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Analysis of Stem Tip Pain in Revision Total Knee Arthroplasty

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ABSTRACT

Stem tip pain following revision total knee arthroplasty is a significant cause of patient dissatisfaction, which in the presence of an aseptic well-fixed component has no widely accepted surgical solution. A definitive cause of stem tip pain remains elusive, however it has been suggested that high stress concentrations within the region of the stem tip may play a role. This paper reports a finite element study of a novel clinical technique where a plate is attached to the tibia within the region of the stem tip to reduce stem tip pain. The results demonstrate that the plate reduces stress concentrations in the bone at the stem tip of the implant. The magnitude of stress reduction is dependent upon plate location, material and attachment method.

In revision total knee arthroplasty (TKA) the operating surgeon may encounter difficulties in maintaining component alignment due to proximal tibial bone defects as a result of the primary TKA. In order to overcome the stability problems associated with these defects a tibial stem extension component is often used. However, one issue, which has been reported with this method of fixation and has been identified previously in revision total hip arthroplasty (THA) [1], is stem-tip pain. In a clinical study carried out by Barrack [2] a review of 50 TKA patients with a press-fitted stem extension over a 2 year minimum follow-up period identified pain in the stem tip of the tibial component in 14% of the patients. For the 16 patients reviewed with cemented tibial stems the clinical study saw an occurrence of stem tip pain of 19%. Stem tip pain causes significant disturbance to the quality of life of patients [2] and, therefore, resolution of this issue is necessary.

A definitive cause for stem tip pain following TKA or THA is not known but suggestions have been made such as; micromotion at the bone-prosthesis interface, stress shielding resulting in bone resorption proximally at the tibial tray leading to movement at the stem, excessive stress transfer to the surrounding bone due to a mismatch in Young's modulus of elasticity between the stem and the bone and endosteal/periosteal irritation [1,3–5]. The presence of enigmatic thigh pain in THA has been reported to vary depending on the type of implant fixation, implant materials and design. An increase in the width at the distal end of a wedge shaped femoral stem from 5 mm to 20 mm was reported to result in a 40% increase in the occurrence of thigh pain [3]. In terms of the implant material a finite element study [6] identified a 30% increase in stress levels at the anterior femoral cortical interface for cobalt chromium stem extensions in comparison to titanium stem extensions.

A literature review has identified that work is on-going to design a stem extension which will reduce the incidence of stem tip pain. However, for those patients with existing stem tip pain, avoiding another revision is critical. Therefore, a solution is needed that can modify the existing implant and/or bone in situ. One clinical case study [7] has reported attaching a cortical strut graft to the lateral aspect of the tibia to alleviate the modulus mismatch between the stem and bone in revision TKA. This study appears to provide positive results but has only reported one patient with a follow up of 1 year; therefore, the results do not provide any conclusive evidence that this is a suitable option for stem tip pain relief in TKA. The attachment of cortical strut grafts to the region of the stem tip has, however, been reported to be successful in the resolution of enigmatic thigh pain following THA [1]. The limitation in revision TKA is that there is less space available, making attachment of the graft with cables difficult. The use of a metallic bone plate may therefore simplify the surgery in avoiding the need for cabling and reducing the requirement to obtain bone allografts, with its associated risks. The senior clinician behind the current study has experienced some success in the management of stem tip pain, post revision TKA, with the use of metallic plates. The technique has been applied to 2 patients; 1 had complete resolution of symptoms immediately, maintained at 3 year follow-up, the other only had partial success in reducing symptoms but sufficient to allow the patient to carry on without the need for revision over a 3 year period. However, the biomechanical effect of the addition of a plate to

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the region of the stem tip has yet to be analysed. Therefore, the main objective of this study was to analyse the changes seen following the addition of a plate to the tibia in order to determine a possible reason for the reduction in stem tip pain seen clinically.

Materials and Methods

To achieve the objective described above, a 3D finite element model was created of the implanted tibia using the finite element software ABAQUS [8]. The model consisted of six different parts; a mobile bearing, a stem extension attached to a tibial tray, a top cement layer, a lower cement layer, a cancellous bone section and a cortical bone section as shown in Fig. 1.

The connectivity of separate parts in a finite element model needs to be specified. In this study two forms of connectivity have been used, "tied surfaces" and "contact surfaces". In the former, adjacent surfaces are fully fixed to each other whilst in the latter the surfaces can slide over each other providing the specified friction can be overcome, but they cannot penetrate each other. In the model four tied surfaces were implemented, which included the connection of the lower cement layer to the tibial cavity and the stem of the tibial prosthesis; the top cement layer was tied to the cut tibia surface on one side and to the bottom of the tibial tray on the other side. Contact surfaces between the mobile bearing and the tibial tray were modelled using the surface-to-surface contact algorithm and a coefficient of friction of 0.1 [9]. Contact between the stem extension and the cancellous bone was modelled with a surface-to-surface contact with a coefficient of friction of 0.25 [10] to represent a press-fitted stem extension. It should be stated that modelling full contact between the extension and the cancellous bone is an idealisation. The quality of the cancellous bone is less good distally and contact may be patchy. It should however be noted that the modelled contact is not fully bonded but is frictional and thus can sustain relative motion if the friction is overcome. The press-fitted stem extension was chosen for modelling since this is the method considered to provide good clinical results in revision TKA in particular with regards to tibial alignment and ease of removal for further revisions [11]. In addition this was the fixation method used by the senior clinician on the stem extensions where the metal plate attachment technique was applied.

