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Simulated vibrational analysis of internally fixated femur to monitor healing at various fracture angles

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Abstract

Finite element analysis has been performed to investigate the feasibility of using modal analysis to determine whether an internally fixated femur is healing. Two types of fixation are investigated, an intramedullary nail(IM) and a plate style fixation. Both are installed on a Sawbone artificial femur by a surgeon which is then 3D scanned to create the finite element model. Modal analysis of these two fixations will predict the stiffness of the system using each fixation and also identify which type of modes are most sensitive to healing. Various cut orientations are also modelled to test their influence on natural frequency of the femur.

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1. Introduction

Internal fixations are commonly used as operative treatment choices for bone fractures. Intramedullary (IM) nail and plate type fixations are associated with decreased complications such as pin tract sepsis and joint stiffness which may occur with external fixations.

The healing process of a fracture is a complicated procedure, on both a macroscopic and microscopic level. Due to the precise balance required between anabolic and catabolic phases, delayed unions, mal-unions and non-unions are common, occurring in 5-10% of all long bone fractures[1]. Hernigou et al[2] define a delayed union as a fracture site continuing to sustain clinical and radiological signs of fracture outside of the expected healing time, or the

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absence of signs of progressive repair between the 3rd and 6th month of repair following a fracture. Mal-unions are defined as a pathological union of a fracture, usually involving shortening and rotational or angular deformity[3], while non-unions are defined as a lack of union within the expected healing time[1]. Although there is a lack of a standardised definition of these pathologies, they are clinically significant and have an impact on quality of life. With this in mind, adequate monitoring of healing will enable action to be taken sooner in the case of poor union and early mobilization in the case of adequate union resulting in social and economic benefits.

Monitoring healing of internally fixated fractured femurs has been investigated by several authors [4-11]. Talaia et al [5] attached a combination of strain gauges and FBG sensors to a synthetic femur. The strain was measured while intact and plated femurs were loaded to 600 N. The strain readings revealed a clear difference in strain values depending on whether the bone was intact. Wilson and Janna [6] modified a femoral nail to include a wireless strain gauge. This was fixated onto a sheep. This single gauge configuration found no clear correlation between strain on the IM nail and fracture healing when in vivo. However, ex vivo the load share between the bone and IM nail could be detected in the absence of muscle forces. Greve et al [7] installed a wireless SAW strain sensor to monitor healing on a tibia. Although the idea was novel the authors conclude that while strain sensitivity is adequate for monitoring the bone the RF signal strength is marginal and would have difficulty if in vivo testing was required.

The existing literature shares one thing in common, despite using a variety of sensor technologies strain readings are used to determine the extent of healing. One problem with such methods is the loading regime (e.g. 600 N compression) used to determine the strain readings can cause further damage to a fractured femur. Furthermore some authors [6] report that strain could not be correlated to healing. Literature on external fixations exists where vibrational analysis is used to determine the state of healing instead of strain. Ong et al [12, 13] recently used vibrational methods to determine healing in an externally fixated femur. It was shown that changes in the amplitude and frequency of the modes could be correlated to healing. Furthermore, a healing index could be computed based on the frequency response functions to provide quantitative healing measurement.

In this paper, an investigation into the use of vibrational analysis on internally fixated femurs is performed. This work will consist of numerical simulations to identify the effects of healing and also fracture orientation. Two types of internal fixations were modelled; a plate type fixation and an IM nail type. It is hoped that the simulations presented here will provide and insight which will be used in planning experimental work in the future.

2. Numerical simulation of a femur fixated with a plate

A series of numerical models were solved to determine the effects of fracture healing and fracture angle on the dynamic response of the fixated femur. These findings will be used in future studies to determine the potential of locating sensing devices on the external fixation to determine the state of healing of the fractured femur. It will also be used to identify the appropriate frequency bandwidth that will facilitate the monitoring of the healing of the fixated femur.

The geometry of the femur and the plate was digitally scanned using structured light 3D scanning technology. A finite element model was created from the scanned geometry as shown in Figure 1. The cortical shell thickness of the femur bone is approximated from the Sawbones catalogue by using photogrammetric software ImageJ to measure the cortical bone thickness at various points from cross sectional photographs. This was done to improve model accuracy over models which assume uniform cortical bone thickness such as those presented by Oshkour et al [14] and Cilingir et al [15]. Due to the model's complex geometry; it was meshed in a commercial package (UGS NX 7.5) using tetrahedral elements set to a spacing of 2 mm. In practice the plate fixation is fastened to the femur using several screws; however for simplicity in this model the plate fixation is rigidly mated to the cortical shell of the femur. The material properties used are summarized in Table 1. The plate fixation as indicated on Figure 1 was made from titanium. Figure 1 also shows the coordinate system and excitation for frequency response calculation which will be referred to later on. A fixed constraint was applied to the ball joint shown on the right side of the femur in Figure 1. This mimics a potential future experimental setup and also approximates a connection to a human pelvis.