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Finite element analysis of Puddu and Tomofix plate fixation for open wedge high tibial osteotomy

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ABSTRACT

The use of open wedge high tibial osteotomy (HTO) to correct varus deformity of the knee is well established. However, the stability of the various implants used in this procedure has not been previously demonstrated. In this study, the two most common types of plates were analysed (1) the Puddu plates that use the dynamic compression plate (DCP) concept, and (2) the Tomofix plate that uses the locking compression plate (LCP) concept. Three dimensional model of the tibia was reconstructed from computed tomography images obtained from the Medical Implant Technology Group datasets. Osteotomy and fixation models were simulated through computational processing. Simulated loading was applied at 60:40 ratios on the medial:lateral aspect during single limb stance. The model was fixed distally in all degrees of freedom. Simulated data generated from the micromotions, displacement and, implant stress were captured. At the prescribed loads, a higher displacement of 3.25 mm was observed for the Puddu plate model ($p < 0.001$). Coincidentally the amount of stresses subjected to this plate, 24.7 MPa, was also significantly lower ($p < 0.001$). There was significant negative correlation ($p < 0.001$) between implant stresses to that of the amount of fracture displacement which signifies a less stable fixation using Puddu plates. In conclusion, this study demonstrates that the Tomofix plate produces superior stability for bony fixation in HTO procedures.

Introduction

High tibial osteotomy (HTO) is a well established procedure used to treat uni-compartmental osteoarthritis of the knee.[1] Due to its success in treating this condition, the use of HTO has since been extended to include many other indications such as, correction of various angular knee deformities and ligamentous injury.[2] In addition, HTO have also been widely advocated for use in paediatric patients which includes correction of congenital malformation.[1–3] At present, there are two types of HTO which are commonly described: the medial open wedge HTO (OWHTO) and the closed-wedge HTO (CWHTO). It is apparent from most studies that OWHTO is more widely preferred owing to the lesser likelihood of developing complications; which may include peroneal nerve injury and disruption of the proximal tibiofibular joint.[4]

To maintain the stability of the OWHTO, specialized implants were introduced. The two most commonly described are the Tomofix and Puddu plates.[5] Although the former provides stability to the osteotomized tibia fixation using locking head screws (LHS), the Tomofix plates maintains its fixation on the bone using the fixed-angle plate concept.[6] However, the comparative biomechanics between these two different implants has not been demonstrated and analysed computationally.

One of the computational methods that has received wide acceptance in orthopaedics research is the Finite Element Analysis (FEA).[7–9] In this technique, three dimensional models of bone-implant construct are converted into finite elements with simulated physiological loads applied to analyse and predict the outcome of surgery. Various biomechanical studies via computer simulation have provided further insight into the stability and functionality of joints and bone construct.[7,10–13] Hence, the present study was conducted to determine the stability of these implants following OWHTO procedure through the use of finite element analysis.

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Materials and methods

Three dimensional model design

Three dimensional (3D) model of human tibia and fibula was reconstructed from two dimensional computed tomography (CT) image using 3D model reconstruction software (MIMIC 10.01, Materialise, Belgium). The CT image dataset was obtained by scanning the lower limb of a single male subject in one medical centre. An opening of 10 mm gap was simulated by removing a wedge-shaped bone piece from the proximal part of the tibia. The three dimensional models of both implants were designed according to the manufacturers' specifications using computer-aided design (CAD) software (SOLIDWORKS 2009 SP2.1, Dassault Systems, Massachusetts, USA). Two components make up both the Tomofix and Puddu plates, which is the plate and screws. The Tomofix plate system has a total of 8 screw holes: 5 of these are able to adapt either the LHS or conventional screws while the remaining three can only allow the LHS screws to be inserted. In the Puddu plate system, in addition to the plate and screw holes, a block configuration was incorporated into the plate design to allow additional support at the osteotomy. In this system, two conventional screws were used, which is commonly described in several literatures.[5,14,15]

The implants were then carefully positioned across the gap. A 10 mm wedge size Puddu plate was selected, and placed across the opening as shown in Fig. 1. The Tomofix was positioned as recommended by the manufacturer as demonstrated in Fig. 2.

