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Real-time Inverse-dynamic FE Modelling of Shoulder Articular Cartilage

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INTRODUCTION

Alterations in mechanical conditions on shoulder articular cartilage have been hypothesized to initiate cartilage degeneration following rotator cuff injuries. Detailed biomechanical conditions are required to understand the role of mechanical factors on cartilage degeneration.

Although various image-based finite element (FE) techniques have been developed to estimate cartilage stresses, none of them were able to successfully reproduce physiologic stresses associated with normal daily activities due to the limitations in imaging spaces.

We aimed to calculate continuous variations in cartilage stresses in the shoulder joint during the gait of canine models by using maker-based motion analysis system. Inverse-dynamic FE analysis was then used to estimate articular cartilage stress patterns.

METHODS

Specimes: Three dogs were tested (approximately 1 year old and 15kg).
Motion Analysis: Two custom maker sets (Fig 1a) were rigidly installed directly to the scapula and humerus (Fig 1b). Movement of markers was recorded with 8-infrared cameras at the sampling frequency of 120 frame/s (MotionAnalysis Co., USA).

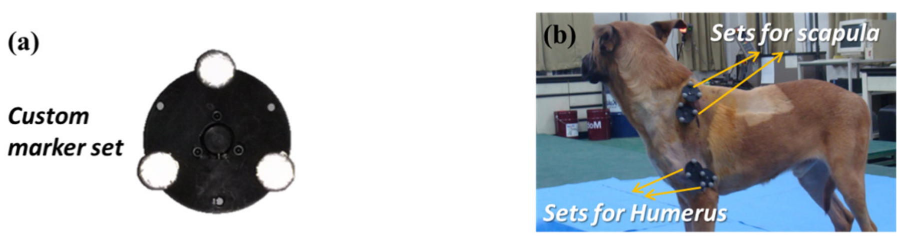

Fig 1. (a) A custom maker set with 3 balls, (b) Maker set installation in scapula & humerus

CT & MR Imaging: MR imaging of the shoulders was performed prior to the motion analyis (Achieva 3.0T TX, Philips, Netherlands). CT scanning (Brilliance CT 64-channel, Philips, Netherlands) of shoulder bones and ball makers were followed.
3D Bone-Cartilage Model: Articualr cartilage and subchondral bone interfaces were manually segmented from the MR images to create 3D cartilage models. OSIRIX (Pixmeo, Switzerland) software was used to produce 3D shoulder bone models from CT data (Fig 2).

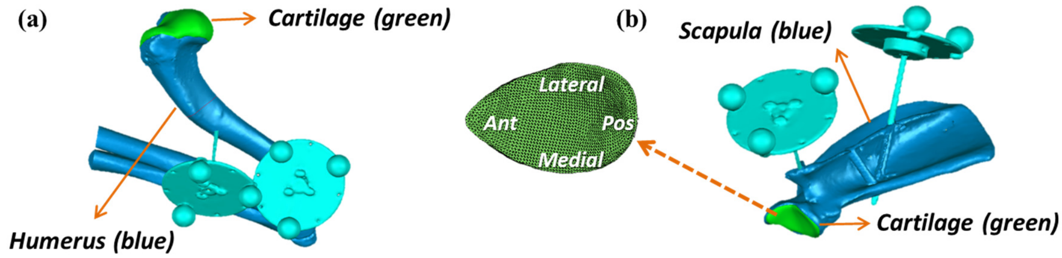

Fig 2. 3D shoulder models for (a) humerus and (b) scapular

Registration: Ball marker centers in the 3D model were alinged with the maker positions in the motion analysis data to determine the postions of humerus and scapula at each gait cycle.
FE Analysis: FE analysis was done by ABASQUS v6.10 (Dassault Systems, France). The articular cartilage was modelled with neo-hookean hyperelastic material property (shear modulus(μ) = 0.21, bulk modulus(κ) = 0.396) and tetrahedral meshes. Initially, humerus cartrilage was completely seperated from the scapular. Humerus cartilage was then gradually moved back to the position estimated in registration precess while the scapular cartilage was rigidly fixed.

RESULTS

Changes in stress pattens in glanoid cartilage were calculated in a full gait cycle. One example of *von Mises* stress was displyed in Fig 3. This result showed detailed spatial variations in cartilage stresses while peak stress was mostly happened at the medial and posterior side of the cartilage during the load bearing period (from 'heel strike' to 'toe off').

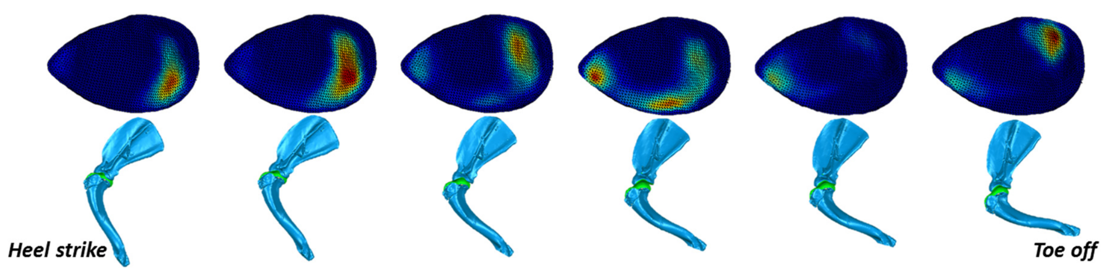

Fig 3. Variations in stress pattern during a gait cycle

DISCUSSION

We successfuly developed a patient-specific real-time stress model of the shoulder by using inverse-dynamics FE modeling. Stress values estimated in this study may not be accurate due to the absence of external force data. However, we believed that the stress comparisons between healthy and injured joints would be critical to understand biomechanical changes and their roles in cartilage degeneration following different injuries. Our novel real-time stress analysis technique would provide previously unavailable detailed dynamic biomechanical information to assist the diagnosis and prediction of osetoarthritic cartilage degradation.

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