**EFFECT OF CALIBRATION RANGE OF MOTION ON THE ACCURATE DEFINITION OF FUNCTIONAL JOINT CENTRES OF THE FINGERS**

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**SUMMARY**

Finger joint kinematics are an important input to biomechanical models. The effect of the calibration Range of Motion (RoM) on the accurate definition of functional joint centres of the fingers has been assessed. The accuracy was found in terms of joint centre displacement and percentage error in calculated tendon tension. Stereophotogrammetry was used to capture hand motion and the Phalanx Transformation Technique (PTT) was used to calibrate the location of the joint centres. The PTT assumes that each joint centre has a fixed location relative to the bones. Analysis was carried out to define the instantaneous centres of rotation as a function of joint angle. For a RoM typical of a subject with rheumatoid arthritis the percentage errors in calculated tendon tension were 4-12%. The skin movement artifact at the interphalangeal joints was found to be greater when the joint was highly flexed, due to the skin stretching across the joints. The instantaneous axes of rotation at the interphalangeal joints were found to move proximally and dorsally as the joints were flexed. This correlates with the cam profile of the joint geometry that would relate to an increased radius of curvature of the joint surface as it was flexed.

**INTRODUCTION**

An accurate measure of finger joint kinematics is an important input to biomechanics models to calculate internal loading. The improved understanding of finger biomechanics that this provides can be used in a variety of clinical applications, such as management of injury and pathology or to predict outcomes of surgical intervention [1].

A technique of finger motion capture has been proposed using functional definitions of the joint centres [2]. The PTT utilises the centre transformation technique and axis transformation technique [3, 4] and allows a measurement of accuracy without expensive imaging or invasive methods.

For the most accurate results, a large RoM for calibration is preferred. However some subjects, such as those with injuries or pathologies including rheumatoid arthritis, may have a significantly reduced RoM [5]. It was therefore important to understand the influence of reduced RoM on the accuracy of joint definition and subsequent output from a biomechanical model.

The PTT assumes constant joint centres. This was not strictly accurate and analysis was carried out to define the instantaneous joint centres as a function of joint angle.

**METHODS**

Six subjects were recruited (age: 26 ± 6 years; height: 1.77 ± 0.1 m; Mean ± SD). A six camera Vicon T20 motion capture system (Vicon, U.K.) was used with a sampling rate of 100Hz. 12 hemispherical markers, 4mm in diameter were attached to each phalanx of the index finger and dorsal surface of the right hand. Each set of three markers defined a cluster technical frame fixed to each segment. The PTT was used to define functional axes and centres of rotation (AoR and CoR) and subsequently the anatomical coordinate system (ACS) [2]. \( e_{PTT} \) was the error associated with these definitions of ACS.

For the reduced arc analysis, new sets of calibration data were created simulating a reduced RoM. Three types of reduction were applied: Type I with the minimum RoM at full extension, Type II with the minimum at full flexion and Type III with the minimum in the middle of the original RoM arc. \( e_{ROM} \) was defined as the vector between the original joint centre and those defined with reduced RoM. The total error (\( e_{total} \)) was expressed as the sum of this error and the original error.

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e_{total} = e_{ROM} + e_{PTT}
\]

To provide clinical relevance this error was also expressed in terms of percentage error in calculated flexor tendon tension using a biomechanical model (\( e_{FDP} \)).

Multiple arc analysis was done to calculate the change in position of the instantaneous joint centre throughout finger flexion. New arcs of calibration data of equal magnitude were created centred at different angles of flexion. \( e_{ROM} \) in this case gave a measure of the difference between the instantaneous mean joint centres. This was used to calculate coefficients (\( c_{ROM} \)) to transform from the mean joint centre to the instantaneous as a function of flexion angle.

**RESULTS AND DISCUSSION**

| \( e_{total} \) | for the reduced arc analysis is shown in Figure 1. Similar profiles with different magnitude were observed between reduction types. At the interphalangeal joints the largest error magnitude was observed when the Type II
reduction was applied. This agrees anatomically as the most skin movement occurs when they are highly flexed, due to the skin being stretched across the dorsal side of the joint. The $\varepsilon_{\text{RoM}}$ and subsequently the $\|\varepsilon_{\text{total}}\|$ resulting from the Type III reduction was the smallest, due to the centre of this reduced arc always being aligned with the centre of the original arc.

At the metacarpo-phalangeal (MCP) joint the largest $\|\varepsilon_{\text{total}}\|$ occurred when applying the Type I reduction. As this joint could extend more than the interphalangeal joints there was more skin movement artefact at full extension as the skin wrinkles on the dorsal surface. The smallest $\|\varepsilon_{\text{total}}\|$ was observed when applying the Type II reduction. It is likely that the assumption of a CoR results in these error patterns and further analysis out with the scope of this study is needed to investigate this.

The RoM for subjects with rheumatoid arthritis were taken as: distal interphalangeal (DIP) joint = 58°, proximal interphalangeal (PIP) joint = 66° and MCP joint = 50° [5]. For these RoM, the $e_{\text{FDP}}$ were typically 4-12%.

![Figure 1: Effect of the range of motion (RoM) on ($\|\varepsilon_{\text{total}}\|$).](image)

It was found that the multiple arc analysis was only valid at the interphalangeal joints. As with the reduced arc analysis, the limitations of the CoR model at the MCP joint become apparent when analysing the errors in this level of detail.

$\varepsilon_{\text{RoM}}$ as a function of interphalangeal joint angle is shown in Figure 2. The interphalangeal joints predominantly flex in the sagittal plane and the normal to this was the radially directed $z$ axis, therefore $e_{\text{ROM}_z}$ was expected and calculated to be minimal. With increased flexion the instantaneous AoR moved proximally and palmarly (positive gradient of $e_{\text{ROM}_y}$ and negative gradient of $e_{\text{ROM}_z}$). This can be explained by the joint geometry. At either interphalangeal joint the radius of the distal phalanx joint surface is larger than the proximal surface. In addition the cam profile of the proximal articular surface meant an increase in radius of the joint contact surface as the joint was flexed. The resulting rolling and sliding motion resulted in the non-constant AoR. The skin movement artefact will also have an influence.

![Figure 2: $\varepsilon_{\text{RoM}}$ as a function of interphalangeal joint angle.](image)

**CONCLUSIONS**

It has been shown that the PTT will provide accurate and valid definition of the functional joint centres and ACSs, even when the subject has a significantly reduced RoM at one or more joints. This makes these techniques applicable to subject with injuries and pathologies. The position of the instantaneous AoR of the interphalangeal joints as a function of flexion angle has been quantified and shown to move proximally and dorsally with increasing joint flexion. This allows a more accurate definition and better understanding of the interphalangeal joint kinematics.

**REFERENCES**