■ INSTRUCTIONAL REVIEW: KNEE

Cementing techniques for the tibial component in primary total knee replacement

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The optimum cementing technique for the tibial component in cemented primary total knee replacement (TKR) remains controversial. The technique of cementing, the volume of cement and the penetration are largely dependent on the operator, and hence large variations can occur. Clinical, experimental and computational studies have been performed, with conflicting results. Early implant migration is an indication of loosening. Aseptic loosening is the most common cause of failure in primary TKR and is the product of several factors. Sufficient penetration of cement has been shown to increase implant stability.

This review discusses the relevant literature regarding all aspects of the cementing of the tibial component at primary TKR.

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An absolute revision rate following total knee replacement (TKR) of 10% over 15 years has been reported by the Swedish registry[1] and a mean revision burden of 8.2% described in the United States.[2] Aseptic loosening accounts for between 16.1% and 41.5% of revisions, particularly with failure after more than two years.[3-6] Modern cementing techniques at the hip have lowered the rates of loosening by a factor of almost ten.[7] It is commonly accepted that aseptic loosening has a multifactorial aetiology that includes stress shielding, micromovement and high joint fluid pressure, culminating in macrophage activation owing to the movement of wear particles into the bone–implant interface.[8]

At the knee, cementless fixation has so far not been shown to be superior to cemented fixation.[9,10] Facilitating potential revision should be considered during primary TKR, but the achievement of stability and maintenance of proximal tibial bone stock are key objectives.

The amount of bone lost in a failed TKR may relate to the mechanism of failure.[11] A press-fit stem without associated cement will not cause excess unintended bone loss on removal.[12] In contrast, a well-fixed stem is difficult to remove, and metal cutting tools may be required to cut the condylar portion of the tibial component in order to allow access to the stem. Osteoporotic bone is particularly affected by the removal of a cemented stem, resulting in a funnel-shaped metaphysis with a thin, sclerotic cortical shell.[13] A cancellous bony defect of ≤ 12 mm can be filled with cement, but anything larger requires bone grafting.[13]

Bone preparation

Once the osteotomy of the tibial plateau has been made, the bone is prepared in such a way as to provide maximal stability. This is facilitated by suitable exposure, and extra care is required to ensure adequate preparation during minimally invasive surgery. Bone density at the level of the plateau is influenced by the degree of deformity.[14] Conceivably cement penetration on the medial side of a varus knee may be reduced owing to sclerotic bone, and likewise for the lateral side of a valgus knee. In unicompartmental replacement multiple-drill-hole interdigitation and pulsed lavage provide consistently superior fixation compared to cut-only and curettage-only techniques.[15] Drilling the cut surface will allow the passage of cement to the depth drilled, but might leave larger defects if subsequent revision is required.

Bone debris must be cleared from the cancellous bone, as it can inhibit the penetration of cement.[16] The presence of blood at the cement–bone interface can also reduce shear strength by up to 50%.[17] Several factors have been shown to be effective through the radiological assessment of cement penetration under the tibial component. Pulsed lavage enhances penetration better than manual flushing alone, as this provides more effective debridement.[18-21] The debris-free cancellous bone can be adequately dried using laparotomy sponges and suction.[21-24] The application of a tourniquet minimises the bleeding from bone, which improves fixation.[25,26] Venting the proximal

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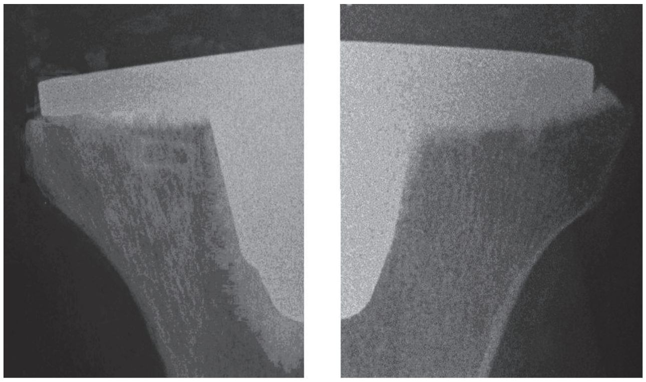

