Risk of fracture modelling in healthy and osteoporotic tibia

Abstract:

Background

Osteoporosis has detrimental effects on the structural integrity of the skeletal system. The degeneration of bone material can be seen in spinal cord injury (SCI) patients due to lack of mechanical stimulation following extensive muscle paralysis.

Aim

The aim of the study was to simulate and compare the mechanical response of the tibia of both able bodied (AB) subjects and SCI patients under four different types of loading, compression, A-P bending, M-L bending and torsion, and map how the risk of fracture (RF) correlated with bone mineral density (BMD) and type of loading. The stress distribution was calculated using the finite element method.

Material and methods

Eight male SCI subjects with varying degrees of bone loss and four age-matched AB male control subjects were recruited for the study. The bones were scanned in vivo at the Queen Elizabeth National Spinal Injuries Unit (Glasgow) using a multi-slice peripheral Quantitative Computed Tomography, and individualised three dimensional finite element models were created of each subject's tibia from the scans using Mimics (Materialise). The material assignment was based on the greyscale pixel values of the scan images from which BMD was calculated. An empirical power law was used to estimate the Young's modulus and the ultimate tensile strength for each element from the BMD.

Results

Analysis of the material distribution in the tibia showed large numbers of elements with low BMD for the SCI group whereas a larger proportion of high density bone was seen in the AB group. The average BMD was lower at the epiphyses for the SCI group, but overall little difference was seen around the diaphysis between the groups. The finite element modelling was carried out using Abaqus (v.6.11, Simulia). The analysis was performed using 4 node tetrahedral elements and the element density was on average 2.9 elements/mm^3. The von Mises stress values of each element were exported and the percentage of elements exceeding an estimated RF threshold calculated. The results showed an increase in percentage of elements exceeding the RF threshold for the SCI group in bending and torsion compared to compression which is in agreement with clinical experience. On average, the SCI group showed greater numbers of elements exceeding the RF threshold than the AB group for all four loading conditions. The majority of the fractured elements were located around the epiphyses for all subjects.

Conclusions and clinical implications

Using the analysis methods described can provide clinicians with useful patient-specific information about the amount of loading that can be put safely on the osteoporotic bone. That is of importance in SCI patient rehabilitation where musculoskeletal rehabilitation techniques include stimulating the bone via mechanical methods such as vibration or electrical stimulation of the muscles. Using such subject-specific analysis it is possible to determine the location along the bone that is most likely to fail along with the risk associated.