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DEVELOPMENT OF A KINEMATIC HAND MODEL HAND WITH A REALISTIC REPRESENTATION OF THE METACARPAL ARCH

Peter J. Keir, David M. Cocchiarella, Aaron M. Kociolek
Department of Kinesiology, McMaster University, Hamilton, ON, Canada, L8S 4K1
email: pjkeir@mcmaster.ca

SUMMARY

To assess injury risk in the hand, an accurate model that represents complex and diverse capabilities of the hand is needed. We aimed to improve on a previous model by adding a more realistic representation of the thumb and the transverse metacarpal arch. To evaluate kinematic performance of the model, 8 participants performed 3 static postures (neutral hand posture, natural grip and a pronated cap top grip). Calculated joint angles and translations served as the basis of comparison for the two models. The metacarpal arch proved to be a very mobile structure as abduction and transverse components changed independently of each other. Inclusion of the metacarpal arch significantly reduced supination at the 4^{th} and 5^{th} MCP joints, especially near maximal flexion, such that they were similar to a previous radiographic study. With the addition of the trapezium, segment pronation reflected in vivo study data. Minor changes to marker placement may improve future flexion and deviation estimates.

INTRODUCTION

An accurate model of the hand is needed to represent its complex and diverse capabilities for use in ergonomic assessments. Previous studies have created unconstrained kinematic models using passive reflective markers to define the finger segments [1]. Unanticipated deviation and rotation angles have been reported ranging from +19° to -23° ulnar deviation at the DIP and PIP joints, and +14° to -19° pronation in the DIP, PIP, and MCP [3]. The purpose of this study was to further develop an existing model of the hand [1] by improving the thumb representation, including a metacarpal arch, and using alternative segment definitions to improve accuracy and reduce accessory rotations.

METHODS

Eight healthy participants (4 men, 4 women) held three static postures including a neutral pose (fingers straight), natural grip (fingers grasp 33 mm tube), and cap grip (pronated forearm, pads of fingers grasp an 80 mm cap) (Figure 1).

The hand and fingers were instrumented using 97 hemispherical reflective markers (4 mm diameter). Marker coordinate data were recorded at 60 Hz (12 Raptor-4 Cameras and Cortex v1.3.0.475, Motion Analysis Corp.) and imported in Visual 3D Professional (C-Motion Inc.). Two models were created: (i) an aggregate metacarpal model based on the model of Buczek et al. [1] and (ii) a segmented metacarpal model. Both models considered each phalanx as a conical frustum but differed in the definition of the local coordinate system (Figure 2). The aggregate model considered metacarpals 2-5 as a single rigid segment whereas the segmented model defined each metacarpal individually (Figure 2), allowing movement between metacarpals. The segmented model also included the CMC and trapezium. Coordinate systems were assigned to each segment based on ISB recommendations [2,3]. Each joint was assumed to have 6 DOF.

A repeated measures ANOVA tested differences in metacarpal arch x (longitudinal), y (abduction), and z (transverse) components between grips (α = 0.01). Finger joint rotations and translations in each axis were also compared using repeated measures ANOVAs with four independent variables: (i) modelling approach, (ii) hand position (neutral, natural, cap), (iii) finger (digits 2-5), and (iv) joint (DIP, PIP, MCP).

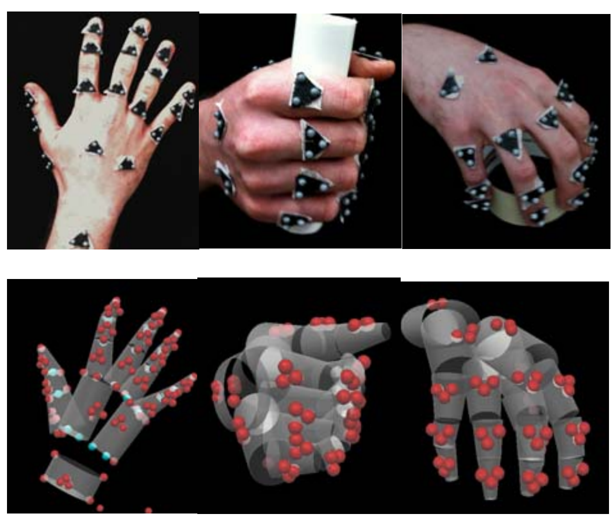
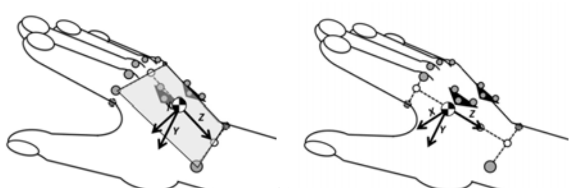