Fig. 1

Sample anteroposterior radiographs of implanted proximal tibiae showing evidence of (a) full cementation with polymethylmethacrylate (PMMA) both under the baseplate and circumferentially around the central stem (left) and surface cementation with a penetrating layer of PMMA exclusively under the baseplate (right).

tibia through the cutting jig pin sites creates a negative pressure sufficient to enhance the penetration of cement.[22,27,28]

Application of cement

Since its introduction in the 1950s, polymethylmethacrylate (PMMA) cement has played a central role in arthroplasty surgery. It conforms to the shape of its surroundings, forms a strong bond between the implant and bone, and distributes load. Several studies have suggested that optimal fixation requires penetration of cement into the proximal tibia by 3 mm to 4 mm.[29-31] Controversy surrounds the optimal method of application of cement to the tibial component in cemented TKR. Contemporary components generally have a flat tibial tray, also known as a baseplate, with an underlying central stem that necessitates drilling the proximal tibial metaphysis. The operator may apply cement to a varying degree – from fully cementing the surface of the plateau and the hole created for the stem to cementing the plateau only (Fig. 1). Typically, in surface-cemented components the stems are press-fitted to achieve fixation.

Previous studies have claimed that full cementing provides better fixation, less potential for micromovement and long-term stability,[32,33] but this may result in unnecessary cement in the proximal tibia and cause problems at revision. Conversely, advocates of surface cementing claim sufficient stability of the component, and greater loading of the proximal tibial corticocancellous cut surface so that the underlying bone density and architecture are maintained.[24,34-36] Opponents of surface cementing maintain that this technique provides an inadequate seal and inadequate fixation.[37]

A number of series report the outcome of patients treated with surface, full or both methods of cementing,[34,35,38-44] but there are no randomised controlled studies. In a series by Sharkey et al[33] loosening accounted for respectively 16.9% and 34.4% of early (< 2 years) and late failures (> 2 years). Surface cementing was used in 10.5% of the revised components, with 44% of the revisions possibly occurring secondary to malalignment.[33,41] In a clinical study on mobile-bearing designs, Lombardi et al[45] reported that two of 23 surface-cemented TKRs were revised, compared with none of 45 fully cemented implants.

Hofmann et al[24] reported the five-year results of 128 consecutive TKRs using a strict surface-cementing technique. The mean age of the patients was 74 years and the series included patients with low activity levels, avascular necrosis, poor bone quality and physiological compromise. Three tibiae had radiolucent lines that were non-progressive and asymptomatic. No tibial component was revised. The success of the surface-cementing technique was attributed to the penetration of cement achieved by meticulous bone preparation, the application of PMMA in its low-viscosity state and the implant's peripheral lip (Natural Knee II; Zimmer), which was designed to prevent escape of the cement. Similarly, Wall et al[42] presented a series of surface-cemented TKRs with a mean penetration of 2.9 mm and a failure rate of < 0.1% at 75 months.

The optimal cementing technique in TKR has been investigated experimentally using synthetic[32,33] and cadaver tibiae.[46] Biomechanical studies have largely relied on cyclical point loading of the tibia to detect micromovement between the baseplate and the cut surface,[32-34,46,47] and others have investigated surface cortical bone strains using strain gauges.[34-36]

An *in vitro* study by Bert and McShane[32] compared full and surface cementing using the Advantim knee system (Wright Medical Technology, Arlington, Tennessee) with a cement overlay mantle of either 1 mm or 3 mm in synthetic models. Greater lift-off was observed for surface cementing with a 1 mm cement mantle, but no difference in lift-off was seen between surface and full cementing with a 3 mm mantle. No difference in micromovement was observed in an experimental cadaver study using 12 matched pairs by Peters et al[46] comparing the initial stability of full and surface cementing with the Maxim Complete Knee System (Biomet, Warsaw, Indiana) with two stem designs (cruciate and I-beam) after 6000 cycles at three times body weight. A correlation was found between micromovement and the depth of cement penetration in surface cementing. These studies contribute little to establishing long-term stability, but do identify cement penetration as a key factor.

