Spinal Cord (2005) 43, 620–624
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Original Article

Quantifying the passive extensibility of the flexor pollicis longus muscle in people with tetraplegia

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Study design: Repeat measures design.
Objective: The purpose of this study was firstly, to describe a simple clinical tool that can be used to measure the extensibility of the flexor pollicis longus (FPL) muscle; secondly, to test its reliability; and thirdly, to attain some 'normative' data of the extensibility of the FPL muscle in a representative sample of people with tetraplegia.
Setting: A spinal cord injury unit in Sydney.
Subjects: A total of 37 people (62 hands) with C4–C7 tetraplegia.
Main outcome measures: Angle of the carpometacarpal (CMC) joint of the thumb was measured in all subjects with the application of a series of thumb extensor torques. A device specifically designed for this purpose was used to standardize the torque and objectively quantify the CMC joint angle. In addition, repeat measurements were taken 3–5 days later in one subgroup of 13 subjects (one hand per subject) and 3 months later in another subgroup of 13 subjects (one hand per subject).
Analysis: Intraclass correlation coefficients and percent close agreement scores were derived to quantify the 3–5 days and 3-month reliability between repeat measurements.
Results: The median CMC angle of the thumb with the application of a 0.044 Nm torque was 63 degrees (range, 20–93 degrees). The intraclass correlation coefficients with the application of a 0.044 Nm torque were 0.88 (95% CI, 0.65–0.96) for measurements taken 3–5 days apart, and 0.90 (95% CI, 0.67–0.97) for measurements taken 3 months apart.
Conclusion: This study describes a simple and reliable way of measuring the extensibility of the FPL muscle in people with tetraplegia. This assessment tool and the 'normative' data provided in this study can be used to further investigate the contribution of the passive mechanical properties of the FPL muscle to hand function of people with C6 and C7 tetraplegia.

Spinal Cord (2005) **43,** 620–624. doi:10.1038/sj.sc.3101764; published online 3 May 2005

Keywords: hand; tetraplegia; rehabilitation

Introduction

The passive mechanical properties of the paralyzed flexor pollicis longus (FPL) muscle is central to the hand function of people with ASIA A C6 and C7 tetraplegia.[1,2] People with these types of spinal cord injuries have paralysis of all thumb and finger flexor muscles. Despite such extensive paralysis, these individuals have the ability to hold and manipulate objects between their paralyzed thumb and first finger. This is achieved through a passive tenodesis grip whereby wrist position is manipulated to change the passive tension in the FPL muscle.[1–5] Provided the FPL muscle has limited passive extensibility, active wrist extension will generate a thumb flexor torque that will in turn passively pull the thumb towards the side of the first finger.[1,2] Objects can then be held between the thumb and first finger in a crude grasp while wrist extension is maintained. However, if the FPL muscle is *too extensible*, wrist extension will not generate sufficient passive tension in the FPL muscle and the thumb will not be pulled towards the first finger.[1,2] Clinicians utilize different therapeutic interventions (such as splints[1,6] and surgery[7–9]) in an attempt to decrease the passive extensibility of the FPL muscle and enhance the hand function of people with tetraplegia. However, there is as yet no assessment tool that enables clinicians to easily and directly assess the effectiveness of these interventions on the extensibility of the FPL muscle.

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Numerous researchers have examined the relationship between applied torque and joint angle to define the passive extensibility of overlying muscles and soft tissue structures.[10–17] Clinical assessment tools have been designed using these principles to measure the extensibility of muscles such as the plantarflexor muscles,[18–20] hamstring muscles,[21,22] and extrinsic finger flexor muscles.[23] However, no equivalent device to measure the extensibility of the FPL muscle has been described. Instead, researchers to date have relied on either magnetic resonance imaging to quantify the excursion of the FPL muscle[24] or cadaveric studies[25] to examine the passive length–tension relationship of the isolated FPL muscle. Alternatively, clinicians and researchers in the area of spinal cord injuries have used measurements of hand strength[26,27] or function[4,28] to indirectly make inferences about the extensibility of the FPL muscle. The purpose of this study, therefore, was to design and test the reliability of a simple and clinically useful way of measuring the extensibility of the FPL muscle and to attain some initial ‘normative’ data on the extensibility of the FPL muscle in a representative sample of people with tetraplegia.

