A novel technique to analyse trabecular bone mechanics during screw insertion

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PUBLICLY DISSEMINATED WORK

Peer Reviewed Publications:

Ab-Lazid R, Perilli E, Ryan M, Costi J, and Reynolds K, (2014). "Does cancellous screw insertion torque depend on bone mineral density and/or micro-architecture?" J. Biomech 47(2), pp 347-353.

Conference Proceedings:

Ryan MK, Costi JJ, Badiei A, Fazzalari NL, Reynolds KJ. The role of effective tissue modulus in predicting apparent modulus and strength in osteoporotic bone. 56th Annual Meeting of the Orthopaedic Research Society, New Orleans, Louisiana USA, 2010.

Ryan MK, Costi JJ, Badiei A, Fazzalari NL, Reynolds KJ. The role of effective tissue modulus in predicting apparent modulus and strength in osteoporotic bone. ANZORS 12th annual scientific meeting, Adelaide, Australia, 2009.

Ryan MK, Costi JJ, Fazzalari NL, Reynolds KL. Validity of using a linear micro-finite element model to predict trabecular bone apparent mechanical properties: comparison with a non-linear model and experimental data. ANZ/IBMS, Sydney, Australia, 2009. (Poster Presentation)

Ryan MK, Hearn TC, Costi JJ, Fazzalari NL, Reynolds KJ. Assessing failure mechanisms of trabeculae by micro-computed tomography based finite element modelling. 5th Annual Clare Valley bone meeting, Clare, Australia, 2008.

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ABBREVIATIONS

AP	antero-posterior
BV/TV	bone volume fraction
BS/TV	total surface
DA	degree of anisotropy
E_{Tiss}	bone tissue elastic modulus
E_{FEA}	finite element analysis determined elastic modulus
E_{Exp}	experimentally determined elastic modulus
ε_y^c	compressive yield strain
ε_y^t	tensile yield strain
micro-CT	micro-computed tomography
micro-FEA	micro-finite element analysis
SI	supero-inferior
SMI	structure model index
TbN	trabecular number
TbTh	trabecular thickness
TbPf	trabecular pattern factor
TbSp	trabecular separation
$T_{plateau}$	plateau torque
$T_{Stripping}$	stripping / maximum torque

ABSTRACT

During screw insertion, surgeons manually tighten until they subjectively feel that adequate torque has been obtained. This “tightening torque” has been shown to equate to approximately 86% of maximum (stripping) torque. The level of torque to which orthopaedic screws are tightened, however, is highly subjective and can lead to over-tightening or even stripping in cases of poor bone quality. Whilst torque limiting devices exist that are able to terminate tightening at specified torque levels, these are of little value if the optimum torque is not known. Furthermore, the ideal level of tightening torque may vary according to anatomic location, bone quality and screw material and design. Bone quality is determined by the geometry of the bone and it’s underlying micro-architecture, as well as accumulated microscopic damage, the quality of collagen, mineral density and crystallinity, and bone turnover. Therefore to fully understand these interactions at the macroscopic level, and understanding of the bone-screw interactions at the micro-structural level is necessary. The aim of this dissertation was, therefore, to develop a novel technique to analyse the mechanical interactions between cancellous bone and a lag screw during tightening. The ultimate goal was to develop a micro-finite element model that incorporated the screw and its mechanical interactions with the micro-structure of cancellous bone.

The first part of this dissertation explored the application of micro-finite element modelling for analysing vertebral trabecular mechanics at the micro-structural level under a uniaxial load in either the supero-inferior (SI) or antero-posterior (AP) direction. Results demonstrated distinctly different micro-mechanical behaviour between the two loading directions, with a greater volume of tissue reaching yield at the onset of apparent-level yielding, in the SI direction compared to AP. The incorporation of both material and geometric nonlinearity yielded strong agreement between model predictions of apparent yield and experimentally determined values; however the influence of experimental protocol was emphasized if tissue modulus values were derived from experimental data. It was demonstrated that the tissue modulus largely governs the apparent stiffness, whilst tissue yield criterion regulated apparent yield behaviour.

The second part of this dissertation focussed on the main objective, which was to understand the interactions between bone and screw at the micro-structural level. A novel micro-test device was developed that allowed the step-wise insertion of a screw into bone specimens within a micro-computed tomographic (microCT) scanner. Results showed a strong linear relationship between plateau torque and stripping torque, with the screw under investigation. Furthermore, it was demonstrated that the deformation of the trabeculae during screw insertion is restricted to primarily the bone tissue within the screw threads, and that the critical deformation occurs during the load step between 80 % ($T_{stripping}$ - T_{HC}) and $T_{stripping}$.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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