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Estimation of 3D shape in the Patellofemoral Joint using Statistical Shape Models and 2D Data

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ESTIMATION OF 3D SHAPE IN THE PATELLOFEMORAL JOINT USING STATISTICAL SHAPE MODELS AND 2D DATA

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INTRODUCTION

Disorders of the patellofemoral joint (PFJ) including PF osteoarthritis and PF pain disorder have been estimated to represent 25% of all patients presenting for knee joint treatment. The diagnosis and treatment of these disorders is curtailed by lack of understanding of the mechanical operation of the joint. A crucial aspect to be considered in understanding contact patterns and kinematics of the PFJ is the alignment of the patella in the trochlear groove. Investigation of patellar alignment necessitates accurate knowledge of the 3D articular surfaces of both patella and femur, along with underlying bone geometry. These 3D data are generally obtained for bones and cartilage plates through reconstruction of images from computed tomography (CT) and/or magnetic resonance imaging (MRI) respectively.

This research proposes to develop a parametric model to enable the accurate estimation of the patient-specific 3D shape of a patella and distal femur from several 2D images. There are several drivers for this work: the labour and cost (and radiation exposure in the case of CT) entailed in 3D scanning mean that it would be greatly advantageous to have the ability to characterise 3D joint geometry using 2D images obtained through the economical, timely and traditionally widely used x-ray / fluoroscopy method. Statistical shape modelling (SSM) and principal component analysis (PCA) has previously been applied to analysis of the distal femur [1] with the aim of developing more sophisticated sizing and shaping rationales for replacement components. This level of shape analysis has not previously been applied to the patellofemoral joint.

MATERIALS AND METHODS

3D (CT/MRI) data of a large population (n<50) of knees will be obtained for use as training sets for the statistical shape model. The femoral and patellar bones and cartilage plates will be segmented using Mimics software (Materialise BV, Leuven), and surface models will be generated from the data. Arthron software (UCD) will be used to perform geometrical and shape analysis on the datasets. Principal component analysis will be performed on the reconstructed datasets to find the major modes of variation, resulting in a statistical shape model of the PFJ which has the ability to morph its 3D shape based on 2D inputs. This model will be validated using an additional set of 2D and 3D images from a second population of knees (n~15). The 2D images will be input into the statistical shape model and the geometry of the resulting 3D models will be compared to that of models reconstructed in the conventional fashion. In this way, average errors and standard deviations of the estimated shapes will be obtained. It is anticipated that the SSM can be used to predict contact areas in the PFJ. In ongoing research at the University of British Columbia, an MRI-based method has been developed for the in-vivo measurement of PFJ contact area. This method was validated in a cadaver knee model. The cadaver specimens were mounted in an MRI-safe loading rig and contact areas were assessed using MRI, dye staining and a pressure measurement system. Initial results suggest a high level of accuracy in the MRI-based measurement technique. Results from this study will be used to validate contact area predictions from the statistical shape model.

RESULTS AND DISCUSSION

Previous work on other anatomical areas has shown the potential that exists in registration of 2D images to a 3D statistical shape model to yield accurate 3D models. In a study on reconstruction of the proximal femur [2], it was found that 3D shape can be estimated with an average error of less than 1.2 mm with appropriate selection of image directions. This research involves the use of statistical modelling to enable the use of 2D fluoroscopic images to estimate 3D shapes in the PFJ. Future work will aim to ally statistical analysis with cadaveric testing in order to further examine the relationship between knee component shape and function.

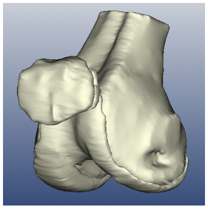

Fig 1: Reconstructed Patellofemoral Joint

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