GENERATING A MUSCULOSKELETAL MODEL OF THE INDEX FINGER FROM MR, CT AND OPTICAL MOTION CAPTURE DATA

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Introduction

Postoperative success in replacing the proximal interphalangeal (PIP) joint is markedly inferior to large lower limb joints. The mean revision rate of primary total knee replacement (TKR) is 0.48% at one year and 5.19% at twelve years [1], and in a meta-analysis Adams et al [2] found at least one complication within one year in 28% of PIP replacements (PIPR). Prior PIPR implant design studies have used measurements of cadaver models [3]. TKR research has employed robust musculoskeletal models for preclinical analysis and surgical technique development, and recent work has aimed to produce similar models of the upper limb. Past finger models represented the PIP using a simple degree of freedom (DOF) hinge [4]. It is established that the knee has complex kinematics including both rotation and translation, and aware of these relative motions, Buczek et al [5] developed a 6-DOF kinematic hand model. Eschweiler et al [6] reported a detailed musculoskeletal model of the wrist, but we are not aware of any such complex hard- and soft-tissue models of the finger. We present a model of the index finger containing the distal upper extremity, with full musculo-ligamentous structures and anatomic joint surface geometry, in an effort to address these issues.

Methodology

From a sample of seven healthy volunteers (UK National Research Ethics ref. 14/LO/1059) we collected CT and MR imaging data, and full hand kinematics from optical motion capture. These data were combined in a musculoskeletal model using AnyBody (AnyBody Technology A/S) [7]. We used an enhanced marker set from Metcalf et al [8,9], which included a triangular marker arrangement on each phalange, enabling full 6-DOF analysis of each bone. To create a comprehensive understanding of the PIP’s functional anatomy, kinematic motion capture included both static and dynamic data. The motion capture markers were left in position during MR and CT imaging. Each volunteer was imaged with the fingers in full extension, and in partial and full flexion, using a poseable support. With the markers visible in the CT images, it was possible to identify their positions relative to each bone’s geometric centre. CT imaging was used to extract the bony anatomy, and MR imaging was used to extract the soft tissue structure trajectories and attachment sites, using ScanIP software (Synopsys Inc). The model includes the tendon-musculature elements of both the intrinsic and extrinsic muscles, including extensor digitorum, extensor indicis, flexor digitorum profundus and superficialis, lumbrical(s) and dorsal and palmar interossei. The soft tissue components include the ulnar and radial collateral ligaments, the volar plates of the MCP, PIP and DIP, and the ulnar and radial retinacular ligaments. The bony components include the distal ulnar and radius, the carpal bones, and the three phalanges.

Results and Discussion

Using the enhanced motion capture markers and AnyBody’s force dependent kinematics (FDK), the simulated PIP demonstrated realistic translation of the three phalangeal joints during flexion, realistic relative flexion angles throughout the finger’s full motion, and prediction of ligament and joint contact forces. Through sensitivity analysis, the model should enhance understanding of the effects of the finger’s soft tissue structures upon deformities and joint degeneration. Thus it may be used to aim for improved outcomes in PIPR through surgical technique and implant design.

References

3. Lawrence T et al, J.HandSurgery 29(3):244–9, 2004

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