AUTHOR QUERIES

DATE 1/5/2022
JOB NAME JAAOS

ARTICLE JAAOS-D-21-00913
QUERIES FOR AUTHORS Charles Ayekoloye, MD, FRCS, et al

THIS QUERY FORM MUST BE RETURNED WITH ALL PROOFS FOR CORRECTIONS

AU1) Please confirm the spelling of all authors' names and confirm all earned degrees, affiliations, and disclosures.
AU2) Please check the phrase "45 months (cemented) and 52 months (cemented)," for accuracy in the sentence "At a mean follow-up. . ."
AU3) Please check and confirm the caption of Figures 1, 2, and 4
AU4) Please check the caption 4A for clarity.
AU5) Please spell out NS in the footnote of Table 2.

Review Article

Cemented Versus Hybrid Technique of Fixation of the Stemmed Revision Total Knee Arthroplasty: A Literature Review

Charles Ayekoloye, MD, FRCS
Mehran Radi, MD
David Backstein, MD, MED, FRCSC
AU1 Moayad Abu Qa'oud, MD

ABSTRACT

Stems are required during revision total knee arthroplasty to bypass damaged periarticular bone and transfer stress to healthier diaphyseal bone. The mode of stem fixation, whether fully cemented or hybrid, remains controversial. Improvements in surgical technique and implant and instrument technology have improved our ability to deal with many of the challenges of revision total knee arthroplasty. Recent publications that reflect contemporary practice has prompted this review of literature covering the past 20 years to determine whether superiority of one fixation mode over the other can be demonstrated. We reviewed single studies of each type of fixation, studies directly comparing both types of fixation, systematic reviews, international registry data, and studies highlighting the pros and cons of each mode of stem fixation. Based on the available literature, we conclude that using both methods of fixation carries comparable outcomes with marginal superiority of the hybrid fixation method, which is of nonstatistical significance, although on an individual case basis, all fixation methods should be kept in mind and the appropriate method implemented when suitable.

From the Gluskin Granovsky Division of Orthopaedics, Mount Sinai Hospital, Toronto, Canada.

None of the following authors or any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article: Ayekoloye, Radi, Backstein, and Qa'oud.

J Am Acad Orthop Surg 2022;00:1-11

DOI: 10.5435/JAAOS-D-21-00913

Total knee arthroplasty (TKA) results in excellent pain relief, restoration of function, and improvement in quality of life with up to 95% 15-year survival.[1] As the proportion of the elderly population rises due to increasing life expectancy and with many wishing to remain active for longer, the demand for both primary and revision total knee arthroplasty (rTKA) will continue to rise. Indeed, projections show that demand for rTKA will increase by 601% between 2005 and 2030, as that for primary TKA increases by 673% in the same period in the United States.[2]

Revision TKA can be a challenging operation. An issue that surgeons are often faced with is severely compromised metaphyseal bony support. Using stemmed implants in rTKA is necessary to bypass the periarticular bone and transfer load to the stronger diaphyseal bone.[3] Stable stem fixation is a crucial

goal of rTKA and whether to choose cemented or press-fit stems remains controversial.[4]

Recently, the concept of zonal fixation has aided our understanding of the requirements for durable reconstruction in rTKA.[5] In addition, the introduction and use of porous metal cones and metaphyseal sleeves has helped provide a means of more consistently achieving successful and lasting biologic reconstruction of large metaphyseal bone defects.[6] These void fillers, combined with stems, have resulted in more secure two-zone fixation, a requirement for long-term durable rTKA.[5]

Most of the more recent literature compare the hybrid technique with the fully cemented technique.

This study reviewed the literature of the past 20 years, including the biomechanics of stem fixation, clinical results of the hybrid, and the fully cemented methods of stem fixation. The goal was to determine whether superiority in the performance of either technique can be demonstrated and provide guidance on appropriate use of either technique in rTKA based on recent available knowledge.

Hybrid Fixation

The hybrid method of fixation in rTKA is achieved using press-fit diaphyseal stems in conjunction with cementing the epiphyseal and metaphyseal regions up to the metadiaphyseal junction of the implant[7] (Figure 1). F1

The hybrid technique has some advantages over the fully cemented method (Table 1) including relative ease T1 of removal and preservation of bone stock if additional revision is required. Wood et al[8] in 2009 explained that because noncemented stems are not intended to produce ingrowth or ongrowth, stem extraction, when necessary, is a more bone-conserving procedure. In the presence of cement lock caused by an offset implant, removal of hybrid stem may become very difficult. Other advantages include the ability to achieve mechanical alignment using the intramedullary anatomic axis and offloading interface stresses.[9] It also allows fixation distal to the area of metaphyseal bone loss and provides favorable support for allograft prosthetic composites when used. The available literature shows that adequate canal fill of the stems is required to attain adequate fixation.[10] Hybrid technique requires maximal canal fill to attain a solid press fit.[10] When used appropriately, noncemented stems have demonstrated lower rates of radiographic loosening when compared with cemented stems.[11]

Hybrid technique exhibit certain disadvantages such as increased risk of an intraoperative periprosthetic fracture and stress shielding.[12] Press-fit stems also have a 20% reported incidence of end of stem pain, which may affect overall functional outcomes.[13]