Experimental strain or carefully modelled finite element analysis studies offer prediction of the strain experienced by the bone after implantation. We have compared intact, surface and fully cemented synthetic tibiae by measuring cortical strains, by simulating the loading effects of walking, at three times body weight, with axial loading and in 15° of flexion.[36] Both loading configurations resulted in statistically significant differences between full and surface

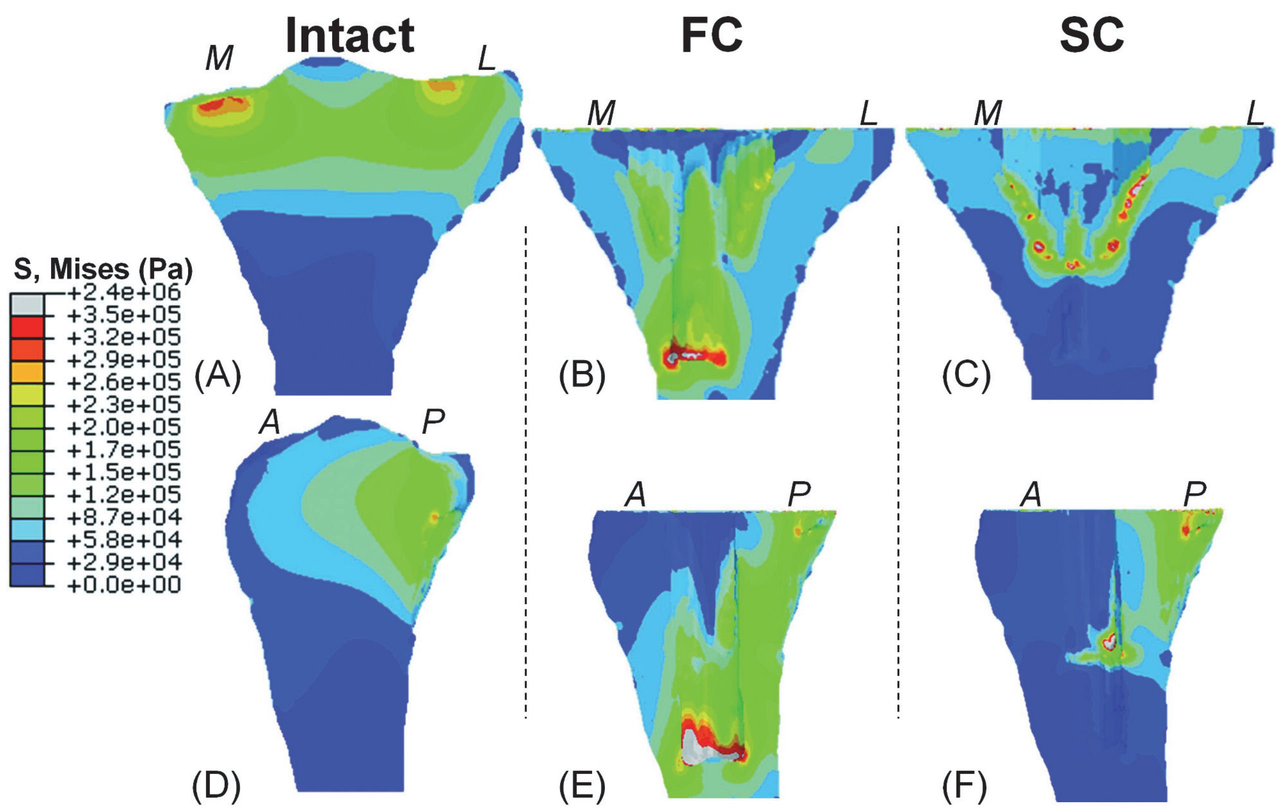

Fig. 2

Finite element contour plots showing coronal (A to C) and sagittal (D to F) section views of von Mises cancellous bone stress results for axially loaded models. From Cawley et al[36] (M, medial; L, lateral; A, anterior; P, posterior; FC, full cementing; SC, surface cementing). Reproduced with permission from *Clinical Biomechanics*.

cementing for half of the measurements, with lower strain recorded in cortical bone directly under a fully cemented baseplate. The experimental study was validated using three-dimensional finite-element analysis, and lower cancellous stresses were recorded under the baseplate for full cementing than for surface cementing (Fig. 2). Bone remodelling simulations predicted greater resorption for full than for surface cementing under the baseplate, suggesting that full cementing would result in greater proximal tibial bone resorption. Similarly, Chong et al,[48] in a finite element analysis study, demonstrated similar metaphyseal stress profiles, and predicted up to 29% resorption in proximal bone in fully cemented tibiae at 60 months.

