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A Novel Technique Quantifying Phalangeal Cylinder Reaction Forces During Gripping

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INTRODUCTION: The forces experienced by the hand during tool use have been identified as important risk factors for hand-related musculoskeletal disorders such as hand-arm vibration syndrome, carpal-tunnel syndrome, and hand/wrist tendinitis. Inverse dynamics models of the hand used to investigate these disorders require accurate phalangeal kinetics. We present a method utilizing six degree-of-freedom (6DOF) hand kinematics and a pressure film kinematic calibration to produce phalangeal cylinder reaction force vectors for use in inverse dynamics analyses.

METHODS: Subjects gripped cylinders wrapped with thin-film pressure grids under a protocol approved by the agency Human Subjects Review Board. Motion capture marker trajectories were collected at 100 Hz using 14 Vicon MX-F40 cameras, and pressure data were collected at 10 Hz using Tekscan thin-film pressure grids. We utilized a 6DOF hand kinematic model [1], where phalanges were modeled as frusta of cones. The cylinder and pressure film were instrumented with tracking and calibration markers to create several local reference frames (Fig. 1A). Frusta silhouettes were projected onto S and transformed into P to create phalangeal regions of interest (ROIs). Finally, surface-normal force vectors were summed to create ROI resultant force vectors (Fig. 1B).

To evaluate our algorithm, we made a phalange surrogate designed such that, when tracked and treated as a phalanx in our method, it would create an ROI around the cells contacted by its supports (Fig. 1C). Surrogate performance was evaluated using an adaptation of receiver operating characteristic (ROC) analysis, where pressure cells were classified based on their inclusion in the ROI. The unweighted harmonic mean of precision and the true positive rate, denoted as the F_1 score and often used in ROC analysis, was calculated to measure the degree of fit of the surrogate ROI to the target ROI.

RESULTS AND DISCUSSION: The F_1 score for the 50 mm handle (Fig. 1B) was 0.96, where a score of 1 is perfect classification. Both the qualitative results using human subjects and the quantitative evaluation of surrogate trials demonstrated reasonable accuracy and suggest that the approach can be used in the

laboratory to assess phalangeal kinetics of the hand during cylindrical gripping.

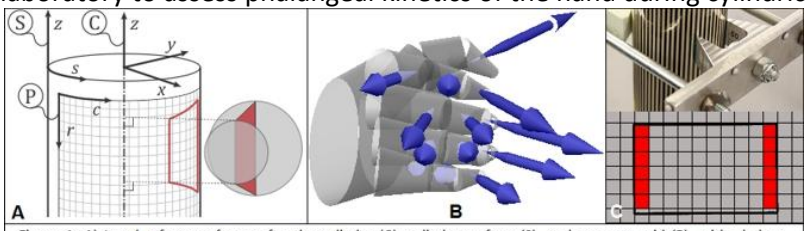

Figure 1: A) Local reference frames for the cylinder (C), cylinder surface (S), and pressure grid (P), with phalanx frustum and projected silhouette; B) phalangeal cylinder reaction force vectors applied to the 6DOF hand kinematic model, in Visual3D software; C) phalanx surrogate attached to 50 mm handle with resulting ROI in the pressure map (F_1 = 0.96).

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