Grant, Caroline A. and Schmutz, Beat and Steck, Roland and Schuetz, Michael and Epari, Devakara R. (2009) ***Creation of a validated 3D finite-element model of an ovine tibia***. In: 4th Asia Pacific Biomechanics Conference, 14-17 April 2009, University of Canterbury, Christchurch.

Creation of a validated 3D finite element model of an ovine tibia

Caroline A. GRANT[1,2], Beat SCHMUTZ[2], Roland STECK[2], Michael SCHUETZ[2], Devakara R. EPARI[2]
[1]Paediatric Critical Care Research Group, Paediatric Intensive Care Unit, Mater Children's Hospital, South Brisbane, Queensland
[2]Orthopaedics & Trauma Qld, Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Queensland
E-mail: c.grant@student.qut.edu.au

Abstract
Ovine models are widely used in orthopaedics and trauma research. We present the development and validation of an FE model of an ovine tibia for use in the testing of tibia fracture fixation plates. The FE model was generated from CT data of a cadaveric tibia and validated by mechanical testing of the bone. An offset 3-pt bend test was conducted with strain gauges placed on the anterior and posterior surfaces of the diaphysis. The loads applied during testing were applied to the model after digitising their location and orientation with a 3D digitiser. A comparison of the surface strains was conducted. Initial results show a good correlation between the mechanical test and the FE model with calculated strain values within 2% of the measured strains. Further improvements are expected with the incorporation of bone density-specific material properties in the model.

Key words: Finite Element Analysis, Mechanical testing, Ovine Tibia, CT, Orthopaedic implant, Fracture fixation plate

1. Introduction

Ovine models are widely used in orthopaedics and trauma research. However data recorded during mechanical testing is limited in detail and can only tell us so much about the behaviour of the bone. 3D finite element (FE) models of bones generate highly detailed outputs and allow the local mechanical environment to be determined both internally and externally under complex loading scenarios. A formal validation of the FE model with mechanical testing is essential for further use. We present the development and validation of an FE model of an ovine tibia for use in the testing of tibia fracture fixation plates.

2. Methods

2.1 Mechanical Testing

Mechanical testing of the tibia was conducted in a manner that could be replicated in the computational model. Strain gauges were attached to the anterior and posterior surfaces of the cleaned bone, and an offset 3-pt bend test was conducted. A preload of 50 N was applied followed by three cycles of loading to 350 N. Load/displacement data was recorded throughout the test along with strain information (Table 1).

To accurately reproduce this test in the FE model and compare strain results, information was required on the exact orientation of the bone within the rig, the position and angle of the loads applied and the position of the strain gauges. This data was acquired using a FARO arm 3D digitiser (FARO Technology Inc) after the preload had been applied. The solid model was then aligned with the positional data from the testing using a surface registration algorithm in the software package Rapidform (INUS Technology).

2.2 Model Creation

The FE model was created from Computer Tomography data and then validated by mechanical testing. A cadaveric ovine tibia was CT scanned and a 3D computer solid model generated using the software packages Amira (Mercury Computer Systems) and Geomagic (Raindrop Geomagic). Using Abaqus (Simula) an FE model was then generated from the solid model. Homogeneous material properties were applied to the bone. A tetrahedral mesh was applied and the bone constrained and loaded in an offset 3-pt bend test. A point load of 350 N was applied to the model with the bone constrained in x, y and z at one support and in y and z at the other, allowing the bone to move along its length during the bending.

Resultant peak surface strains were recorded at the locations of the strain gauges in the mechanical test as determined with the FARO arm (Table 1).

3. Results

Comparison of the results from the mechanical testing and the finite element modeling showed good correlation in the surface strains. Values from nodes in the FE model at the locations of the anterior and posterior strain gauges were 11% larger and 5% larger respectively than the values recorded from the gauges themselves. Displacement of the load was also measured, in the mechanical testing a total displacement of 0.79 mm was recorded of which 0.38 mm was recorded during the preload, the FE model underwent a displacement of 0.50 mm in a similar location with a 350 N load applied.

	Mechanical Testing	Finite Element Model
Anterior	-1.44 E+03 $\mu\varepsilon$	-1.60 E+03 $\mu\varepsilon$
Posterior	1.56 E+03 $\mu\varepsilon$	1.64 E+03 $\mu\varepsilon$
Displacement	-0.79 mm total -0.38mm preload	-0.50mm

Table 1 Surface Strains recorded during a 3-pt bend mechanical test and the same test simulated using a finite element model

4. Discussion

In this study our aim was to develop and validate an FE model of an ovine tibia. Good agreement between the model and the experiment was achieved with a difference in strain of approximately 10%. This discrepancy could be attributed to a combination of a number of different factors; use of a cortical shell model, homogeneous material property assignment, boundary condition application and the assumption of linear elasticity are all likely to have contributed.

In the mechanical testing component a 3-pt bend test was chosen as the initial load case as it generates a range of compressive and tensile strains across the bone.

5. Further Work

Subsequent model iterations will integrate CT based material property assignment. By deriving the material properties from the CT data a heterogeneous map of values can be applied across the bone. The methods of material property derivation from CT however will require close examination as currently established relationships have been validated for use with human rather than ovine bone.

Additional loading environments, particularly those that are physiologically and clinically relevant will also be explored. Further testing will also incorporate additional surface strain recording to facilitate validation of larger areas of the model.