The distal end of the tibia was constrained in the x, y and z directions to prevent rigid body motion and a pressure load was applied to the medial and lateral surface contact patches of the mobile bearing [9], see Fig. 2. The model was based upon the leg in late stance phase (40% of gait cycle) where the joint reaction force is maximum and the majority of loading is reported [12] to be on the medial condyle. Morrison [12] used experimental data from 14 normal adults to calculate, through the use of biomechanical principles, the location of the centre of pressure at this point of the gait cycle. On this basis the distribution of loading on

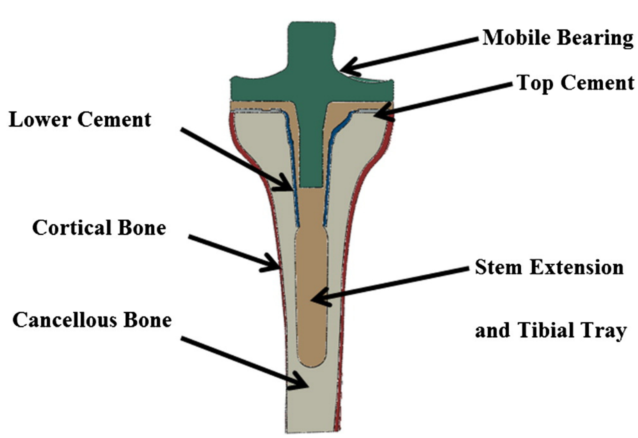

Fig. 1. Stem extension model.

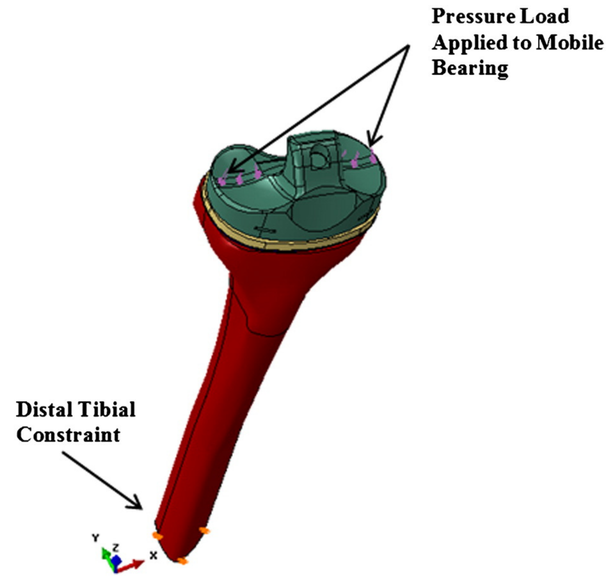

Fig. 2. Completed 3D Finite Element model showing tibial constraint and bearing loading.

the medial and lateral condyles for this model was calculated to be approximately 70% and 30% respectively. A compression force of 2208N was applied. This was based on a pressure load of three times the body weight of a 75-kg person due to the combined effect of body weight and the gastrocnemius muscle loading in late stance phase [12].

A rectangular plate (90 mm × 15 mm × 5 mm) was used for the initial studies, based on a standard 4-hole locking compression plate (LCP, Synthes Ltd, Welwyn Garden City, UK) similar to that used by the senior clinician. The positioning of the plate in the finite element model was such that it was placed as close to the surface of the tibia as possible in the dysphyseal area at the stem tip. It was equidistant on the medial and lateral side of the stem tip in the superior/inferior directions, as shown in Fig. 3 (b) and (c). The full surface of the plate was constrained using a tied surface to the tibia to model a fully integrated bone plate condition.

Further detailed analysis was also completed by refining the plate attachment method and conducting an analysis of different plate material options. The refined attachment method of the plate to the tibia applied fixation through only four tied surfaces of 5 mm diameter, rather than the full surface area. This simulated the initial screwed attachment of the plate to the tibia with 4 unicortical screws. The most commonly used bone plate materials in fracture repairs are titanium and stainless steel; therefore, these materials have been used in this study. In addition, plates of cortical bone were also modelled as they have been reported to be used in revision THA with some success as a possible solution to stem tip pain [1].

The implanted tibial model was meshed using quadratic solid tetrahedral elements, the plate was meshed using quadratic brick elements for the full surface tied plate and quadratic solid tetrahedral elements for the models with the refined plate attachment method.

Material properties were applied and all parts were assumed to be linearly elastic, homogenous and isotropic [11]. The material properties used for the various parts of the models are shown in Table 1.

Results

Fig. 3 shows the von Mises stress plots for the un-plated and medially and laterally attached, plated (titanium) models. The plots show the anterior of the tibia sliced through the coronal plane to demonstrate the area of stress at the stem tip. A threshold value of 1 MPa was arbitrarily chosen for the von Mises stress plots since it showed the concentrations of stress at the stem tip most clearly.