction with porous metal components may hinder press-fit stem and articular component placement has not been supported in the literature as a CFR>0.85 is reliably achieved regardless of the use of metaphyseal cones [42].

Authors' preferred technique

At our institution, we prefer to use DES for the majority of revision TKA. Long-leg standing films are used to perform appropriate pre-operative planning and to assess for ipsilateral hardware, diaphyseal bowing, or other deformity which would preclude the use of a DES. Once confident that a DES is appropriate for the patient, a press-fit modular system utilizing titanium, slotted, bullet-tipped stems is used to minimize stress at the end of the construct. Stems are reamed line to line until good cortical chatter is obtained. Stems shorter than 80 mm are not used for diaphyseal engagement. Metaphyseal reconstruction is accomplished with porous metaphyseal sleeves to create a construct with broad bony engagement. At implantation, the articular implant and the modular junction of the stem and articular components are cemented, whereas care is taken to keep all cement off the porous ingrowth surface of the metaphyseal sleeve.

In the event a patient has an ipsilateral total hip replacement or deformity not amenable to a DES, a cemented, solid metaphyseal-engaging stem 35–75 mm in length is used for metaphyseal reconstruction. The cement is hand packed and pressurized to achieve a robust cement mantle within the metaphysis. If the stem extends into the diaphysis or no bone exists to confine the cement, a restrictor is placed to improve the cement mantle and prevent cement from extruding down the medullary canal.

Conclusions

Stems are an invaluable tool for revision knee arthroplasty and have been shown to substantially increase the mechanical stability of rTKA. Stem length should be tailored both to the patient as well the intended fixation strategy as decided by the surgeon. The optimal stem length is the one that achieves a mechanically sound construct while preserving as much native bone as possible. The literature review we completed failed to identify an "ideal" length, and it is unlikely that an ideal length will be described. Revision TKA requires patient-specific tailoring of the reconstruction strategy to match the patient's dimensions, bone loss, and constraint requirements. We feel that it is helpful to divide revision TKA stems into metaphyseal-engaging stems and diaphyseal-engaging stems as this guides the fixation strategy for the revision construct.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Patel and Dr. Barlow have no conflicts of interest. Dr. Ranawat reports personal fees from DePuy, Stryker, Convatec, and ConforMIS in addition to grants and personal fees from Ceramtec.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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