Fehring et al[14] reported a comparative analysis of stem fixation in 475 rTKAs and showed that 29% of press-fit metaphyseal engaging noncemented stems were unstable compared with 7% of cemented stems according to a radiological analysis. Hybrid stems in this study were metaphyseal engaging and did not engage the diaphysis. This also appears to be responsible for the poor results in the study by Shannon et al.[15] Other studies where longer diaphyseal engaging stems were used in hybrid fixation have demonstrated excellent outcomes at mid-term follow-ups (Table 2). Hybrid T2 fixation technique remains an effective option in rTKA.[8,15-19]

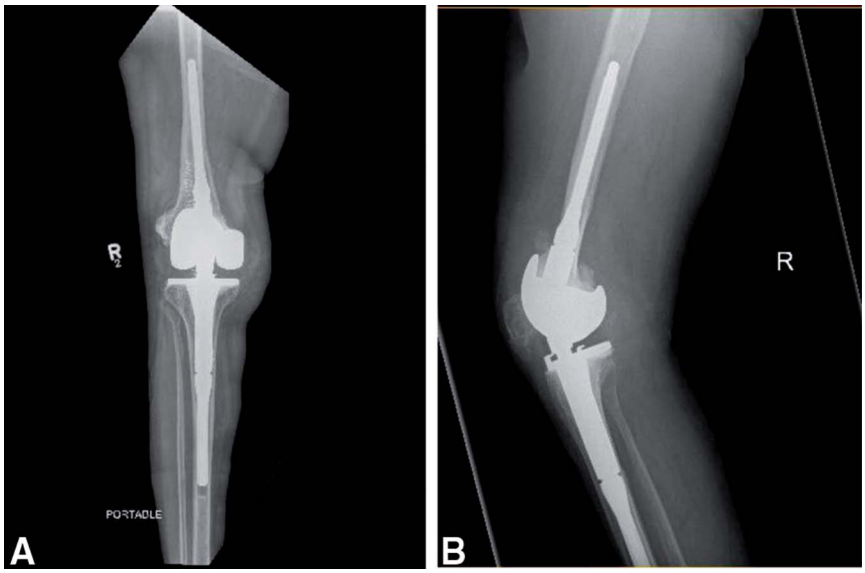
Cemented Stems

Cemented technique for total knee revision stems has been used widely. Fully cemented short metaphyseal engaging stems (30 to 70 mm) and longer, narrower stems, which are not canal fitting, are an option to decrease the micromotion in the wide cancellous bone area (Figure 2). When cementing stems in revision sur- F2 geries, intramedullary cement restrictors should be placed in tibial and femoral canals. The canals should be pressurized and filled in a retrograde manner before stem insertion. Moreover, the cement should be placed on the undersurface of the base femoral and tibial implant, at the stem-coupler junction, and along the cleansed and dried bony cuts.

Gililland et al reviewed 49 revisions with cemented stem at 10 years follow-up. A 4% risk of re-revision was shown. None of the patients had subsidence or migration of the prosthesis. Knee Society Scores (KSSs) were improved significantly from preoperative value (mean of 52 points). The success rate of the cemented stems with aseptic failure as an end point was 92% for the femoral implant and 94% for the tibial implant.[7]

Kim et al reported the results of cemented technique in 97 patients (114 knees) who underwent rTKA. The mean Hospital for Special Surgery knee score and mean Knee Society knee and functional scores were 31, 35, and 16 points before the operation and 83, 90, and 64 points at the time of the final follow-up, respectively. The complication rate was 9%. Kaplan-Meier survivorship analysis, with revision or radiographic failure as the end

Figure 1



Radiograph showing hybrid fixation technique of stemmed rTKA. **A**, AP view of rTKA with a hybrid fixation stem. **B**, Lateral view of rTKA with a hybrid fixation stem. rTKA = revision total knee arthroplasty.

point, revealed that the 10-year rate of implants survival was 96% (95% confidence interval, 94% to 100%).[20]

Baggio et al analyzed 27 patients older than 75 years retrospectively. With an average age of their participants of 82.6 ± 4.4 years and a follow-up of 43 ± 14.4 months, they did not find any mechanical failure of the implants. The functional average score was 115 ± 32 in the total KSS, of which 77 ± 17.5 points were in the KSS knee and 42 ± 24 in the KSS function. Radiologically, 18 patients presented radiolucent lines, but only three needed follow-ups using the modified Knee Society radiographic scoring system. Their results revealed that cemented stems are a good method for fixation in the rTKA in people older than 75 years with acceptable medium-term clinical results.[21]

Table 1. Summary of Advantages and Disadvantages of Cemented and Hybrid Stem Fixation Methods

Factor	Advantages	Disadvantages
Hybrid press-fit stem	Relative ease of implant removal Relative preservation of bone stock Ease of finding the anatomic axis th achieves more proper alignment of rTKA Allows fixation distal to the metaphyseal region Lower rates of radiographic loosening Less proximal stress shielding and bone loss	Higher risk of periprosthetic fractures End of stem pain from distal stress concentration Unsatisfactory distal fixation in severely osteopenic patients Epiphyseal tray malpositioning due to diaphyseal-epiphyseal malalignment requiring offset stem Difficulty removing offset stem due to geometric offset-proximal cement lock
Fully cemented stem	Potential long-term stem fixation Canal deformities more easily accommodated Antibiotic-loaded cement extends into the medullary canal Decreased transfusion due to tamponade effect of cement More variability of implant positioning and sizing is possible Useful especially in diaphyseal bowing Increases area of cement fixation to bone	Potential for malalignment associated with the use of short stems Difficulty of extraction if implant removal required Longer operating time Decreased references for proper alignment Stress shielding particularly with long cemented stems

