Impact of Long Flexor Versus Intrinsic Dominance in the Generation of Arc of Finger Flexion

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Abstract

Background: Finger flexion is a composite movement involving both long flexors and intrinsic hand muscles. Previous studies have characterized this but have not investigated differences within the normal population. Were discrete finger motion patterns identified, this could guide rehabilitation programs following flexor tendon surgery. **Methods:** Twelve volunteers repeatedly flexed and extended at a comfortable speed, resting their hand on a horizontal surface. Video was recorded perpendicular to the little finger flexion plane, and the little finger tip position was identified frame by frame to create a composite curve. Its highest point was noted, and the horizontal distance was measured from this point to the palmar digital crease (ΔX^H). **Results:** In addition, 2 investigators independently reviewed frame-by-frame images and allocated subjects into groups based on the motion pattern. ΔX^H demonstrated 2 clusters within our study population, and there was a statistically significant ($P < .036$) difference between groups. **Conclusions:** This study demonstrated that qualitative and quantitative differences exist in flexion curves between individuals.

Keywords: finger flexion arc, finger movement pattern, finger motion path, finger flexion, hand flexion, flexion

Introduction

Finger flexion is a composite movement involving both the action of the long finger flexors and the lumbrical muscles of the hand. In 1973, Littler proposed that the motion path of the digits follows an equiangular spiral.⁴ Human volunteer studies have since looked at the anatomical evidence for an equiangular spiral during finger flexion and have reached contradictory conclusions^{1,3,5,6}: Arbuckle and McGrouther used frame-by-frame analysis from video clips and found that the finger motion path was not consistent with an equiangular spiral, whereas Gupta et al used a 3-dimensional optical tracking system using reflective markers attached to the hand to record the path of the fingers and found that the motion paths were consistent with this type of spiral. Park et al investigated the ratios of bone lengths of the digits to determine an anatomical basis for the equiangular spiral motion path and found that the bone length ratios do not approximate the appropriate ratio, although it was noted that the lengths from each joint's axis of rotation to the next do approximate this ratio. These studies, however, did not investigate differences in finger motion paths within their sample population.

It is known that isolated flexion at the metacarpophalangeal joints (MCPJs) is achieved by lumbrical (intrinsic) contraction. In contrast, isolated long flexor tendon

contraction produces interphalangeal joint (IPJ) flexion with the MCPJs flexing subsequently.² The senior author has observed a variable intrinsic tone impacting the rehabilitation of MCPJ replacements in rheumatoid patients, but it has not been clear whether or not there are discrete patterns of finger flexion in the normal population. If discrete patterns could be identified, this would be useful information to guide and modify hand therapy regimens for flexor tendon surgery.

Methods

Twelve healthy volunteers were recruited to this study. Two of the 12 were male, and the other 10 were female. All volunteers were aged between 25 and 35 years and had no history of hand pathology or trauma. Participants were asked to rest their right hand and forearm, supine, on an examination table and were asked to repeatedly flex and extend all

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Figure 1. This image illustrates the measured distance ΔX^H .
 Note. The highest point of the flexion curve was identified, and the horizontal distance from this highest point to the palmar digital crease was recorded.

fingers at a comfortable speed. Once a stable speed and pattern developed, a tripod-mounted digital video camera was used to capture video images at 50 frames per second from the ulnar border of the hand, perpendicular to the plane of the motion arc of the little finger.

The digital video file was then imported into Adobe Premiere Pro CS4 (Adobe Systems Incorporated, San Jose, California), and each frame was exported as an image file in the Tagged Image File Format (Aldus Corporation, Seattle, Washington). The image files were imported into Adobe Photoshop CS4, the junction of the nail and pulp of the little finger was identified in each frame, and its position was recorded on the image with a green marker. The images were combined using Adobe Photoshop's channel blending tools to create a composite image of the little finger tip path throughout the flexion arc. The little finger was chosen for analysis due to the ability to identify its anatomy reliably from frame-by-frame images taken from the ulnar side of the hand.

