A subject-specific three-dimensional finite element model of the human hand and wrist

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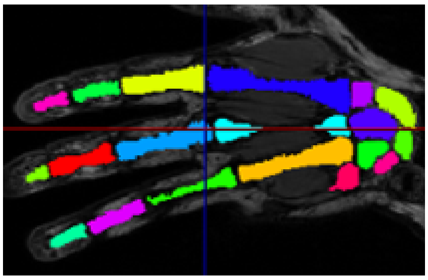
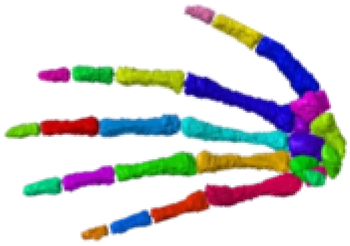
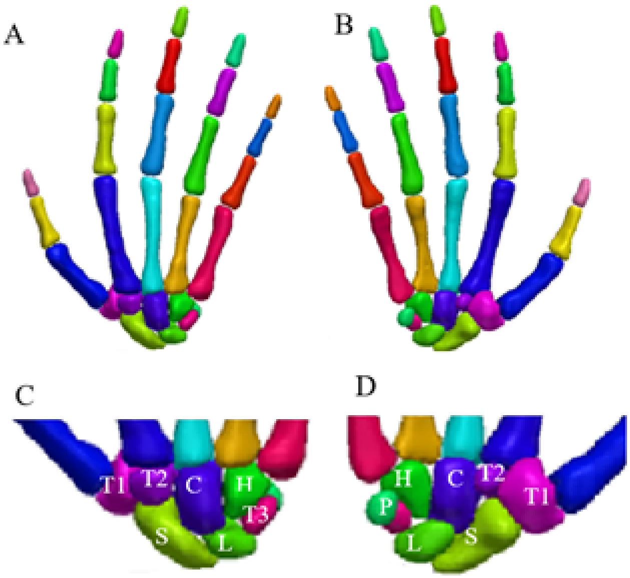
Abstract

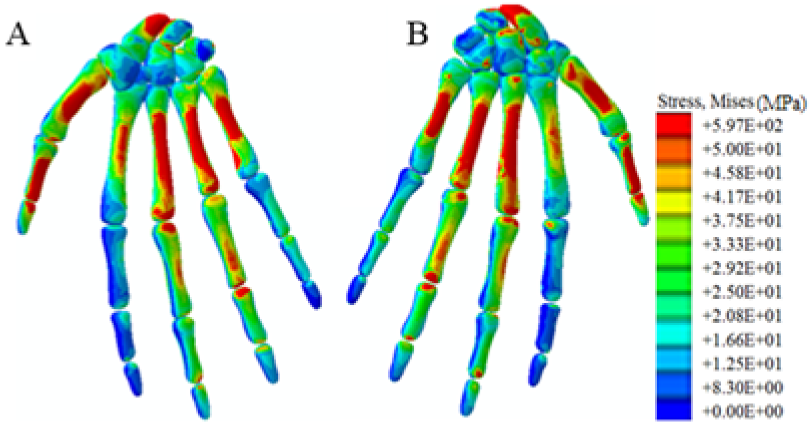
Computer-aided tissue engineering has led to the production of subject-specific, in vivo models of joints which provide valuable information regarding the causes and treatment of joint disease. There is a lack of models for complex joints such as the human hand and wrist which consider all comprising tissues, whilst achieving convergence using only physiological loading conditions. This paper aims to create a holistic, subject-specific, three-dimensional, in vivo model of the hand and wrist, with physiological loading conditions in order to better understand the joint's behaviour. A three-dimensional finite element model of the hand and wrist was constructed using ABAQUS based on individualised Magnetic Resonance Images. The MR image data were converted into a solid model using the medical imaging software SCANIP.

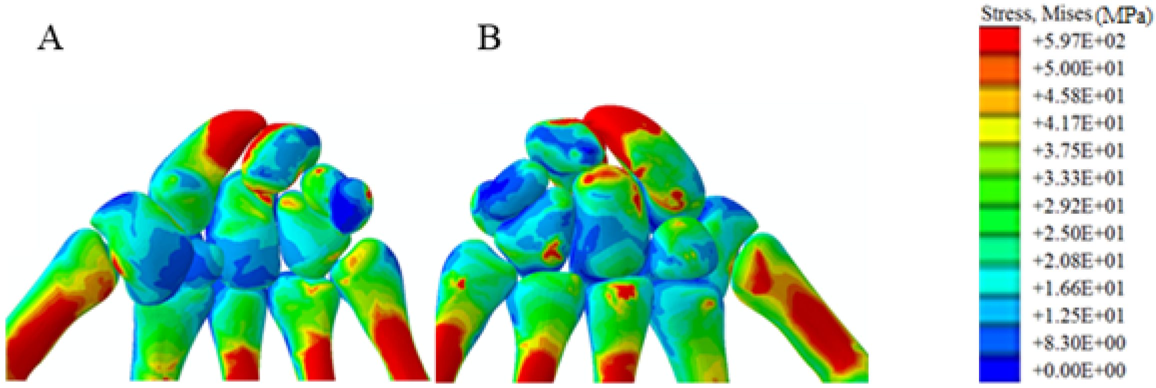






Physiological loading conditions during gripping were applied to the hand in neutral position, based on available references. The results show that the maximum von Mises stress was located on the scaphoid (596.2 MPa). A majority of model elements (96.8%) had stresses which were within the expected physiological range of up to 50 MPa. The average bone von Mises stress was 17.16 MPa. The second digit was discovered to be the least integral to gripping, and the first, third and fourth, the most integral. The extensor hood was found to be most prone to tearing on the second and third digits.





The scaphoid was the most likely to fracture and the most important for stability as it plays a vital role in preventing ‘zig-zag’ collapse of the wrist. The lunate was revealed to be more integral to stability than the capitate. The distribution of stress in the phalanges and metacarpals highlight the importance of the thenar eminence, hypothenar and flexor pollicis muscles to gripping. The distinct types of soft tissue were not constructed separately, instead, they were all assumed to be one unique bulk of soft tissue embedding the 27 hand and wrist bones. The cartilage layers were modelled in each joint to simulate the artiuclating behaviour of the human hand joints while the ligaments transfer the loads from one bone to another. The model was verified by examining the difference between the input and output forces; a comparatively small difference (9.9%) indicated that the model had converged reasonably well. The model was shown to be exhibiting quasi-static behaviour because kinetic energy was negligible compared to internal strain energy. Thus, the model was simplified by negating time and inertial mass. The model was validated by comparison to existing literature [1].

References:
[1] Gislason, M. K., et al. (2009). "A three-dimensional finite element model of maximal grip loading in the human wrist." Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine 223(7): 849-861.