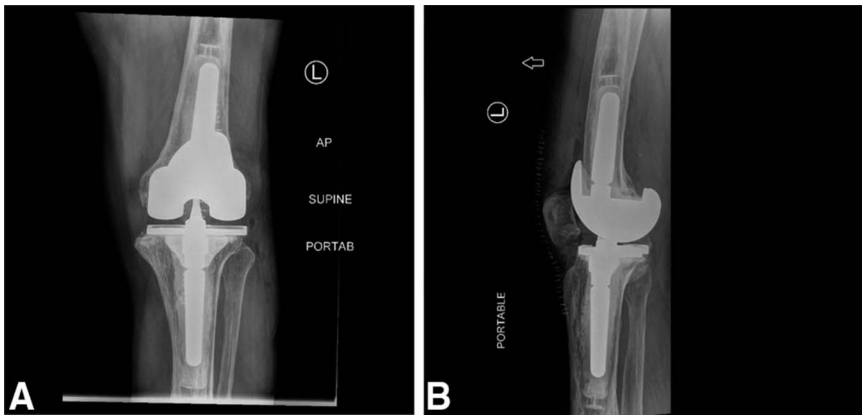
rTKA = revision total knee arthroplasty

Table 2. Hybrid Stem Fixation: Results From Articles in the Past 20 Years.

Study	No. of Patients	Revision Indication	Re-revision Indication (Infection)/n	Indication for Re-revision due to Aseptic Causes/n	Stem Length F/T (mm) (CRF-F/T %) Stem Type	Function KSS (KS/FS)	% Loosening	% Survival	Mean F/U (mo)
Shannon et al[15]	60 (63 rTKA)	AL 33 Poly wear 7 Ins 2 Inf 21	4	8 (AL 6 pain and ins 2) HO in 3 patients 1 treated surgically	F-140/T-85 (F-84%/T-88%) Smooth	KS 56-81 FS 49-62	10	81	5.75
Peters et al[16]	47 (50 rTKA) 8 died leaving 39 pts (42 knees)	AL 11 Inf 17 PPF 8 Implant failure 6 Ins 6 Malalignment 2	4	2 (1 PFCS treated arthroscopically; 1 post op hematoma treated by I&D)	F&T-120-200 (F-95% T-98%) Fluted	KS 49-87	0	92	36
Wood et al[8]	127 (135 knees) 31 died, 2 lost to F/U (38 knees)	Ins 46 Inf 34 AL 28 Osteolysis 25 PPF 2	5 (2 treated via 2 stages, 1 died before surgery, 1 refused surgery, and 1 was awaiting surgery)	4 (AL, ruptured MCL)	F 150/T 150 (NS) Fluted	KS 32-55 FS 38-86	1.5	92	60
Peters et al[17]	184	Aseptic causes 121 PPF 10 Inf 53 (of whom 15 didn't have 2 stages arthroplasty)	13 (9 recurrent sepsis and 4 new inf cases)	2 (non-union femur PPF and valgus-internal rotation malalignment femur)	F&T-120-205 (NS) Fluted	KS 72-85 FS 63-82	0	97.5	49
Greene et al[18]	119	AL 78 Inf 28 Ins 8 RDs 2 PPFs 3 Falls 2 Pathological fracture 1	1	2 (PPF 1; ins 1)	F 90.5/T 98.6 (NS) Fluted	KS 39-68 FS 37.1-79.2	0	97.5	62
Stockwell et al[19]	233 (234 knees of which 51 were previously revised)	AL 73 Stiff/pain 54 Ins/wear 49 Inf 42 Fracture/dislocation 7 Others 9	4	12 (ins 5, AL 2, PFJ maltracking/pain 2, reverse tibial slope 1, and unknown [no data] 2)	F 157/T 154 (NS) Fluted	OKS 18.8-30.6	0.9	92.3	60

AL = aseptic loosening, CRF = canal fill ratio, F = femur, F/U = follow-up, FS = function score, KS = knee score, KSS = Knee Society score, Inf = deep infection, I&D = irrigation and débridement, IKS = international knee score, Inst = instability, MCL = medial collateral ligament, OKS = Oxford knee score, PFCS = patellofemoral clunk syndrome, PFJ = patellofemoral joint, PPF = periprosthetic fracture, RD = recurrent dislocation, rTKA = revision total knee arthroplasty, Stiff = stiffness, T = tibia

Figure 2



Radiograph showing fully cemented stemmed rTKA. **A**, AP view of rTKA with a fully cemented stem. **B**, Lateral view of rTKA with a fully cemented stem. rTKA = revision total knee arthroplasty.

