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Computational comparison of tibial diaphyseal fractures fixed with various degrees of prebending of titanium elastic nails and with and without end caps

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ABSTRACT

Introduction: Elastic stable intramedullary nailing (ESIN) is a treatment strategy for the management of diaphyseal long-bone fractures in adolescents and children, but few studies have investigated the mechanical stability of tibial diaphyseal fractures treated with various degrees of prebending of the elastic nails. Therefore, the aim of this study was to compare the mechanical stability, including the gap deformation and nail dropping, of a tibia fracture with various fracture sites and fixed with various degrees of prebending of the elastic nails by the finite element method. Furthermore, the contribution of end caps to stability was taken into consideration in the simulation.

Methods: A tibia model was developed with a transverse fracture at the proximal, middle and distal parts of the diaphysis, and fixed with three degrees of prebending of elastic nails, including those equal to, two times and three times the diameter of the intramedullary canal. The outer diameter of the nail used in the computation was 3.5 mm, and the fractured tibia was fixed with two elastic double C-type nails. Furthermore, the proximal end of each nail was set to free or being tied to the surrounding bone by a constraint equation to simulate with or without using end caps.

Results: The results indicated that using end caps can prevent the fracture gap from collapsing by stopping the ends of the nails from dropping back in all prebending conditions and fracture patterns, and increasing the prebending of the nails to a degree three times the diameter of the canal reduced the gap shortening and the dropping distance of the nail end in those without using end caps under axial compression and bending. Insufficient prebending of the nails and not using end caps caused the gap to collapse and the nail to drop back at the entry point under loading.

Conclusions: Using end caps or increasing the prebending of the nails to three times the diameter of the canal is suggested to stop the nail from dropping back and thus produce a more stable structure, with less gap deformation, in the management of a simulated tibial diapyhseal fracture by using titanium elastic nails with a double C-shape.

Introduction

Elastic stable intramedullary nailing (ESIN) has been used for the management of displaced diaphyseal long-bone fractures in children over the age of three years old for many years, although this method has a high complication rate of up to 37% [1]. The major complications are pain at the site of nail insertion, inflammatory reaction/bursitis at the entry site, superficial infection, knee swelling (synovitis due to nails), leg length discrepancy and proximal nail migration. Lack of stability causes

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deformation of the fracture gap and the dropping back of the end of nails when loading is added [1–8]. The repeated dropping back of the nail at the entry site during loading and unloading irritates the soft tissue around the entry site and results in complications.

Prebending of the nail is an essential technique to increase the stability of a fractured long bone fixed with elastic nails, and which has been examined in a number of fractured femoral models [5,9,10]. However, to date, the mechanical stability of tibial diaphyseal fractures with various degrees of prebending of the elastic nails have not been discussed in the literature. The geometry and loading mode are different between the femur and tibia in this context. The femur contains a neck while the tibia is much like a straight structure, and thus the latter sustains more axial compression force than the former. Moreover, the use of end caps in the treatment of a diaphyseal fracture has rarely been examined using mechanical testing, although Kaiser applied a fractured femur model with nails prebent to 40 and examined the effects of end caps on structural stability [11]. Although the results demonstrated no difference between with and without using end caps, only 40 of prebending of the nails was used. In clinical practice, the degree of prebending of the nails varies depending on the surgeon and cases [11–16]. It is thus necessary to examine the effects of using end caps with various degrees of prebending of the nails when treating tibial diaphyseal fractures, thus enabling surgeons to perform stabilisation for fracture healing and achieve more favourable outcomes.

The finite element (FE) method is a powerful tool that can be used to calculate the gap deformation and the internal stress and strain of a fractured bone with irregular geometry during time-dependent loading conditions, such as walking [17–20]. FE models have also been applied to calculate the sliding of nails inside the canal of a fractured femur, and in radius and clavicle models to reveal the stress and the slipping of nails [18,21,22]. However, the degree to which the nails are prebent has not been examined in previous FE simulations. Since the prebending of the nails is regarded as a critical factor for the stability of the fixation of fractures in previous experimental studies, it should also be taken into consideration in simulations to present the real responses of the nails with various degrees of prebending inside the canal. Therefore, the aim of this study was to compare the mechanical stability of a fractured tibia with various fracture sites and fixed with various degrees of prebending of the elastic nails by the FE method. Furthermore, the contributions of end caps to the structural stability was taken into consideration in the simulation.