Figure 1. The three static postures. From left to right: neutral hand and fingers, natural grip, cap grip. Top – photos, Bottom – model graphic with 2 metacarpal segments rather than complete model with four.



a) b)

Figure 2. Local coordinate system metacarpals for models. (a) Aggregate model in which all metacarpals are represented by a plane, (b) Segmented model in which each metacarpal is independent.

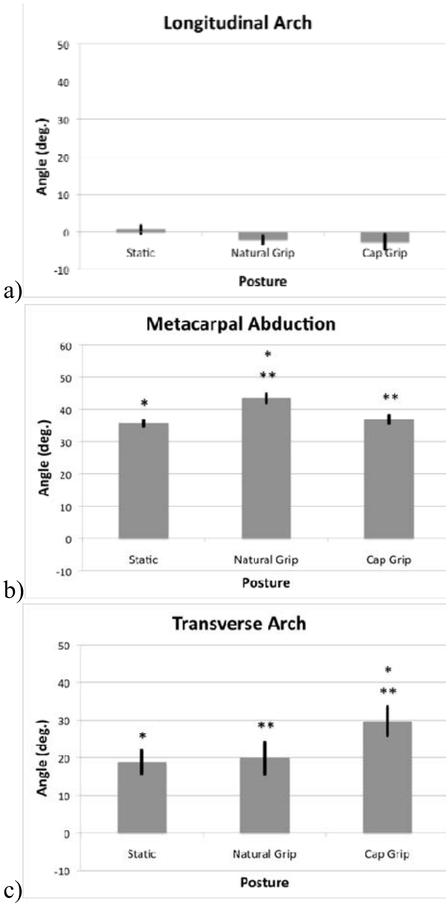
RESULTS AND DISCUSSION

In the segmented metacarpal model, the longitudinal arch was small, ranging from 0.7° to 2.7°, while the mean metacarpal abduction and transverse arch angles were much higher ranging from -35.8°to -43.5° and from 18.9°to 29.7°, respectively (Figure 3). Metacarpal abduction was significantly greater in the natural grip than either the neutral (static) posture or the cap grip. The transverse arch was significantly greater in the cap grip than the other two postures (Figure 3). Because the aggregate model assumed the metacarpals were a planar segment, these significant changes indicate important additions to modeling the hand.

While the above significant changes are important to improving function of the model, few differences were found between DIP and PIP angles, and joint translations between the models. The largest differences in joint kinematics were noted at the MCP. Most notably, the 4th and 5th MCP joints in the segmented model displayed lower supination angles with differences ranging from 9.3° to 17.0° and 16.3° to 33.0°, respectively (across all grips). These values were within ranges previously reported [4]. The segmented model also calculated smaller joint translations where significant differences occurred in all but two exceptions. Furthermore, the addition of the TMC closely depicted pronation of the trapezium reported by a previous radiographic study (approx. 82°) [2].

CONCLUSIONS

The metacarpal arch proved to be a very mobile structure as abduction and transverse components changed independently of each other. Inclusion of the metacarpal arch significantly reduced supination of the 4th and 5th MCP joints, especially near maximal flexion. The change in segment definitions (linear projection method in the second model) had no significant effect on model outcomes. With the addition of the trapezium, segment pronation was accurate compared to in vivo studies, which allows for the measurement of thumb opposition. Minor changes to marker placement may improve future flexion and deviation estimates.



a) b) c)

Figure 3: Mean with standard error of metacarpal arch components in the 3 postures using the segmented model. a) longitudinal arch, b) metacarpal abduction, c) transverse arch. *, ** significant pair wise comparisons at alpha = 0.01.

ACKNOWLEDGEMENTS

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