EFFECT OF STEM SIZE, CEMENT, AND INTERLOCKING SCREWS ON STRESS SHIELDING IN REVISION TKA: A BONE REMODELING SIMULATION

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Introduction: When the failure of a TKA is accompanied with significant bone loss, a long stem (> 80 mm) is implanted at revision to provide sufficient stabilization, thus allowing reconstruction of the bone defect (e.g. with a bone allograft). Unfortunately, the metal components of a TKA induce stress shielding; and subsequently, bone integrity becomes compromised. Securing stems with a small diameter to the contiguous bone is often achieved with acrylic bone cement. However, complications in removing cemented components have encouraged the insertion of large diameter stems that fit snuggly into the medullary canal, despite the apparent increase in stiffness. Unfortunately, there is no consensus from clinical follow-up studies on which fixation technique provides the best stability and lowest rate of loosening [1]. Passing interlocking screws through prefabricated holes of a small stem has been found to provide a good functional outcome [2]. Yet little is known about its effect on stress shielding; and there is a paucity of information on which technique provides the lowest postoperative bone loss in the tibia. Addressing this concern, a bone remodeling simulation was developed for the tibia to compare bone loss after revision TKA for different fixation techniques involving cement, stem diameter, or interlocking screws.

Methods: A FE model, consisting of 3884 quadrilateral, 4 node, plane strain elements, was developed with a mesh that was designed to accommodate the following: a tibial tray attached to a stem with a length of 120 mm, a stem diameter of 12 mm, 14 mm, or 16 mm, two screws (5 mm in diameter) passing through the stem at 25 mm and 50 mm from stem tip, and a 2 mm cement layer below the tibial tray and around the 12 mm wide stem. In addition, no loosening was assumed for all stems, the condyles had a profile of a tibial insert, and the titanium screws were in intimate contact with bone and stem. Isotropic material values for PMMA, UHMWPE, and titanium from [3] were used. To account for the out-of-plane contribution to stiffness, the 2D elements were assigned a thickness value of 27 mm and a bony side plate (2279 quad. elements) with graded thickness (5.5 mm distal to 1 mm proximal) [4] and cortical property values from [5] was attached to the periphery.

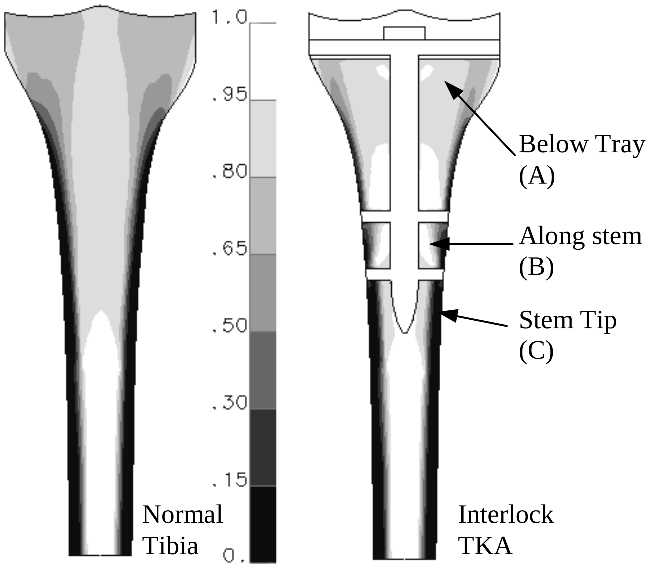
A mechanistic model of bone remodeling, where disuse and micro-damage stimuli dictate changes in bone porosity, was coupled with the FE model [6]. Three load cases that represent a joint reaction force (JRF) of 2058 N (3xBW) for a spectrum of distributions and directions were used to provide a daily loading history. Cases were: 1) 50 % of JRF distributed vertically across each condyle for 3000 cycles per day (cpd), 2) 70 % and 30 % of JRF distributed across the medial and lateral condyle, respectively, at an angle of –5.0 degrees from tibial mechanical axis for 500 cpd, and 3) 30 % and 70 % of JRF distributed across the aforementioned order of condyles at +5.0 degrees for 500 cpd. The bone remodeling algorithm was integrated into the FE analysis with a subroutine that provides user-defined material property behavior (UMAT), and the simulations were run using ABAQUS 5.8 (HKS, Pawtucket, RI). Initially, with UMAT set to allow all elements with an initial porosity of 4.82 % (approximately 18 GPa) to remodel, porosity was predicted for 1200 simulation days (equilibrium was visually observed in contour plots of porosity). From this equilibrium distribution, 5 simulations were run for 1000 days (i.e. a new steady state was achieved). They included the following fixation methods: fully cemented small (12 mm) stem (Cem12), cementless large (16 mm) stem (Cls16), cementless intermediate stem (Cls14), cementless small stem (Cls12), and interlocked small stem (Lock12).

Results and Discussion: In Figure 1 the predicted porosity distribution at steady state is shown for the normal tibia and a revision TKA with an interlocked stem. Quantified as percent increase in porosity from the normal tibia, stress shielding for each case in three regions of interest is provided in table 1. Consistent with FEA studies, increasing stem size was found to increase stress shielding. Although the effective width is the same, a 2 mm layer of cement surrounding a 12 mm stem appears to cause less bone loss than a cementless stem with width of 16 mm. Interlocking screws appear to cause similar bone loss as a cemented construct and may be a better option because it avoids the complications of cement. The use of contact behavior at the cementless stem-bone interface and 3D elements would improve the prediction of stress shielding.

Table 1. Average % increase in porosity at 3 sites.

	Lock12	Cem12	Cls12	Cls14	Cls16
A	55.8	54.3	48.3	61.6	81.5
B	170.9	193.9	119.5	181.4	300.1
C	8.5	11.3	4.4	5.4	7.5

Figure 1. Comparison of porosity (void space/unit area of bone) distribution between a normal tibia and TKA reveals regions of stress shielding with increases in porosity.



References: [1] Barrack *et al. Clin Orthop*, 367:216-225,1999. [2] Rodrigo *et al. Clin Orthop*, 392:139-146,2001. [3] Lewis *et al. Biomed Mater Eng*, 8:11-23,1998. [4] Huiskes *et al. J Biomech*, 20:1135-1150,1987. [5] Ahmed *et al. J Orthop Res*, 8:435-447,1990. [6] Hazelwood *et al. J Biomech*, 34:299-308,2001.