Cementing techniques

Previous studies have highlighted that cement penetration plays a key role in implant stability with both cementing techniques.[24,49,50] Walker et al,[51] having evaluated follow-up radiographs and performed biomechanical experiments, proposed that a 3 mm to 4 mm mantle is the optimum for the penetration of cement into bone. Given the quality and porosity of cancellous bone, cement can permeate to varying degrees beyond the cut surface, creating an interdigitated cement–bone interface. The formation of interlocking shapes of cement and bone is the main component of interface strength.[31]

Spatula or finger packing achieves adequate cement penetration.[52,53] Vanlommel et al,[52] when simulating osteoporotic bone, reported insufficient penetration with isolated application of cement on to the tibial component and excessive penetration when using a cement gun. In contrast, in a porcine model Bauze et al[54] found that the cement gun provided the most consistency and the least micromovement of the three options.

Penetration beyond 5 mm may increase the risk of thermal damage.[55] *In vitro* studies have shown that thicker cement mantles, higher ambient temperatures and an increased ratio of monomer to polymer increases the heat, which is produced by PMMA curing.[56] Although the maximum temperature of curing cement recorded was 48°C during hip replacement,[57] one must bear in mind that the temperature at the knee joint with an inflated tourniquet without the cooling effects of blood may be significantly higher. Collagen denatures with prolonged exposure to temperatures > 56°C.[58]

Prolonging the curing time allows increased cement flow, facilitating penetration. The use of high-viscosity PMMA reduces the penetration compared with medium-viscosity

PMMA, and has significantly quicker setting times.[59] Low storage temperatures, low mixing temperatures and high humidity prolong the curing time.[56,60] Additionally, mixing in a vacuum reduces the curing time by almost two minutes.[61] When these features were combined, no difference was observed in penetration between vacuum mixing and gun pressurisation and hand mixing and packing.[53]

The timing of the application of cement after mixing is inversely proportional to the depth of penetration.[50,51] In an *in vivo* analysis, Kopec et al[53] mixed for one minute and then probed with a latex glove every 15 seconds until the cement no longer adhered to the glove, at which time they finger-packed the cement. This was compared with vacuum mixing with gun pressurisation, with the latter failing to demonstrate an advantage *in vivo*. In a series using low-viscosity PMMA that was hand-mixed for one minute, allowed to rest for an additional minute, then applied to the components but not directly to the bony surfaces, with the tibial component firmly impacted at the 3.5-minute interval a mean depth of penetration of 2.7 mm was obtained.[24] The technique described by Walker et al[51] involved mixing for four minutes and fenestration of the tibial cancellous bone.

Radiological studies

Non-progressive radiolucent lines < 2 mm thick have shown no correlation with a poor clinical outcome,[62] and this has been confirmed by other studies on radiolucent lines in surface tibial components where none warranted revision.[24,38,43]

Smith et al[43] evaluated the natural history of radiolucent lines using the surface-cementing technique in 195 TKRs over a ten-year follow-up, using the Freeman–Samuelson implant (Sulzer, Winterthur, Switzerland) with a tibial stem of 80 mm to 120 mm. No tibial implants became loose. Separately from this cohort, 12 femoral components that loosened were reviewed, one of which had associated tibial loosening. The authors demonstrated that there are two types of radiolucency. The first is a non-progressive radiolucent line, as a result of poor cement penetration into sclerotic bone, which does not affect fixation but may facilitate the entry of debris to the interface, which may then progress and become the second type, which reflects aggressive osteolysis in the presence of high wear.[43]

Despite the equivocal value of radiolucent lines, pulsed lavage and single-stage (cementing both components at the same time) cementing have been shown to reduce their incidence.[63,64]

Radiostereometric analysis (RSA) has been used to record early migration of tibial components as a reliable predictor of failure.[65,66] No difference has been shown through RSA between surface-cemented and fully cemented tibiae.[37,67]

Intuitively, it is easier to define a radiolucent line at a regular interface orthogonal to the X-ray beam, such as with an uncemented component, than it is at an irregular cemented surface. Furthermore, a non-progressive radiolucent line along the side of an uncemented stem in surface-cemented tibiae might be an expression of the space created as a result of micromovement between the stiff implant and weaker cancellous bone.