The highest point of the flexion curve was identified, and the horizontal distance from the highest point of the flexion curve to the palmar digital crease was recorded (Figure 1). This variable was labeled ΔX^H . This distance was used as it is unaffected by mild variability in the extent of forearm supination as observed in individuals performing this study's task.

In addition to an objective measurement, 2 observers independently reviewed both the slow motion analysis and the composite images of the fingertip path to determine whether there was an observable difference in the fingertip motion paths between individuals. The observers determined whether the fingertip motion path appeared to be best characterized by early flexion of the more distal or more proximal joints, and, on this basis, participants were assigned into 1 of 2 categories. A Cohen's kappa coefficient was measured to assess inter-rater reliability.

One participant was excluded from the study for technical reasons: the plane of the flexion curve altered between setup and video recording, so it was not perpendicular to the video camera during sequence capture.

Table 1. Values of ΔX^H for Each Participant.

Participant	ΔX^H (cm)
1	0.4
2	1.4
3	1.5
4	1.5
5	0.5
6	0.6
7	2.5
8	1.6
9	Excluded
10	0.7
11	0.4
12	1.6

Assigning participants into 2 groups enabled a comparison of ΔX^H values between the 2 groups of participants. Our null hypothesis was that there is no difference in the fingertip motion path between individuals, and so ΔX^H should be equivalent in both groups. As the ΔX^H spread in our participants was non-parametric in nature, a Mann-Whitney *U* test was performed to determine whether a statistically significant difference exists in ΔX^H values between our 2 groups of participants. A second participant was excluded from the Mann-Whitney *U* test as the finger flexion pattern was determined on observer assessment to be so anomalous with the remainder of participants in both groups that this participant could not be assigned to either.

Results

Early analysis of ΔX^H values revealed that, rather than a single, uniform pattern of finger flexion following an equiangular spiral, the motion path of the fingertips of individuals tended to follow a range of patterns. The ΔX^H values tended to form 2 discrete clusters of similar frequencies, centered at approximately 0.5 and 1.5 cm. Individual values of ΔX^H for each participant are displayed in Table 1. After exclusion of participant 9 for technical reasons, the overall mean for the group of 11 participants was 1.15 cm with a standard deviation of 0.68 cm. ΔX^H values for each participant together with overlays demonstrating the 2 clusters are displayed in Figure 2. The bars in the figure represent the mean and standard deviation of the entire group of participants and the means and standard deviations of each of the 2 clusters.

To further evaluate the differences in finger motion path represented by the 2 clusters, analysis of the study data was expanded to include a qualitative analysis of motion path by 2 observers independently. Slow-motion video and composite images of each participant's fingertip motion path revealed variable patterns between individuals but that most participants tended to follow 1 of 2 groups of fingertip motion arc.

Figure 2. This graph demonstrates ΔX^H values for each participant with overlays demonstrating the 2 clusters. Note. The bars represent the means and standard deviations of the entire group of participants and each of the 2 clusters.

Figure 3. This image demonstrates the 2 main patterns of finger flexion in our participants. Note. Pattern type A has a lower maximum height and has its highest point further away from the hand, whereas pattern type B is higher with a more proximal maximum.

These patterns are demonstrated in Figure 3. Based on the shape of the motion path, the 2 observers assigned each participant into either group A or group B. There was good inter-rater reliability, as determined by a Cohen's kappa coefficient of .82. One participant had a third type of shape of their fingertip motion path and could not be assigned into either group A or B. This patient was assigned to a separate group, C. A total of 6 participants were assigned to group A and 4 participants were assigned to group B. The outcome of this grouping is presented in Table 2.

Table 2. Values of ΔX^H for Each Participant and the Motion Pattern Group Into Which They Were Assigned.

Participant	ΔX^H (cm)	Observed pattern group
1	0.4	B
2	1.4	A
3	1.5	A
4	1.5	A
5	0.5	A
6	0.6	B
7	2.5	C
8	1.6	A
9	Excluded	Excluded
10	0.7	B
11	0.4	B
12	1.6	A

To determine whether the differences in motion path visualized by the observers represented a statistically significant difference between the 2 groups, a Mann-Whitney U test was undertaken. This test was chosen as our data, comprising a bimodal distribution with an outlier, is clearly non-parametric in nature, and the Shapiro-Wilk test of normality revealed that the distribution of ΔX^H in each of the two groups cannot be considered to arise from a normally distributed population. The participant in group C was excluded from this analysis to compare group A with group B. Comparing ΔX^H between the 2 groups was statistically significant with a P value of .036.