Fehring et al reviewed 113 rTKAs with 202 metaphyseal engaging stems. Of the 202 stems, 107 were cemented metaphyseal stems. Using a modified Knee Society radiographic scoring system, 100 (93%) of the 107 implants with cemented stems were considered stable, 7 (7%) were categorized as possibly loose requiring close follow-up, and none were loose after 57 months of follow-up. They urged caution in using noncemented metaphyseal engaging stems in rTKA.[14]

Lachiewicz et al retrospectively reviewed 54 patients (58 knees) with fixation of the revision tibial implant with a 30-mm cemented stem extension. No loosening of any tibial implant was observed, and no re-revision was performed. There were no tibial radiolucent lines in 33 knees (57%). Seventy-three tibial radiolucent lines were seen in 25 knees (43%). These were seen on either the 6-week or 6-month postoperative radiograph and were not progressive. They found the 30-mm cemented stem extension provides adequate fixation for the tibial implant in rTKA, even in knees with metaphyseal defects reconstructed with tantalum cones and in knees with varus–valgus constrained polyethylene liners required for stability.[22] Table 3 summarizes the studies of cemented tibial implants in rTKA.

Proponents of cemented stems believe that this method allows more freedom for AP and medial-lateral placement of the tibial baseplate and femoral implants (Table 1). In this way, the surgeon can fit the femoral prosthesis in the coronal plane more accurately and are able to manage flexion gap precisely.[23] The risk of end-of-stem pain is lower with this technique.[13] Shorter cemented stems can be easily used in those patients with previous trauma and diaphyseal deformity or those with the ipsilateral implant. Short, cemented stems may be considered the method of choice for individuals with dysplasia or inflammatory arthropathies who are not suitable for longer diaphyseal engaging stems.[24]

Disadvantages of fully cemented stems are greater bone loss when removing these stems and reduced references for proper alignment of the prosthesis due to bone defects in epiphyseal–metaphyseal part of tibia and femur (Table 1).[15,24] Cemented implants have a larger cement mantle compared with hybrid fixation, which may require extended surgical time and result in greater bone loss than noncemented stems during revision, thereby cause more damage to the bone.[15,24] Edwards et al showed that cemented stems were significantly more likely to have radiographic loosening compared with noncemented stems (4.9% versus 1.6%, $P = 0.02$). The reamed diaphysis was a poor surface for cement interdigitation, leading to higher rates of radiolucency (32% versus 17%, $P = 0.006$).[11]

Biomechanical Studies of Stem Fixation in Revision Total Knee Arthroplasty

A cadaveric study by Jazrawi et al[25] compared the effects of stem length, diameter, and mode of fixation on motion and stress transfer of a cemented tibial tray. Twelve fresh cadaveric tibiae had modified tibial tray cemented after resecting the proximal tibia to a depth of 10 mm. Each tibial tray and tibia were instrumented with transformers to measure tray micromotion and strain gauges to measure bone strain at specified levels below the tibial tray. Press-fit stems of 75 × 10 mm, followed by 150 mm stems of increasing diameters, were press fit into the tibiae underreamed by 1 mm. Then,

Table 3. Studies of Cemented Tibial Implants in Revision Total Knee Arthroplasty

Study	Stem Length (mm)	Revision Indication	Re-revision Indication (Infection)	Indication for Re-revision due to Aseptic causes/n	No. of Cases	Survival (%)	Mean Follow-up (mo)
Fehring et al[14]	Variable	Infection 33 Aseptic loosening 28 Instability 27 Wear-related problems 19 Periprosthetic fractures 4 arthrofibrosis 2	None	None	113	93	53
Kim and Kim[20]	100	Aseptic loosening 62 Wear of tibial polyethylene 25 Infection 14 Instability 9 Flexion contracture 2 Tight posterior cruciate ligament 1 Failure of unicompartmental prosthesis 1	2	3 cases out of 114 needed revision	97 pt 114 knees 29 fully cemented	96	86
Lachiewicz and Soileau[22]	30	Aseptic loosening 20 Knee infection 10 Knee instability 23 Knee implant malposition 2 Knee stiff, painful knee 3	1	None	54 patients 58 knees	100	60
Baggio et al[21]	70, 120	Loosening 21 Infection 1 Periprosthetic fracture 1 Knee stiffness 3	3	None	27	100	43

75- and 150-mm stems were cemented into the tibia. Both types of constructs were tested with both vertical and eccentric loading in varus, valgus, and flexion, and tibial tray motion and bone strain were measured.

This study showed significantly increased tray micromotion with use of short hybrid press-fit stem compared with longer hybrid press-fit stem. Long hybrid press-fit stems achieved tray stability equivalent to short fully cemented stems. A trend for increasing stability of the tibial tray with increasing length and diameter of the hybrid press-fit stem was observed. Completo et al,[26] using strain gauges in cadaveric tibia also demonstrated that the fully cemented stems resulted in more pronounced stress shielding effect on the bone next to the tibial tray compared with the hybrid press-fit stem.

Completo et al[27] also noted increased concentration of strain at the tip of the stem, which was observed with both types of fixation but was more pronounced in the long hybrid press-fit stem. They postulated that this accounted for stem tip pain noted more with hybrid fixation in clinical practice.

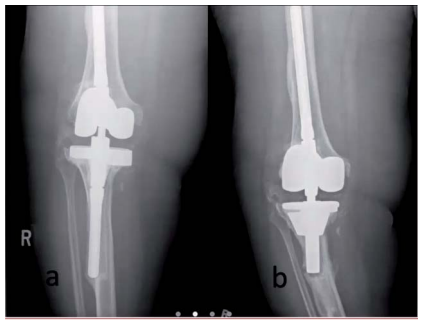
The issue of implant stability was also the focus of a recent prospective randomized controlled study by Kosse et al who used radiostereometric analysis to compare the performance of 12 fully cemented and 11 hybrid stem fixations at a mean 6.5-year follow-up. They did not observe any statistically significant difference between both modes of stem fixation. However, they showed that 5 cemented tibial stems had more than 1-mm micromotion, which might increase the risk of mid-term/long-term loosening, compared with none in the hybrid group. This was, however, not accompanied by radiolucent lines around the implants or the presence of clinical symptoms.[28]

An advantage of diaphyseal engaging stem fixation compared with short fully cemented stem is an accurate

Figure 3

Radiograph showing nonprogressive radiolucent lines.

