DETERMINATION OF MOMENT ARMS OF THE MCP JOINT IN-VIVO USING ULTRASOUND

[1] J.W. Snijders, [1] J.M.A. Visser, [2], J.-W.H. Korstanje, [2] R.W. Selles and [1] H.E.J. Veeger
[1] Department of Biomechanical Engineering, Delft University of Technology, Delft, j.m.a.visser@tudelft.nl
[2] Dept. of Rehabilitation Medicine & Dept of Plastic and Reconstructive Surgery, Erasmus MC, Rotterdam

SUMMARY

Joint angle dependent moment arm parameters for biomechanical finger models rely in general on *in-vitro* data. Recent developments in the technique of ultrasonic measurements have made it possible to accurately measure tendon displacements over a large range of motion. The change in tendon displacement divided by the change in corresponding joint angle ($dl_{mt}/ d\Theta_{joint}$) is a measure for the moment arm (MA). This method was used to estimate joint angle dependent MA's of the long tendons *in-vivo*. The method proved to be promising, but should be further developed to determine all long tendon MA's accurately.

INTRODUCTION

An important parameter in any biomechanical finger model is the moment arm (MA): the shortest distance from a muscle-tendon to a joint axis crossed by this muscle-tendon. Since in the finger most muscle-tendons cross multiple joints, MA's of these muscle-tendons have a major influence on the distribution of joint moments over these joints, which is crucial for finger balance and therefore finger functioning.
Current knowledge of finger muscle/tendon MA's is based primarily on cadaver studies [1,2]. To estimate MA's, the change in muscle-tendon length (dl_{mt}) with respect to the change in joint angle ($d\Theta_{joint}$) is a generally accepted method:

$$MA(\theta) = \frac{dl_{mt}}{d\theta_{\text{joint}}} dt \qquad (1)$$

Recent developments in the technique of ultrasonic measurements have made it possible to quantify tendon movement without the presence of anatomical landmarks and thus over a large range of motion [3]. Moreover, it is fairly straightforward to obtain *in-vivo* joint angles. Therefore it is hypothesized that the method as described above can be conducted *in-vivo*. Once fully developed, this can be a beneficial tool in the clinical field to estimate patient specific MA's and finger balance with relative ease. In addition, *in-vivo* measurements can give more insight in the behavior of MA's in the human hand compared to the studies performed *in-vitro*, as well as insight in the relationship between kinematically obtained MA's and those obtained from joint and skeletal geometry.

METHODS

The moment arms of the finger long tendons Flexor Digitorum Profundus (FDP), Flexor Digitorum Superficialis (FDS) were studied at the metacarpophalangeal (MCP) joint of the middle finger, with the PIP, DIP and wrist joints braced. For dl_{mt}, ultrasound video sequences were acquired using an iE33 ultrasound system (Philips Electronics, Eindhoven, The Netherlands), using a 7 MHz linear array probe at 100-280 frames per second, depending on the type and size of the imaged tendon. For $d\Theta_{joint}$, a digital camera captured the trajectory of a fingertip marker at 30 frames/s. FDS and FDP tendon locations of the long finger were identified just below the wrist by palpation as a starting point for the scanhead of the ultrasound scanner. To distinguish the FDS tendon from the FDP tendon, the anatomical positions of both were used.

Subjects were asked to **actively** move their middle finger from extension to flexion and back and not to use excessive forces at the endpoint of motion. Subjects were allowed to move the other fingers with this finger to minimize the effect of stresses in tendinous cross bridges between the neighboring tendons. The experiment was repeated three times per protocol for each tendon. Each subject underwent the protocol twice. The six repetitions were averaged to estimate the joint angle dependent MA_{est}. The flexor tendons have a thickness of roughly 2 mm; the resulting MA_{est} value was identified as the bottom part of the tendon.

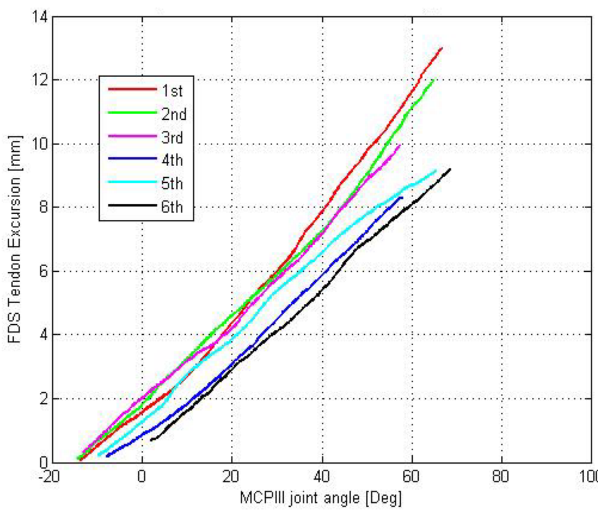

Figure 1: Tendon excursion-Joint angle relation for the FDS tendon.

The MA_{est} result was validated from longitudinal ultrasound images of the centre of the MCPIII joint, with the joint in extension and the long tendons visible. From these images the geometrical MA's, MA_{geo} were obtained.

Five healthy volunteers were enrolled in this study. However, in these proceedings only the preliminary results of 2 subjects will be presented.

