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Correlations Between Maximal Isometric Strength and the Cross-Sectional Area of Lumbrical Muscles in the Hand

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Abstract

The lumbrical muscles contribute to the intrinsic plus position, that is simultaneous metacarpophalangeal (MCP) flexion and interphalangeal (IP) extension. The strength of the lumbrical muscles is necessary for normal hand function. However, there is no objective and efficient method of strength measurement for the lumbrical muscles. In addition, previous studies have not investigated the measurement of the cross-sectional area (CSA) of the lumbrical muscles using ultrasonography (US) and the relationship between lumbrical muscle strength in the intrinsic plus position and the CSA. Therefore, the purpose of this study was to identify the measurement method of the CSA of the lumbrical muscles using US and to examine the relationship between maximal isometric strength and the CSA of lumbrical muscles. Nine healthy males participated in this study. Maximal isometric strength of the second, third, and fourth lumbrical muscles was assessed using a tensiometer in the intrinsic plus position which isolated MCP flexion and IP extension. The CSA of the lumbrical muscles was measured with an US. The US probe was applied on the palmar aspect of the metacarpal head with a transverse view of the hand in resting position. There was no significant difference between maximal isometric strength of the lumbrical muscles, but the fourth lumbrical muscle was stronger than the others. The CSA of the lumbrical muscles was significantly different and the fourth lumbrical muscle was significantly larger than the second lumbrical muscle. There was moderate to good correlation between maximal isometric strength and the CSA of the lumbrical muscles. Therefore, we conclude that maximal isometric strength of the lumbrical muscles was positively correlated to the CSA of the lumbrical muscle in each finger, while the measurement of the CSA of the lumbrical muscles, using US protocol in this study, was useful for measuring the CSA of the lumbrical muscles.

Key Words: Correlation; Cross-sectional area; Lumbrical muscle; Ultrasonography.

Introduction

The fingers are moved by intrinsic and extrinsic muscles of the hand. Although the contribution of intrinsic muscles is small, the interaction between intrinsic and extrinsic muscles is required for the various motions of the hand (Nordin and Frankel, 1980). The intrinsic muscles of the hand are interosseous, lumbrical and hypothenar. Particularly, the contraction of the lumbrical muscles results in interphalangeal (IP) extension and reduces the viscoelastic force of the flexor digitorum profundus muscle for IP flexion. Therefore, they contribute to the intrinsic plus position: simultaneous metacarpophalangeal (MCP) flexion and IP extension of the second through fifth digits. On the middle phalanx, the lumbrical muscle acts as an ex-

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tensor continuously, irrespective of the position of the MCP joint. This muscle is used during an upstroke in writing and contributes to the full hand opening (Gosling et al, 2008; Kaplan, 1953; Kendall et al, 2005; Maeda and Matsui, 1985; Moore, 1992; Platzer, 1992; Thomas et al, 1968). Weakness of the lumbrical muscles would cause IP flexion angle and could not extend the PIP joint actively (Maeda and Matsui, 1985; Thomas et al, 1968). In addition, while there is no issue with in the function of extrinsic muscles, claw-hand deformity results from IP extension loss if MCP hyperextension resulted from weakness of lumbrical and interosseous muscles. In this case, the hand cannot hold a newspaper or a book, thus reducing the overall functionality of the hand (Kendall et al, 2005). Weakness of intrinsic muscles, especially lumbrical muscles, as well as extrinsic muscles may be suspected as a cause if hand function was reduced. Accordingly, activation or strength of the lumbrical muscles is necessary for normal hand function while an objective and efficient method of strength measurement for intrinsic muscles is critical.

Strength measurements for intrinsic hand muscles such as manual muscle strength testing (MMT) (Brandsma et al, 1995; Buschbacher, 1997), dynamometry (Schreuders et al, 2006) and tensiometry measurements are used in the clinical evaluation. Dynamometry scoring can use continuous scale and can assess objective value more than MMT (Schreuders et al, 2006). Power grip and pinch are included in dynamometry measurements for intrinsic muscle strength (Kosin et al, 1999; Schreuders et al, 2004; 2006), and the Jamar dynamometer is the most common device to assess power grip strength (Irwin and Sesto, 2010). However, power grip strength is generated by a combination of the intrinsic and extrinsic muscles (Kosin et al, 1999; Schreuders et al, 2004). The strength measurement of the isolated intrinsic muscle was tested through abduction of the little finger, abduction of the index finger, the intrinsic plus position, palmar abduction of the thumb, and opposition of the thumb (Schreuders et al, 2006). Particularly, the intrinsic plus position can evaluate a combination of interosseous and lumbrical muscle strength (Schreuders et al, 2006). Recently, Raschner et al. (2010) designed a new device using the force transducer to measure strength similar to the Rotterdam Intrinsic Hand Myometer (RHIM). In a MCP flexion test using this device, it shows a significantly higher correlation (r>.7~.8). Muscle cross-sectional area (CSA) is the area of the cross section of a muscle perpendicular to its longitudinal dimension generally at its largest point (Maughan et al, 1983). The relationships between the strength and CSA of the muscle have been reported in previous studies, which found that muscle strength was positively correlated to the CSA (Dons et al, 1979; Ichinose et al, 1998; Kanehisa et al, 1994; Maughan et al, 1983). It is commonly recognized that a larger CSA of the muscle has greater force generation capacity; however, some studies have been shown inconsistent findings (Jones et al, 2008).