Materials and methods

To evaluate the stability of a fractured tibia fixed with various degrees of prebending of the elastic intramedullary nails, an FE model consisting of a fractured tibia and fixed with two elastic nails was developed. Three factors were employed in this study, including the prebending of the nails, the location of the fracture sites and the use of end caps.

Solid model

An intact tibia model was developed based on the CT images of a healthy subject with body weight 62 kg and body height 163 cm. Three different types of fracture were employed, including a transverse gap at the proximal, middle and distal parts of the tibial diaphysis (Fig. 1). The gap was created through a Boolean operation using the CAD software Solidworks 2012 (Dassault Systemes

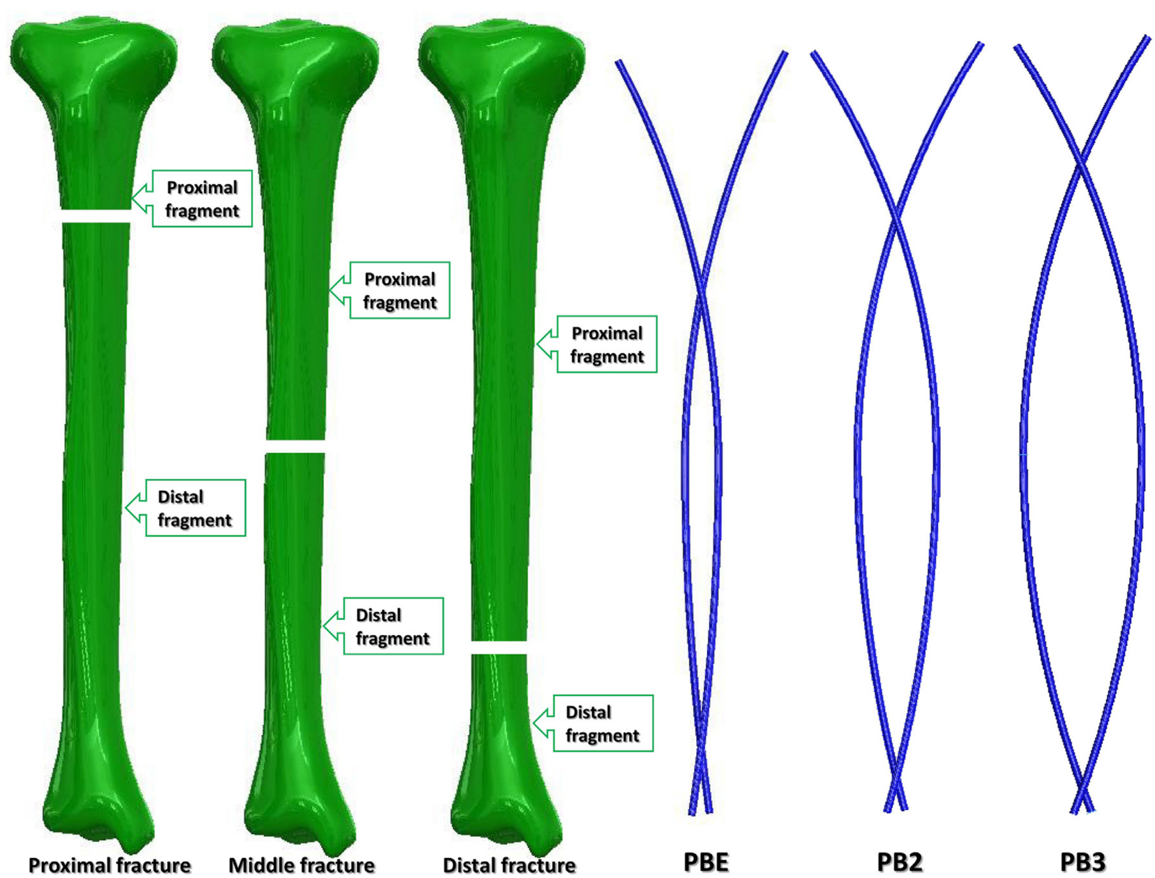

Fig. 1. The models used in this study.

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