Methods

Subjects

In all, 37 subjects were recruited from a sample of convenience. Subjects were eligible if they had paralysis of the thumb flexor and extensor muscles with spinal lesions between C4 and C7. Subjects were excluded if they had received prior hand surgery. In all, 31 subjects were male and six were female. The mean age (SD) and time since injury (SD) was 35 years (±13 years) and 6 years (±7 years), respectively. Both hands were tested in 25 subjects and one hand in 12 subjects (total of 62 hands). All applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

The device

Numerous devices to measure the extensibility of the FPL muscle were initially designed and trialed. The final device measured the carpometacarpal (CMC) joint angle with the application of a thumb extensor torque while all other thumb and wrist joints were maintained in full extension. The CMC joint angle can be used to reflect the extensibility of the FPL muscle when the wrist and other thumb joints are extended much in the same way as hip flexion can be used to reflect the extensibility of the hamstring muscles when the knee is extended.[29] The underlying assumption is that extension of the CMC joint is primarily restricted by the passive extensibility of the FPL muscle when the wrist is extended, and not by periarticular structures (such as joint capsule) spanning the CMC joint.

The device consisted of a board that stabilized the forearm in a mid-pronation position and the wrist in full extension (see Figure 1). The alignment of the hand was such that gravity acted to pull the thumb into flexion against the side of the first finger. The metacarpophalangeal (MCP) joints of the fingers were stabilized in approximately 70 degrees flexion. The thumb was strapped to a metal plate that restricted movement to a flexion–extension plane about the CMC joint. The IP joint of the thumb was stabilized in full extension with a metal plate. The MCP joint was not directly stabilized, though the applied torque acted to passively stabilize the joint in extension. A series of thumb extensor torques were applied to the thumb by hanging small weights (5.7 g each) from a rope that circled around two wheels. The centre of the CMC joint was identified by palpation and aligned with the centre of one wheel. The wheel was attached to the thumb extensor plate in such a way that its rotation resulted in extension of the thumb. The second wheel was merely used to redirect the line of pull so as to ensure that the weights attached to the end of the rope hung freely over the edge of the testing table. The extensor torques due to the suspended weights were equivalent to the radius of the wheel (0.049 m) and the mass of the suspended weights. The corresponding angle of the CMC joint was measured with a digital inclinometer attached to the metal plate. All angle measurements were taken in relation to deviation from the horizontal. By repeatedly hanging a series of incrementally larger weights from the wheel and measuring the corresponding CMC angle, torque-angle curves of the CMC joint were generated reflecting the passive length–tension relationship of the FPL muscle.

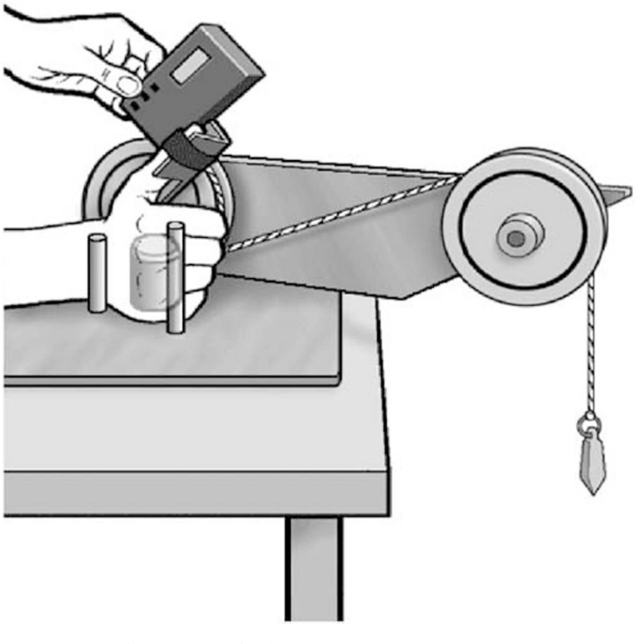

Figure 1 The testing device

Testing procedure
Testing always followed the same format with subjects seated in their wheelchairs (except in the case of two subjects that were tested lying down). Initially, the CMC angle was measured with the application of three torques (0.027, 0.035 and 0.044 Nm). These torques were selected after testing people with and without tetraplegia. They represented torques typically applied to the thumb when grasping objects and torques readily tolerated by people with sensation. Each torque was applied for 1 min prior to measuring. In this way, reflex activity around the thumb and wrist, if present, was minimized and most viscous deformation exhausted.[22,30] Following these three initial measurements, the stretch torque was removed. The second phase of testing involved applying incrementally larger stretch torques (increments = 0.003 Nm), starting with 0.003 Nm and finishing with 0.044 Nm. Each stretch was applied for 30 s prior to measuring. These data were not collected in the initial four subjects, but only in the subsequent 33 subjects (58 hands). The data were used to generate torque–angle curves and derive the 'normative' data.

