A Novel Method for Measuring Tendon Strain

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Introduction: A precise understanding of the forces acting at a joint is necessary to design a successful prosthesis. The Proximal Interphalangeal Joint (PIPJ) has a complex arc of motion and a unique, intricate arrangement of tendon fibres acting at the joint. In the current study we seek to develop an accurate, non-contact, non-invasive method for measurement of tendon strain in the Flexor Digitorum Superficialis (FDS) tendon of cadaveric hand specimens. The method is being developed in order to investigate the hypothesis that the complex motion of the PIPJ is driven by differential loading with the terminal tendons of the FDS. A more precise knowledge of the forces in the FDS will facilitate the development of a prosthesis with lower rates of failure.

Method: The study was performed using fresh frozen cadaveric hand specimens. Ethical Approval was obtained from the Preston, Chorley & South Ribble Local Research Ethics Committee. A rig was developed to hold the specimen whilst a measured load was applied to the tendon. The hand was positioned palm up with the finger flexed at the PIPJ at a fixed angle. A clamp held an 4cm surface coil centred over the Palmer surface of the PIPJ. In addition the finger was oriented at 55^0 to the main magnetic field, the so-called magic angle where nulling of the dipole-dipole interaction leads to a greatly enhanced T2 relaxation time within the tendon. [1]. Imaging was performed on a 1.5T Siemens Symphony Maestro scanner. T1-weighted images were acquired in a coronal plane oriented to the plane of the FDS terminal tendons. The in-plane resolution was 0.18mm with a 1mm slice thickness. Pairs of images were acquired with a strain of 49N and 5N respectively applied to the FDS tendon. Points on the outer edge of the FDS tendon on the pairs of images were marked by an experienced hand surgeon (GL) from which the tendon outline was completed by linear interpolation. Data processing then proceeded, using purpose-written software. The program first converts each boundary into a continuous closed curve represented by a 32-degree Fourier composition. This represents the boundary with extremely close agreement to the empirical data (total residual less than 1 pixel). Two estimation methods were used: the Lagrangian strain tensor and the thin-plate spline (TPS) [2]. The TPS consists of a pure deformation component plus an affine component, and is therefore preferable to the affine-only strain tensor because it is more sensitive to the inhomogeneities of deformation that may occur in biological materials. This method compares the two boundaries to find the optimal correspondence while preserving the intrinsic shape of the boundary as defined by its local curvature and continuity. From these calculated displacements the strain could be measured.

Results: The results from the third finger of one of the specimens are shown in Fig. 1. The method is capable of calculating the intra-tendinous strain within the terminal tendons of the FDS and movies have been synthesised from the data showing the dynamics of strain variations for all fingers.

Conclusions: Most methods for estimating strain in materials measure an optical displacement field using the brightness variation of the material [3]. However, the MRI imagery shows the tendon as an area of fairly uniform brightness, so there is no significant texture on which conventional algorithms can get reliable purchase. This new method is capable of calculating the strain from images that would not be possible with methods that have previously been described.

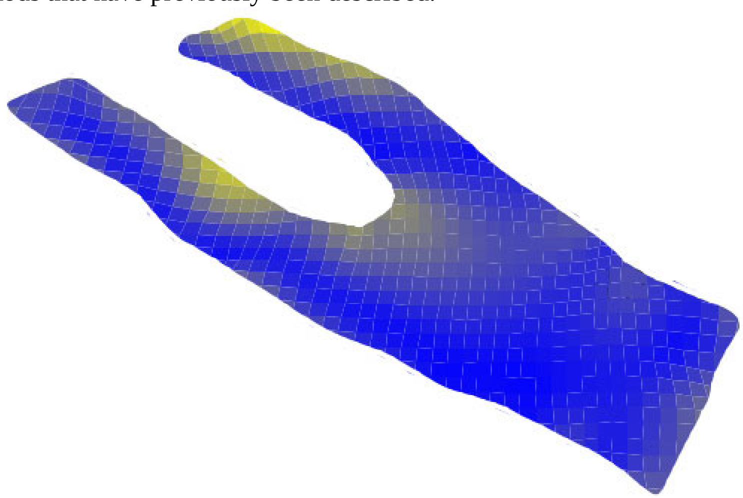

Fig 1. Segmented tendon with imposed colour fill. Areas of low strain are represented by blue and high strain by yellow.

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