Discussion

This study demonstrates that both qualitative and quantitative differences exist in the shapes of finger flexion curves between normal individuals, although they tend toward 2 main shapes of fingertip motion path. In our group of participants, there was a roughly even split between participants with motion pattern in groups A and B. Reviewing the slow-motion video, the pattern observed in group A commences the motion with flexion of the distal IPJ (DIPJ), followed shortly thereafter by flexion of the proximal IPJ (PIPJ). Flexion of the finger occurs by composite flexion of mainly these 2 joints in the early stages of the motion path, combining with flexion of the MCPJ at a later stage. This pattern is consistent with a flexion path powered predominantly using the long flexors of the finger. The pattern observed in group B initiates flexion at the MCPJ and combines later in the motion path with DIPJ and PIPJ flexion. This is consistent with a flexion path initiated by the intrinsic muscles of the hand, only using the long flexors later in finger flexion.

The curves demonstrated in the composite images in Figure 3 also demonstrate these differences. Pattern type A

has a lower maximum height and has its highest point further away from the hand, as expected by a motion path dominated by flexion of the long flexors of the finger, whereas pattern type B is higher with a more proximal maximum. Slow motion analysis of this pattern demonstrates that the finger flexes at the MCPJ while the finger itself is relatively straight, explaining the greater height in the early part of the curve. The curve loses height when the long flexors work to flex the DIPJ and PIPJ, but this occurs more proximally than in pattern type A, resulting in a lower ΔX^H value.

The authors, therefore, hypothesize that pattern type A represents a motion path in which the long flexors are dominant and pattern type B represents a motion path in which the intrinsic muscles of the hand are dominant. We hypothesize that the cluster of ΔX^H values with a mean of 0.51 represents participants whose flexion pattern is *intrinsic dominant* and the cluster with a mean of 1.52 represents participants whose flexion pattern is *long flexor dominant*.

Slow motion analysis of the participant who fits neither the group A nor group B patterns raises an intriguing possibility of a motion path initiated by a third mechanism, possibly the flexor digitorum superficialis action. This was an isolated observation in our series but might be more frequently observed in a larger series.

One limitation of our study includes the sample size with a total of 12 participants. Another is the accuracy of measurement: There was inevitable blurring of the definition of the point between the fingernail and pulp given the speed of finger movement and the use of a video camera using the CCIR 601 standard (50 interlaced frames per second of 625 lines with 720 samples per line). This introduced a systematic error of less than 3 mm, so this error is unlikely to be significant within this study. Choosing not to use a splint allowed participants the most natural finger movement but at the expense of rigid standardization of the plane of finger movement relative to the camera angle. This freedom of movement allowed 2 types of foreshortening errors to be introduced. The first is due to the camera recording obliquely to the plane of finger flexion if the hand, wrist, or forearm were to supinate or pronate: This error has the effect of decreasing the overall measured height of the curve but not its shape or the location of the highest point along the curve. The second is due to the plane of flexion of the little finger tending to change during the motion path: abducting when close to fully extended and adducting when more flexed; this has the effect of reducing the distance from the fingertip to the palmar digital crease during abduction but, as this has a maximum error of 2 mm when the little finger is fully abducted, this error is unlikely to be significant in this study.

The clinical implications of these observations relate to the rehabilitation of flexor tendons following acute repair and also cases of tenolysis and tendon grafting. It

may be important to identify the particular mode of finger flexion in the individual patient so that standard therapy regimens may be customized to the same. For example, patients who flex from the MCPJ with a predominant intrinsic tone may experience less good results unless the IPJ flexion is specifically isolated by the treating therapist. This further hypothesis would need to be confirmed in a clinical study.

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Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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