A total of 26 subjects took part in the reliability aspect of the study. All these subjects had measurements taken at baseline with some ($n = 13$; mean time since injury = 1 year ± 1; mean age = 29 years ± 10) measured again 3–5 days later and others ($n = 13$; mean time since injury = 10 years ± 5; mean age = 44 years ± 14) measured again 3 months later. Repeat measures were taken of the CMC angle with the application of the 0.027, 0.035 and 0.044 Nm torques. The 1–3-day reliability data were collected by the same assessor. On the second day of testing, the assessor was not given access to the results from the first day of testing. The 3–5-day period between repeat measurements was sufficiently long to minimize the chances of the assessor remembering previous results. The 3-month reliability data were collected by one of four assessors. Similarly, the assessors were not given access to the results from the baseline assessments.

Statistical analysis
The repeat measures of the CMC angles with the application of the 0.027, 0.035 and 0.044 Nm torques were used to test the 3-day intratester and 3-month intertester reliability on the two groups of subjects. Intraclass correlation coefficients (ICC) and percent close agreement of CMC angles were derived. Percent close agreement indicates the percentage of pairs of repeat measurements that were within 10 degrees of each other. The torque–angle measurements taken with the incrementally larger torques were used to derive the 'normative' data. The median and interquartile ranges of the CMC angle were calculated with the application of a 0.003, 0.014, 0.027, 0.035 and 0.044 Nm torque. In addition, a third-order exponential function was fitted to each subject's torque–angle data as recommended by others.[31,32]

Results

Reliability
The CMC angle with the application of 0.044 Nm ranged from 20 to 93 degrees (median = 63 degrees; interquartile range = 55–71 degrees; see Table 1). The intraclass correlation coefficients for the repeat measures taken 3–5 days apart were 0.89 (95% CI, 0.68–0.97) with the application of the 0.027 Nm torque, 0.84 (95% CI, 0.58–0.95) with the application of the 0.035 Nm torque, and 0.88 (95% CI, 0.65–0.96) with the application of the 0.044 Nm torque (see Table 2). The equivalent ICC for the repeat measures taken 3 months apart were 0.89 (95% CI, 0.66–0.97), 0.88 (95% CI, 0.67–0.96) and 0.90 (95% CI, 0.67–0.97). That is, repeat measurements taken with the application of 0.044 Nm were within 10 degrees of each other 80% of the time when measured by the same assessor 3–5 days apart, and 92% of the time when measured by a different assessor 3 months apart.

Figure 2 shows the raw torque–angle data and corresponding fitted curves for five representative subjects. The differences in the torque–angle relationship between different subjects are evident. The third-order exponential curve provided a good fit for all data (median $R^2 = 0.9851$; interquartile range = 0.9769–0.9905) reflecting that subjects' data were well modeled with this function.

Table 1 Median (and interquartile ranges) of the CMC angle with the application of 0.003, 0.014, 0.027, 0.035 and 0.044 Nm torque in 58 hands of people with C4–C7 tetraplegia

	CMC joint angle (degrees)	
Torque (Nm)	*Median*	*IQ range*
0.003	33	24–38
0.014	46	39–51
0.027	54	45–62
0.035	58	51–67
0.044	63	55–71

Table 2 Intra-class correlation coefficients (95% CI) for repeat measurement taken 3–5 days apart (one hand of a subgroup of 13 subjects) and 3 months apart (one hand of a second subgroup of 13 subjects)

	ICC	
Torque (Nm)	*3–5 days*	*3 months*
0.027	0.89 (0.68–0.97)	0.89 (0.66–0.97)
0.035	0.84 (0.58–0.95)	0.88 (0.67–0.96)
0.044	0.88 (0.65–0.96)	0.90 (0.67–0.97)

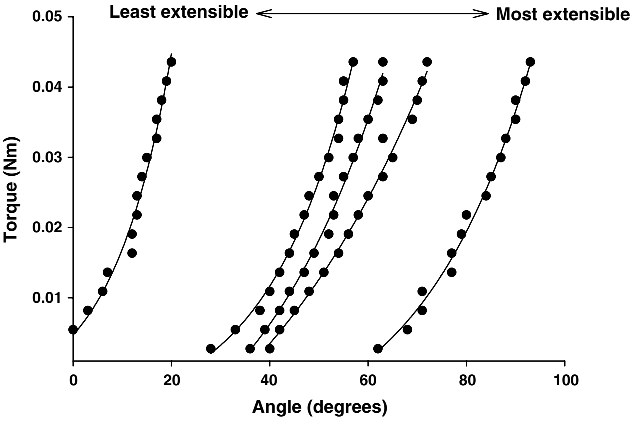

Figure 2 Torque–angle data of the CMC joint of five subjects representing minimum, maximum, median, 25 and 75% of the 58 hands tested. The symbols represent the real data and the solid line represents the fitted data