Implant design

Several authors have demonstrated that a central stem or keel improves rotational stability and avoids anterior rocking forces.[68-70] This is required because a rigid metal-backed tibial implant tends to rock.[71] However, long stems are not more stable than short stems.[72] Rand et al[73] suggested that revision in the presence of osteoporotic bone should warrant a cemented stem if an adequate press-fit cannot be achieved. This principle also applies to primary TKR.

Stress shielding occurs because of the presence of a stem in the metaphysis.[74] Proximal tibial bone density has been analysed when the stiffer cobalt–chrome mobile bearings were compared with the less stiff titanium alloy fixed-bearing baseplates, cemented with uncemented implants and posterior-stabilised with cruciate-retaining polyethylene inserts, and no difference was observed between the groups.[75-77]

The stem adds complexity to cementing, and some designs have attempted to account for this. The Total Condylar and Posterior Stabilised Prosthesis (Zimmer) and the I-beam shaped stem (SLK-Evo Anatomical Knee System, Implants International, Thornaby-on-Tees, United Kingdom) were designed for full cementing.[78] The Scorpio TKR (Stryker Orthopaedics, Mahwah, New Jersey) has the option of either cementing method. Scott[79] used the PFC prosthesis with a cylindrical stem with wings (PFC Sigma, DePuy, Raynham, Massachusetts), which was designed for use with surface cementation. However, the author's recommendations were to fully cement this implant.[44] The Genesis II Total Knee System (Smith & Nephew, Memphis, Tennessee) has a press-fit proximal stem, hence the diameter of the punch is smaller than that of the stem. The distal portion of the stem (30 mm to 50 mm) has a reduced diameter, allowing a potential space if surface cementing or for cement with full cementing. A recent study suggested that for surface cementing of the Genesis II a shortened stem would provide equivalent distribution of stress, which would also reduce the amount of cancellous bone removed and thus be advantageous if revision is required.[36]

As design concepts have evolved this has also affected cementing recommendations. Hyldahl et al[80] found less initial rotation on RSA with an all-polyethylene than with a metal-backed tibial component when they were surface cemented. However, the same difference was not apparent when compared with fully cemented models. These authors cited the absorptive qualities of the all-polyethylene component, which needs less cement when eccentrically loaded, whereas the more rigid metal-backed implant needs a greater cement mantle.

The addition of an underlying peripheral lip to the baseplate prevents cement escaping, thereby doubling its penetration.[81] Rough, grit-blasted or plasma-spray porous coating improves shear strength at the implant–cement or the implant–bone interface.[82-84]

Discussion

Optimising the way in which the cement is applied remains a priority in the endeavour to improve the survival of TKR. Penetration of 3 mm to 4 mm remains the target depth. Several factors improve this, including a dry porous clean bone bed, venting of the metaphysis, the judicious use of low- or medium-viscosity PMMA, hand packing, a time to application of 3 to 4 minutes, and low theatre and storage temperatures. Use of a cement gun should be reserved for bone with dense trabeculae, as over-penetration may occur. Knowledge of cement-related features of the design of the components and the manner in which the instrumentation prepares the bone bed may further optimise the implant–cement–bone interfaces.

Most peri-prosthetic radiolucent lines are non-progressive, and successive series have not shown an increased risk of revision following surface over full cementing. Bone mineral density studies and experimental work have demonstrated distal stress shielding with stemmed as opposed to non-stemmed tibial components.[74] Cement-related changes to the design of the stem are likely to affect the distribution of load in the tibial metaphysis.

Randomised controlled trials provide unbiased, quality-controlled research to an issue of this complexity. There are theoretical advantages for each technique (surface *vs* full). The experimental and correlating finite element studies conducted by Cawley et al[36] substantiate the claim by advocates of the surface-cementing technique that bonding of the stem to the surrounding cancellous bone in full cementing results in the transfer of stress to the distal cancellous bone, and hence reduced stress in the proximal cancellous bone under the baseplate.[48] However, there has so far been no link between finite element analysis and densitometry studies and implant survival. It should be noted that certain designs of baseplate, keel and stem are likely to perform better with certain techniques, and this should be considered at the time of implantation. There is no single formula for all knees.

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