THE EFFECT OF TIBIAL TRAY AND ARTICULAR SURFACE GEOMETRY ON TIBIAL BONE STRAINS

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Introduction: The procedure of Total Knee Arthroplasty is very successful with revision rates between 3 - 10% at ten years [1]. Aseptic loosening remains the greatest indication for revision surgery [2] and is more prevalent in larger patients due to the higher loads experienced. Aseptic loosening may be due to local bone failure leading to migration of the implant [3]. Early implant migration has been shown to be a good indicator of implant failure [4]. By utilising explicit Finite Element Analysis (FEA) it is possible to model the gait cycle for total knee arthroplasty [5] and so investigate variables and their effect on the tibial bone strain and subsequent success or failure of the implant.

Implant design, in terms of the articular surface geometry and tibial tray geometry are likely to influence the bone stresses. By using a set of well established generic designs for both the bearing surface and tibial tray geometry the current work aims to investigate the relative effect of these variables on the proximal tibial bone strain during normal gait.

Materials and Methods: A CT based model of a proximal tibia (from a 115kg subject) was created using Mimics® software. The geometry was resected and implanted with one of the selected geometry combinations. The implant was assumed to be fully bonded to the proximal tibia using a 2mm bone cement mantle. The cement mantle did not include cement around any stem features. The implant to migrate due to the high bone strains seen.

Six ligament bundles were modelled with one LCL, two PCL (one anterior and one posterior) and three MCL (one anterior, one oblique and one deep) bundles and these were given appropriate material properties and initial strain values from the literature [6,7]. The femur and tibia assembly were meshed with triangles and tetrahedra respectively. All prosthetic components were modelled as rigid bodies. This has been previously assessed as a simplification and seen to make negligible difference to the proximal bone strains when compared to a fully deformable model [8]. Bone cement was modelled as deformable and was given material properties of 2GPa and 0.94g/cm³ for the elastic modulus and density respectively.

Bone material properties were defined using Bonemat® v2.1. A minimum elastic modulus of 1MPa was applied and other elements had modulus based on a density calculated from a grayscale value assigned by Bonemat. Values for the elastic modulus of bone varied between 10MPa and 22GPa.

Boundary conditions and loading parameters were based on those used in the Stanmore Knee Simulator for normal gait [9]. The flexion angle and axial force were applied to the femoral component. The anterior-posterior force and internal-external torque were applied to the tibial component.

Five different generic designs of bearing surface and five different generic designs of stem design were analysed (fig.1). Each stem design was used with each of the bearing surface designs giving a total of 25 models.

Results: Plots of compressive principal strain, were examined in the transverse plane directly beneath the cement in the tibia. The majority of the interrogated surface experienced little or no strain (Fig. 3). A maximum compressive strain of nearly 20% was seen in the model with the “Pegs” tibial tray with a “Medial Pivot” articular surface. The high strains seen in this study may be attributable to the very large patient. In all cases we would expect the implant to migrate due to the high bone strains seen.

Principal strain pattern and magnitude were affected little by changes in kinematics but were more dependent on the fixation device. The “Pegs” tray design showed the largest variation in principal strain magnitude due to changes in bearing surface.

Discussion: When compared to the effect of changing the tibial tray design, the effects of the bearing surface on the compressive bone strains were negligible. A comparison of the robustness of each fixation device can be made from these results. The “Keel” fixation device showed the least variation of tibial strain with changes in bearing surface and it is reasonable to say that this design would be the most robust when using tibial bone strain as the failure criteria.

Results produced in this study show that, if using tibial bone strain as the only criterion for success or failure of a total knee arthroplasty design, it may be more important to concentrate on the stem design than on the articulation. Also some stem designs require an appropriate articulation to minimise tibial bone strain. If using other success criterion, such as wear performance, it may be more important to investigate the articulation to achieve appropriate kinematics than the stem design.

Bartel et al. stated that the stem design had no effect on the tibial bone strain [10]. The different results seen in the present study may be attributed to the use of an explicit dynamic analysis technique in contrast to Bartel’s static loading technique.


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