Discussion

The purpose of this study was firstly, to describe a simple clinical tool that can be used to measure the extensibility of the FPL muscle and secondly, to test its reliability. Validity was not directly tested because there is no alternate 'golden standard' method of measuring the extensibility of the FPL muscle. The device described in this study does, however, have face validity. The extensibility of any muscle is primarily determined by its passive length and compliance.[33,34] In the clinical setting, these two passive mechanical properties of muscles are best reflected by torque–angle curves.[10–17] Although more than one soft tissue structure spans a joint, the torque–angle curve of a joint can be used to primarily reflect the passive mechanical properties of an overlying multiarticular muscle (such as FPL muscle) when this muscle primarily restricts joint movement. Therefore, provided the FPL muscle is placed at a stretch by positioning the wrist, MCP and IP joints in full extension, the torque–angle curve of the CMC joint will primarily reflect the passive mechanical properties of the FPL muscle. This principle is widely used to reflect the passive mechanical properties of other multiarticular muscles. For example, the torque–angle curves of the ankle (with the knee extended) are used to reflect the passive mechanical properties of the gastrocnemius,[35] and the torque–angle curves of the hip (with the knee extended) are used to reflect the extensibility of the hamstring muscles.[29] This study shows that this simple principle, when applied to the thumb, is reliable when measurements are repeated 3 days and 3 months apart.

There are two main factors that may have reduced the reliability of the device. Firstly, clinical judgment was used to align the center of rotation of the CMC joint with the center of rotation of the device. It is possible that there was error in this procedure and the center of rotations were not perfectly aligned. Secondly, measurements may have reflected some involuntary active contraction of the FPL muscle. However, involuntary active contraction of paralyzed muscles can be substantially reduced by sustained stretch. Hence, all measurements in this study were taken after 1 min of prestretch.

Clinicians working in the area of spinal cord injuries are primarily interested in the extensibility of the FPL muscle because of its perceived importance on the hand function of people with C6 and C7 tetraplegia.[1,2] However, clearly, more work is required to better understand how length and compliance of the FPL muscle correlates with more traditional measures of hand function such as pinch strength and ability to grasp different sized, and weighted objects between the thumb and first finger. Likewise, more work is required to identify the optimal passive mechanical properties of the FPL muscle for hand function. Such information will enable clinicians to ensure that their interventions are targeting the appropriate characteristic of the FPL muscle and will enable clinicians to better understand the mechanisms underlying the effectiveness of different hand interventions. In addition, this type of information will enable clinicians to use measures of the extensibility of the FPL muscle as treatment goals and outcome measures.

In the absence of more precise information about the optimal extensibility of the FPL muscle for the hand function of people with C6 and C7 tetraplegia, this paper provides some initial 'normative' data of the extensibility of the FPL muscles in persons with tetraplegia. While the subjects of this study may not have had optimal passive extensibility of the FPL muscle, nor optimal hand function, the results do provide clinicians with some initial data upon which to compare their outcomes. For instance, in this sample at least, 75% of subjects had a CMC angle of between 55 and 71 degrees with the application of a 0.044 Nm torque. Clearly, larger prognostic studies that link the extensibility of the FPL muscle with hand function are now required.

This study provides clinicians and researchers with the necessary tools to commence the process of both better quantifying the relative importance of different aspects of the passive mechanical properties of the FPL muscle to an effective passive tenodesis grip and directly evaluating the effectiveness of hand interventions on the passive mechanical properties of the FPL muscle.

Acknowledgements

Special thanks to the clients of the Moorong Spinal Injury Unit from the Royal Rehabilitation Centre Sydney for their time and cooperation; Deborah Killorn, Adrian Byak, John Barron and James Puttock for their input into the design of the device; Bronwyn Ritchie and Rowena Baillie for their assistance with data collection; the Department of Biomedical Engineering at the Royal Rehabilitation Centre Sydney for manufacturing the device; and Paul Pattie for his illustration of the testing device. This project was funded by the Royal Rehabilitation Centre Sydney and the NSW Registration Board.

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