Figure 4



Radiograph showing loose implant with stem failure. Tibia loose stems in a hybrid fixation stem (**A**), and in a fully cemented stem of the tibia (**B**).

mechanical alignment, a prerequisite for successful long-term knee function after knee arthroplasty.[29]

An important variable in achieving accurate mechanical alignment is the canal fill ratio. The canal fill ratio is the ratio formed by dividing the diameter of the stem measured at 2 and 7 cm from the tip of the stem by the width of the diaphyseal medullary canal at those levels. A canal fill ratio greater than 85% is associated with restoration of normal mechanical alignment.[29]

Completo et al[30] showed that use of titanium rather than cobalt chrome resulted in lower strain at the stem tip. A clinical study by Barack et al corroborated these biomechanical findings by showing significantly reduced incidence of stem tip pain in a slotted titanium stem (8.1%) when compared with a solid cobalt chrome stem (18.8%).[13]

Radiographic Analysis: The Implication of Radiolucent/Radiodense Lines

Radiographic assessment of TKA is undertaken using the original Knee Society Total Knee Arthroplasty Radiographic Evaluation and Scoring system designed by Ewald[31] or its modification.[32] It assesses implant position, knee alignment, and fixation interface integrity. Tibial fixation integrity is evaluated on AP (7 zones) and lateral views (3 zones), while femoral fixation interface is assessed on the lateral view (7 zones) with patella assessed on skyline views (3 to 5 zones). Scores are determined by measuring the width of radiolucent line in each zone in millimeters, the sum of which provides an indication of the integrity of the bone–cement/cement–implant interface. A score of 4 or less and nonprogressive is probably not significant (Figure 3). A score of 5 to 9 should be closely followed up, particularly if progressive and 2 mm or more in thickness. Finally, a score of 10 or more signifies possible or impending loosening with implant migration denoting a definitely loose implant (Figure 4). Studies have shown that complete radiolucent lines do not necessarily imply loosening.[33] A histologic analysis of bone–cement interface demonstrated that even with partial or complete radiolucent lines seen on radiographs, cement–bone contact can be observed, thus indicating fixation stability.[34] Other factors such as a history of symptoms, presence of features suggestive of a biomechanically unsound reconstruction, time of onset, and progression and widening of radiolucent lines are important considerations in determining whether a complete radiolucent line portends loosening.[35]

Porous Metal Sleeves and Cones

Recent introduction and use of porous metal cones and metaphyseal sleeves as void fillers have helped to provide a means of more consistently achieving successful and lasting reconstruction of large metaphyseal bone defects. These are used in combination with stems that are fixed by either technique. Tantalum is a frequently used metal because it has excellent material and biomechanical properties that make it an ideal material for reconstructing bone defects. It is highly biocompatible with extremely low immunogenicity and has high corrosion resistance. Its high coefficient of friction results in immediate primary press-fit stability in metaphyseal bone. It has identical elastic modulus to bone, which avoids stress shielding of adjacent proximal bone.[31]

The high (80%) porosity of tantalum encourages rapid and extensive bone ingrowth of 40% to 50% by 4 weeks and 80% or more by 18 weeks.[31] This results in the formation of a strong, stress-resistant biologic interface and a stable and lasting metaphyseal reconstruction.

A recent experimental study evaluating the use of cones with stems fixed by either hybrid or fully cemented modes in moderate metaphyseal defects showed that the cones provided stability to the whole construct with both modes of stem fixation performing equally well.[36]

Clinical studies have shown excellent results at a short-term to medium-term follow-up with low aseptic loosening rates when porous metal cones are used with stems in patients with high-grade (AORI 2B/3) defects.

Meneghini et al undertook 15 knee revisions in 15 patients using 15 cones with both types of stem fixation. At mean 34 months of follow-up, the mean KSS improved from 52 to 84 points. All cones had osteointegration with no aseptic loosening.[37] Lachiewicz et al reported 24 patients with 24 tibial and 9 femoral cones combined with both modes of stem fixation. Thirteen patients (48%) underwent reimplantation for infection. The mean KSS improved from 40 to 79 points with functional score improving from 19 to 47 points. One septic loosening was reported at a mean 39-month follow-up with no case of aseptic loosening.[38] Backstein et al examined 29 patients treated with 33 cones (17 tibia and 18 femur) combined with hybrid stem fixation. At a mean 33-month follow-up, the mean KSS improved from 42 to 88, function improved from 32 to 65, and mean ROM improved from 88 to 112 degrees, with no aseptic loosening.[39]

These results are better than those obtained with use of bulk allograft. Backstein et al[40] at a mean follow-up of 64 months reported 21.3% allograft failure rates due to nonunion, loosening, infection, periprosthetic fracture, and instability when bulk allograft was used to reconstruct major bone defects in rTKA. A systematic review by Beckmann et al[6] showed significantly higher failure rates with bulk allograft compared with TM cones.