RESULTS AND DISCUSSION

In Figure 1, the raw signals of the joint angle and tendon excursion are plotted for Subject A. A fairly smooth curve is obtained, due to a good correlation between both signals. The MA's, represented by the slope of the curves, are reasonably consistent over the six measurements. On average, the slopes increase a little over the range, resulting in a small joint angle dependency, which agrees with the findings *in-vitro* [1]. The estimated and geometrical MA for the FDS tendon of subject B is visualized in a longitudinal ultrasound image of the centre of the MCPIII joint (Figure 2). It can be seen that the estimated FDS MA is smaller than the geometrical MA, but larger than the joint articulation. In Table 1, it can be seen that this is also found for subject A. For both subjects the estimated FDP tendon MA is estimated within the articulation of the MCP joint, which obviously cannot be correct.

The major underestimation of the FDP MA can be explained by the reasoning that the FDP tendon probably did not or not always actively contributed to the MCP joint flexion. This is possible since this studied musculo-skeletal system is over actuated with one degree of freedom and five muscles: FDP, FDS, lumbrical, volar- and dorsal interosseous. It is suggested that for this particular motion with the PIP and DIP joints braced, FDP contribution is not always present, resulting in less tendon displacement and therefore an underestimation for the calculated MA. In future work it would be better to incorporate EMG measurements in the protocol, so one can be sure that the muscle of interest is indeed activated, or use a finger posture where FDP muscle activation is granted for MCP flexion. Why the FDS tendon MA is underestimated is more difficult to explain. It could be due to the fact that the motions during the experiments were conducted with very little force, resulting in little tension in the tendons, making it vulnerable for influences from surrounding tissues and/or cross bridges to other tendons; data from experiments with an external applied load will be needed to see whether the addition of such a load would result in larger MA values.

Table 1: Overview of the preliminary results. At the top the estimated joint angle dependent moment arms from the dl/dΘ method are shown, at the bottom the geometrical moment arms at 0 degrees of flexion.

Estimations from dl/dΘ method	**Subject A** 0^0 *flex. – 60^0 flex.*	**Subject B** 0^0 *flex. – 60^0 flex.*
MA_{est} FDS	6,6 – 9,1 mm	8,1 – 9,0 mm
MA_{est} FDP	4,5 – 6,5 mm	4,7 – 7,7 mm
Geometrical data from ultrasound joint image	0^0 *flexion*	0^0 *flexion*
Radius of the Joint Articulation	6,3 mm	6,6 mm
MA_{geo} FDS	10,1 mm	9,7 mm
MA_{geo} FDP	8,7 mm	8,0 mm

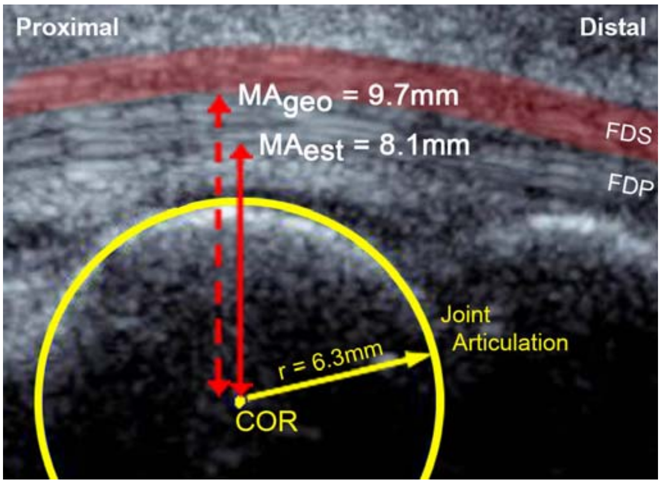

Figure 2: Longitudinal ultrasound image of the MCPIII joint in extension, for subject B. The Centre of Rotation (COR) is obtained by a circle fit on the distal articulation of the third metacarpal. The geometrical FDS moment arm (MA_{geo}) derived from this figure is indicated by the dashed arrow. The estimated FDS moment arm (MA_{est}) obtained by the dl/dΘ method (at 0 degrees flexion) is indicated by the solid arrow.

In the future, more subjects will be analyzed in order to obtain a better insight in the results and accuracy of the suggested method. In addition, the Extensor Digitorum Communis will be added to the analysis. At that point we should be able to analyze generic and patient specific MA balance around a joint, which can help us in deeper understanding the functioning of the finger/hand.

CONCLUSIONS

The described method of *in-vitro* determination of joint angle dependent MA's is promising, but should be further developed to yield sufficiently reliable results.

REFERENCES

1. Brand, P.W. and A. Hollister, *Clinical Mechanics of the Hand.* 1993, Chicago: Mosby Year Book.
2. Buford, J.W.L., et al., *Analysis of Intrinsic-Extrinsic Muscle Function Through Interactive 3-Dimensional Kinematic Simulation and Cadaver Studies.* The Journal of Hand Surgery, 2005. **30**: p. 1267-1275.
3. Korstanje, J.-W.H., et al., *Development and validation of ultrasound speckle tracking to quantify tendon displacement.* Journal of Biomechanics, 2010. **43**: p. 1373-1379.