A METHOD FOR QUANTIFYING ACTIVE THUMB CIRCUMDUCTION MOTION IN CHILDREN

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INTRODUCTION

Defects of the thumb, such as hypoplasia, trigger thumb, triphalangeal thumb, and syndactyly or polydactyly, represent approximately 16% of all upper extremity congenital anomalies [1]. Quantitative measurements of thumb function, such as those needed to evaluate surgical outcomes, have been difficult to establish due to the complex nature of thumb motion [2]. Motion analysis has been proposed as an alternative to traditional passive goniometric methods [3, 4] as it can be used to capture active movements. However, motion analysis may be difficult to use with certain populations. For example, Su et al. [4] created an algorithm to determine the workspace, or functional area within which the thumb operates. This was defined by two circumduction motions, one with the thumb fully extended and one with the MCP and IP joints flexed. The workspace was defined as the quasi-conical surface area between the two 'circles'. The method was tested only on normal adults, and in applying this method to children, both normal and those with anomaly, we found that the complicated motions required by the method are difficult for young children and impaired patients to perform. Furthermore, many children that we desire to evaluate do not have motion at the MCP or IP joints, a requirement to determine the area workspace. For these reasons, we desired an alternative method to evaluate thumb motion, and particularly the circumduction pattern, in pediatric populations. The purposes of this study, therefore, were to develop such an algorithm and to establish baselines of normal motion in pediatric subjects.

METHODS

Nine pediatric subjects with normally developing thumbs participated in the study (ages 2-18, mean 9.5). Both thumbs were tested on 5 of the 9 subjects, bringing the total to 14 thumbs. The length of each thumb, from the radial styloid to the thumb tip, was first measured. Each subject's wrist and hand were then placed into a custom wooden jig to keep wrist motion to a minimum. A 4-mm diameter retro-reflective marker was placed on the nail bed near the thumb tip and a three-marker cluster was placed on the radius. Subjects were instructed to keep the thumb extended (at the IP joint) while moving the tip in a large circle. For younger children, various techniques (toys, etc.) were employed to guide the thumb tip trajectory. Marker trajectories were captured at 120 Hz. using a 10-camera Vicon 612 motion analysis system.

Data processing was performed using custom Labview and Matlab software. Marker trajectories were low-pass filtered at 3 Hz. The marker cluster was used to construct a local coordinate system fixed to the radius and the thumb tip trajectory was expressed in this local coordinate system to account for extraneous movements of the arm and hand within the laboratory coordinate system.

Su et al. calculates a perimeter based on a single circular movement. In our experience, younger subjects require several motions to fully capture the end ranges of motion. To incorporate the end ranges of several circles, we used a convex hull algorithm to enclose the entire data set. First, the data was fit to a least-squares plane using singular value decomposition (SVD). Then, a two-dimensional convex hull was fit to the cluster of points. The hull indices were then used in the original 3-dimensional data set to create the enclosed circular perimeter. The length of the perimeter was calculated as the Euclidean distance between each successive hull indexed point. The perimeter values were then correlated to the measured thumb length.

RESULTS AND DISCUSSION

The algorithm was successful in capturing the end ranges of motion from several circular motions so that precise curves are not required (Figure 1). As the thumb passes the palm there is a concavity in the trajectory. This concavity does not necessarily reflect end range of motion, and if follwed in the perimeter calculation, could result in erroneously greater perimeters when the concavity increases. In the present algorithm, the concavity is enclosed by a straight line between the end ranges of motion before and after it.

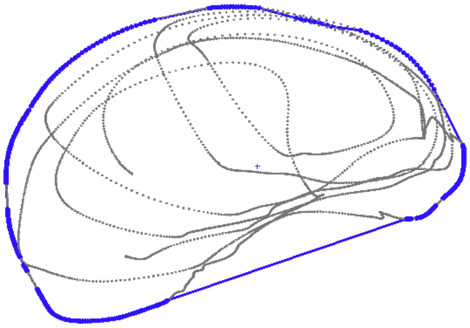

Figure 1: Sample circumduction motion in a 6 yr. old subject. Trajectory points are shown in gray, while convex hull nodes, and linear interpolations, are shown in blue.

The perimeter showed a good correlation (R=.90) with thumb length, although some bilaterally tested subjects had slightly different perimeter values between sides. This variability may be a limitation in all active range of motion thumb studies. The correlation is also sensitive to errors in thumb length measurements.

Overall, however, the algorithm captured the motion of interest in a difficult population. By including, and enclosing, all possible trajectory points, we were able to capture the full range of motion of pediatric subjects. In subjects with good cognition and dexterity, and where IP and MP motion is available, the current method is also compatible with Su et al in calculating an active thumb workspace.

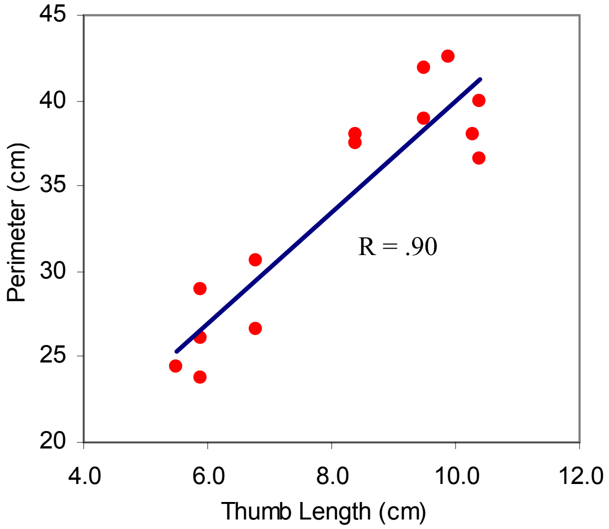

Figure 2: Scatterplot of thumb length and perimeter.

REFERENCES

1. Kleinman, W.B., Hand Clin, 1990. **6**(4): p. 617-41.
2. Staines, K.G., et al., Plast Reconstr Surg, 2005. **116**(5): p. 1314-23; discussion 1324-5.
3. Chang, L.Y. and N.S. Pollard, IEEE Trans Biomed Eng, 2008. **55**(7): p. 1897-906.
4. Su, F.C., et al., J Biomech, 2003. **36**(7): p. 937-42.