Material properties

In this study, the properties of titanium alloy were adopted into the simulated implant models. The Young's modulus (E) was set at 110,000 MPa with a Poisson's ratio (υ) of 0.3.[16] Both implants were modelled to incorporate linear elastic, isotropic and homogeneous properties. As for the tibia and fibula, the material properties were also assumed as linear elastic, isotropic and homogeneous material. Both tibia and fibula were modelled with an assumed Young's modulus, E = 20,000 MPa and Poisson ratio, υ = 0.3.[10] The cortical bone and medullary canal was not modelled in this study.[17] These parameters are summarized in Table 1.

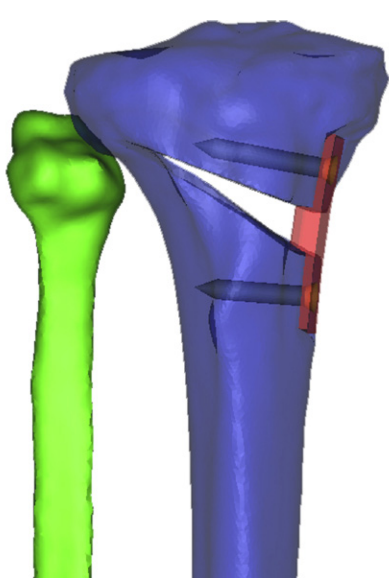

Fig. 1. Puddu plate positioning on 3D model of simulated open wedge high tibia osteotomy.

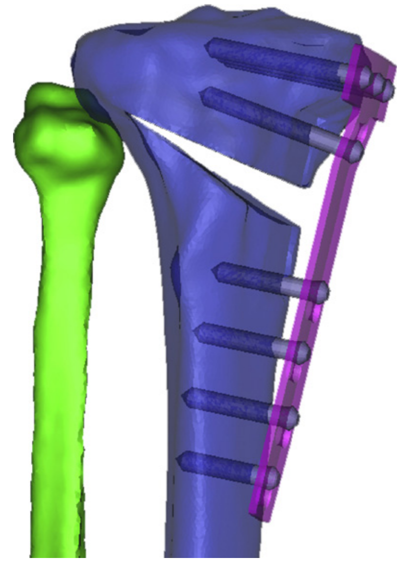

Fig. 2. Tomofix plate positioning on 3D model of simulated open wedge high tibia osteotomy bone.

Analysis

For finite element analysis, both the bones and implants were meshed using 1.0 mm sized tetrahedral mesh.[18] The distal end of the tibia was fixed in all degrees of freedom to prevent rigid body motions during the analysis. An axial force of 2500 N with a distribution of 60% to the medial compartment was applied to simulate the axial compressive load on the knee of an adult during single limb stance.[5,19] The effect of axial load sharing between tibia and fibula was simulated by linking the two bones with virtual mechanical rigid links.[20]

For the Puddu plate system, it was assumed that this plate system had a direct contact with the bone. The same contact properties were also assigned between the LHS and the bone. The contact between the plate and LHS was simulated to imitate strong contact attachment that mimics the locking screw mechanism. All friction coefficient values were set to 0.3.[21] The analysis was done using commercial finite element software (MARC, MSC.Software Corporation, California, USA) with the equivalent von Mises stress (EVMS), displacement of the model relative to the distal tibia, and micromotion of the implant relative to the bone (as a measure of relative fixation strength) used as the output measures. Statistical analysis was done using the IBM SPSS Statistics software using t-test.

Results

Higher amounts of displacement were observed in the Puddu plate system as compared to the Tomofix plate with a mean difference of 3.25 mm observed between the two ($p < 0.001$) (Table 2). The displacement appeared to be directed towards the anterior side of the tibia which was consistently observed in both systems (Fig. 3), decreasing as it approaches distally (Fig. 4).

Table 1
Material properties of reconstructed 3D model.

Materials	Young's modulus, E (MPa)	Poisson ratio, υ
Puddu plate/Tomofix plate	110,000	0.3
Screws	110,000	0.3
Tibia	20,000	0.3
Fibula	20,000	0.3