Comparative Studies

Eight studies in the past 20 years have directly compared the clinical and/or radiologic outcomes between both modes of stem fixation. Seven were nonrandomized cohort studies and 1 was randomized controlled level 1 study. Fehring et al[14] reported a comparative analysis of stem fixation in 113 revisions with 202 metaphyseal engaging stems. Diaphyseal engaging press-fit stems were excluded. Results showed that 29% of press-fit noncemented stems were unstable compared with 7% of fully cemented stems according to a radiological analysis. Gilliland et al reviewed 82 revisions at a midterm follow-up. Thirty-three were hybrid and 49 were fully cemented stem fixation. Re-revision and radiographic failure rates were similar between groups with similar improvements also noted in the knee society clinical scores.[7] This result emphasizes the need for diaphyseal engagement with hybrid fixation and explains the poor result noted in the study by Fehring et al. Cintra et al examined tibial implant fixation in 30 rTKA in 26 patients: 21 fully cemented and 9 hybrid stems. At a mean 52-month follow-up, no difference in clinical, radiographic, or survival outcome was observed.[41] Edwards et al examined 114 patients who underwent 2-stage revision (102 cemented and 126 hybrid stems) for infection. At a mean follow-up of 45 months (cemented) and 52 months (cemented), aseptic loosening, reinfection, and clinical outcomes were identical, but cemented stems were statistically more likely to be radiologically loose (P = 0.006).[11] Kosse et al in a randomized controlled study compared the performance of 12 fully cemented and 11 hybrid stem fixations using radiostereometric analysis. At a mean 6.5-year follow-up, they did not observe any statistically significant difference in median micromotion and clinical outcome between both modes of fixation.[28] Fleischman et al examined 223 revisions in 220 patients (108 fully cemented and 316 hybrid). At a mean of 64.3 months (cemented) and 59.6 months (noncemented) of follow-up, no difference was observed in mechanical failure and infection rates in either mode of fixation.[10] Lachiewicz et al reported 84 revisions (34 fully cemented and 50 hybrid stem fixations) in which femoral stem was used. . Similar improvement in clinical outcomes was observed between groups, and no significant difference was noted in radiographic failure and aseptic loosening rates.[42] Gomez-Vallejo et al examined 67 patients (29 cemented and 38 hybrid stems). At a mean follow-up of 7 years, statistically significant improvement was observed in the Western Ontario and McMaster Universities Osteoarthritis Index scores (total and subgroup) in favor of hybrid stem fixation, all other clinical and survival-related variables being similar. The authors concluded that although results were similar between groups, hybrid fixation tended to produce better results than cemented stem fixation.[43] The studies overall were of low to moderate quality and showed high clinical heterogeneity.

AU2

Systematic Reviews and Meta-analyses and International Registry Data

Three systematic reviews and meta-analyses were reviewed. Beckmann et al[4] undertook a systematic review of studies from 1980 to 2010. Four studies on noncemented stems, 8 on hybrid fixation and 5 on fully cemented fixation were included. Outcomes of interest included survival of arthroplasty, rates of aseptic loosening, and clinical outcome. The included studies were mostly level of evidence III and IV. Most articles (12) had no control groups, had small number of cases, and involved a short follow-up. The authors concluded that no definitive statements could be drawn regarding optimal fixation technique and recommended randomized control trials to answer the question. Wang et al conducted a systematic review and meta-analysis of 17 observational studies from 1980 to 2014 to compare survivorship between fully cemented and hybrid fixation in rTKA. Their study included all articles from the review by Beckmann et al. Results including quantitative analysis showed similar outcomes in all variables studied (all-cause revision, revision for aseptic loosening, and infection) before and after a 60-month follow-up. They concluded that based on the available literature, no superiority of any type of fixation could be found.[44] Most of the reviewed articles had the same quality-related shortcomings noted in the review by Beckmann et al and were assessed to be moderate quality and of grade III to IV level of evidence. Neither review did a subgroup analysis of the three papers with control groups. Sheridan et al[45] in their review and meta-analysis included studies from 2010 with the aim of reflecting contemporary practice with improved proficiency in stem use in rTKA. Furthermore, they only included well-designed comparative studies. In contrast to the findings in the previous reviews, they reported that the hybrid technique had statistically significant lower all-cause failure rate, which is a composite of radiographic failure and all-cause re-revision. The all-cause re-revision, aseptic loosening rate, and radiographic failure showed a trend in favor of hybrid fixation, although not statistically significant. They concluded that the more recent literature supports a lower all-cause failure rate and a trend in favor of hybrid stems compared with all cemented stems regarding all-cause revision rates, revision for aseptic loosening, and radiographic failure.

Petursson et al reviewed the Norwegian Arthroplasty Registry by comparing both techniques in patients with re-revisions. They demonstrated statistically significant improvement in survival estimate for hybrid fixation (96.3%) compared with fully cemented stem (94.3%, relative risk 0.58, $P = 0.001$). They concluded that the hybrid technique showed a significant reduction in risk of revision.[46]

Summary

Revision TKA procedures are increasing in frequency as the rates of primary TKA continue to increase. Stems are mandatory to transfer stress away from the epiphysis into the diaphysis. Major metaphyseal bone defects are often present and need to be properly addressed to prevent failure despite stem use. Modular implants, with variable constraints and attachment sites for augments and stems, are a significant advance, as are the availability and use of porous metal cones and sleeves and offset stem capabilities. Improvement in surgical technique is evidenced, particularly with press-fit fixation.

Both fully cemented and hybrid stem fixations have advantages and disadvantages, but the best mode of fixation remains controversial. Based on the review of the available literature, difference in outcome between either techniques was not found to conclusively demonstrate the superiority of one technique over the other. However, few studies suggest superiority of the hybrid fixation over the fully cemented technique, the difference is at best marginal, and clinical heterogeneity in most of the studies is level 3 and level 4.

Each case should be individualized, and the potential risks and benefits of all fixation methods should be weighed for a given patient's specific case.

References

References printed in **bold type** are those published within the past 5 years.

1. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR): *Hip, Knee and Shoulder Arthroplasty: 2018 Annual Report*. Adelaide, Australia, AOA, 2018.

2. Kurtz S, Ong K, Lau E, Mowat F, Halpern M: Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am* 2007;89:780-785.

3. Mabry TM, Hanssen AD: The role of stems and augments for bone loss in revision knee arthroplasty. *J Arthroplasty* 2007;22:56-60.

4. Beckmann J, Lring C, Springorum R, Kck FX, Grifka J, Tingart M: Fixation of revision TKA: A review of the literature. *Knee Surg Sports Traumatol Arthrosc* 2011;19:872-879.

5. Morgan-Jones R, Oussedik SI, Graichen H: Haddad FS Zonal fixation in revision total knee arthroplasty. *Bone Joint J* 2015;97-B:147-149.

6. Beckmann NA, Mueller S, Gondan M, Jaeger S, Reiner T, Bitsch RG: Treatment of severe bone defects during revision total knee arthroplasty

with structural allografts and porous metal cones—A systematic review. *J Arthroplasty* 2015;30:249-253.

7. Gililland JM, Gaffney CJ, Odum SM, Fehring TK, Peters CL, Beaver WB: Clinical & radiographic outcomes of cemented vs. diaphyseal engaging cementless stems in aseptic revision TKA. *J Arthroplasty* 2014;29(suppl 2): 224-228.

8. Wood GC, Naudie DD, MacDonald SJ, McCalden RW, Bourne RB: Result of press-fit stems in revision knee arthroplasties. *Clin Orthop Relat Res* 2009;467:810-817.

9. Nanson C, Fehring T: Stem fixation in revision total knee arthroplasty. *Tech Knee Surg* 2009;8:161-165.

10. Fleischman AN, Azboy I, Fuery M, Restrepo C, Shao H, Parvizi J: Effect of stem size and fixation method on mechanical failure after revision total knee arthroplasty. *J Arthroplasty* 2017;32:S202-S208.

11. Edwards PK, Fehring TK, Hamilton WG, Perricelli B, Beaver WB, Odum SM: Are cementless stems more durable than cemented stems in two-stage revisions of infected total knee arthroplasties? *Clin Orthop Relat Res* 2014;472:206-211.

12. Cipriano CA, Brown NM, Della Valle CJ, Moric M, Sporer SM: Intraoperative periprosthetic fractures associated with press fit stems in revision total knee arthroplasty. Incidence, management, and outcomes. *J Arthroplasty* 2013;28:1310-1313.

13. Barrack RL, Stanley T, Burt M, Hopkins S: The effect of stem design on end-of-stem pain in revision total knee arthroplasty. *J Arthroplasty* 2004; 19:119-124.

14. Fehring TK, Odum S, Olekson C, Griffin WL, Mason JB, McCoy TH: Stem fixation in revision total knee arthroplasty: Comparative analysis. *Clin Orthop Relat Res* 2003;416:217-224.

15. Shannon BD, Klassen JF, Rand JA, et al: Revision total knee arthroplasty with cemented components and uncemented intramedullary stems. *J Arthroplasty* 2003;18(supp 1):27-32.

16. Peters CL, Erickson J, Kloepper RG, et al: Revision total knee arthroplasty with modular components inserted with metaphyseal cement and stems without cement. *J Arthroplasty* 2005;20:302-308.

17. Peters CL, Erickson JA, Gililland JM: Clinical and radiographic results of 184 consecutive revision total knee arthroplasties placed with modular cementless stems. *J Arthroplasty* 2009;24(6 suppl):48-53.

18. Greene JW, Reynolds SM, Stimac JD, Malkani AL, Massini MA: Midterm results of hybrid cement technique in revision total knee arthroplasty. *J Arthroplasty* 2013;28:570-574.

19. Stockwell KD, Malleck S, Gascoyne TC, Turgeona TR: Clinical and radiographic outcomes of a hybrid fixation revision total knee arthroplasty system at short to mid-term follow-up. *Knee* 2019;26: 240-249.

20. Kim YH, Kim JS: Revision total knee arthroplasty with use of a constrained condylar knee prosthesis. *J Bone Joint Surg Am* 2009;91: 1440-1447.

21. Baggio L, Gil-González S, Barra-González X, et al: Cemented stems in revision total knee arthroplasty on patients older than 75 y/o. Clinical and radiological analysis. *Acta Ortop Mex* 2016;30:85-90.

22. Lachiewicz PF, Soileau SE: A 30-mm cemented stem extension provides adequate fixation of the tibial component in revision knee arthroplasty. *Clin Orthop Relat Res* 2015;473:185-189.

23. Patel AR, Barlow B, Ranawat AS: Stem length in revision total knee arthroplasty. *Curr Rev Musculoskelet Med* 2015;8:407-412.

24. Elia EA, Lotke PA: Results of revision total knee arthroplasty associated with significant bone loss. *Clin Orthop Relat Res* 1991;271:114.

25. Jazrawi LM, Bai B, Kummer FJ: The effect of stem modularity and mode of fixation on tibial component stability in revision total knee arthroplasty. *J Arthroplasty* 2001;16:759-767.

26. Completo A, Fonseca F, Simões JA: Strain shielding in proximal tibia of stemmed knee prosthesis: Experimental study. *J Biomech* 2008;41: 560-566.

27. Completo A, Simoes JA, Fonseca F: Revision total knee arthroplasty: The influence of femoral stems in load sharing and stability. *Knee* 2009;16: 275-279.

28. Kosse NM, van Hellemondt GG, Wymenga AB, Heesterbeek PJ: Comparable stability of cemented vs press-fit placed stems in revision total knee arthroplasty with mild to moderate bone loss: 6.5-year results from a randomized controlled trial with radiostereometric analysis. *J Arthroplasty* 2017;32:197-201.

29. Nakasone CK, Abdeen A, Khachatourians AG, Sugimori T, Vince KG: Component alignment in revision total knee arthroplasty using diaphyseal engaging modular offset press-fit stems. *J Arthroplasty* 2008;23: 1178-1181.

30. Completo A, Fonseca F, Simões JA, Ramos A, Relvas C: A new press-fit stem concept to reduce the risk of end-of-stem pain at revision TKA: A pre-clinical study. *Knee* 2012;19:537-542.

31. Ewald FC: The knee society total knee arthroplasty roengenographic evaluation and scoring system. *Clin Orthop Relat Res* 1989;248:9-12.

32. Bach CM, Biedermann R, Goebel G, et al: Reproducible assessment of radiolucent lines in total knee arthroplasty. *Clin Orthop Relat Res* 2003;434: 183-188.

33. Aebli N, Krebs J, Schwenke D, et al: Progression of radiolucent ines in cementless twin bearing low contact stress knee prostheses; a retrospective study. *J Arthroplasty* 2004;19:783-789.

34. Kendrick BJL, James AR, Pandit H, et al: Histology of the bone-cement interface in retrieved Oxford unicompartmental knee replacements. *Knee* 2012;19:918-922.

35. Bobyn JD, Stackpool GJ, Hacking SA, Tanzer M, Krygier JJ: Characteristics of bone ingrowth and interface mechanics of a new porous tantalum biomaterial. *J Bone Joint Surg Br* 1999;81:907-914.

36. Quevedo González FJ, Meyers KN, Schraut N, et al: Do metaphyseal cones and stems provide any biomechanical advantage for moderate contained tibial defects in revision TKA? A finite-element analysis based on a cadaveric model. *Clin Orthop Relat Res* 2021;479:2534-2546.

37. Meneghini RM, Lewallen DG, Hanssen AD: Use of porous tantalum metaphyseal cones for severe tibial bone loss during revision total knee replacement. *J Bone Joint Surg Am* 2008;90:78-84.

38. Lachiewicz PF, Bolognesi MP, Henderson RA, Soileau ES, Vail TP: Can tantalum cones provide fixation in complex revision knee arthroplasty? *Clin Orthop Relat Res* 2012;470:199-204.

39. Derome P, Sternheim A, Backstein D, Malo M: Treatment of large bone defects with trabecular metal cones in revision total knee arthroplasty: Short term clinical and radiographic outcomes. *J Arthroplasty* 2014;29: 122-126.

40. Backstein D, Safir O, Gross A: Management of bone loss: Structural grafts in revision total knee arthroplasty. *Clin Orthop Relat Res* 2006;446: 104-112.

41. Cintra FF, Yepéz AK, Rasga MGS, Abagge M, Alencar PGC: Tibial component in revision of total knee arthroplasty: Comparison between cemented and hybrid fixation. *Rev Bras Ortop* 2011;46:585-590.

42. Lachiewicz PF, O'Dell JA: Is there a difference between cemented and uncemented femoral stem extensions in revision knee arthroplasty? *J Knee Surg* 2020;33:84-88.

43. Gomez-Vallejo J, Albareda-Albareda J, Seral-Garcia B, Blanco-Rubio N, Ezquerra-Herrando L: Revision total knee arthroplasty: Hybrid vs standard cemented fixation. *J Orthop Traumatol* 2018;19:9.

44. Wang C, Pfitzner T, von Roth P, Mayr HO, Sostheim M, Hube R: Fixation of stem in revision of total knee arthroplasty: Cemented versus cementless—A meta-analysis. *Knee Surg Sports Traumatol Arthrosc* 2016;24:3200-3211.

45. Sheridan GA, Garbuz DS, Masri BA: Hybrid stems are superior to cemented stems in revision total knee arthroplasty: A systematic review and meta-analysis of recent comparative studies. *Eur J Orthop Surg Traumatol* 2021;31:131-141.

46. Petursson G, Fenstad AM, Havelin LI, et al: Better survival of hybrid total knee arthroplasty compared to cemented arthroplasty. *Acta Orthop* 2015;86:714-720.