Rehabilitative ultrasound imaging (RUSI) involves the use of real-time ultrasound imaging (Wang et al, 2006). RUSI is a noninvasive method of quantifying muscle morphology and function (Hebert et al, 2010). Over the past decades, RUSI has become increasingly popular in the field of neuromusculoskeletal medicine (Whittaker et al, 2007). RUSI has been used to assess the effect of stretching exercises and muscle strengthening exercises on the CSA in ultrasound images (Akagi et al, 2009; Wang et al, 2006). Muscle size measurement from ultrasound images can provide an objective assessment of muscle atrophy and hypertrophy (Rankin et al, 2005). Muscle size can provide an indirect measure of strength, as found in the neck extensors (Rezasoltani et al, 2002). The substantial agreement between ultrasound and Magnetic Resonance Imaging (MRI) measurements of the thickness and the CSA providesevidence of the validity of an ultrasound to measure trunk muscle size accurately (Koppenhaver et al, 2009; O'Sullivan et al, 2009). The previous research on the CSA was correlation of linear dimension or anthropometry. The correlation between neck muscle CSA and linear dimension was high (r=.63~.96), but between neck muscle CSA and anthropometry there was a low coefficient (r=.30～.44) (Rankin et al, 2005). The study of relationships between muscle strength and indices of muscle CSA reported that muscle strength is more closely related to muscle CSA (Akagi et al, 2009).

Although the relationship between the strength of the lumbrical muscle and the CSA of the lumbrical muscle is clinically important, to our knowledge, there was no previous study that was conducted to identify the CSA of lumbrical muscles using US and to investigate the relationship between lumbrical muscle strength in the intrinsic plus position and the CSA. Therefore, the purpose of this study was to identify the measurement method of the CSA of lumbrical muscles using US and to examine the relationship between maximal isometric strength and the CSA of lumbrical muscles. We hypothesized that there would be positive correlation between maximal isometric strength and the CSA of the lumbrical muscle in each finger.

Methods

Participants

Nine healthy males were included as they had no history of hand and upper extremity injury such as a sprain or fracture and no restriction of movement. Subjects were excluded if they had inflammatory joint disease or a neurological disorder. All subjects were right hand dominant. The dominant hand was defined as the one preferred for daily activities like writing and eating by self-report (Incel et al, 2002; Jung and Jung, 2009). The university's institutional review board approved the study and all subjects signed a written informed consent form to participate before the beginning of the study. Table 1 summarizes the mean age, height, and weight of the subjects.

Instruments

The maximal isometric strength of lumbrical muscles was measured with a digital tensiometer.[1] The sampling rate was 1000 ㎐ using a low-pass filter at 5 ㎐. The data were digitized using Acqknowledge software (Biopac System Inc., CA, U.S.A.). The tensiometer was calibrated prior to each set of measurements. The data for each trial is expressed in kilograms (㎏), and the mean value of three trials was used for analysis.

The CSA of the lumbrical muscle was measured with ultrasonography[2] (US), with a 7.5 ㎒ liner array probe and B-mode ultrasonic apparatus. A real-time B-mode image depicts a cross-section of anatomical structures. The US probe was applied on the palmar aspect of the metacarpal head with a transverse view (Caine et al, 2009) with the hand in resting position because it was difficult to measure using the US with a folded skin surface. The second, third, and fourth lumbrical muscle was captured on the palmar aspect of the third, fourth, and fifth metacarpal head, respectively. The CSA of the first lumbrical muscle was not measured because it was difficult to place the US probe on the lateral side of the index finger where the first lumbrical muscle is inserted. Images were captured, stored and measured using the US on-screen calipers. The data for each trial are expressed as ㎠, and the mean value of three trials was used for analysis.

Table 1. General characteristics of subjects (N=9)

Characteristics	Mean±SD
Age (yrs)	23.4±2.9
Height (㎝)	174.8±3.9
Weight (㎏)	69.6±4.7

1) Tensiometer TSD121C, BIOPAC System Inc., CA, U.S.A.
2) SonoAce X8, Medison Co Ltd, Seoul, Korea.

Procedures

The experimental procedures were explained to all subjects before they performed the task. The subjects were seated in an upright position with their feet flat on the floor. Their wrist was immobilized by a strap on the table and the arm and finger supported on the table; the elbow was flexed to 90° with the forearm-supinated. Maximal isometric strength of the second, third, and fourth lumbrical muscle was assessed using the non-elastic band that was strapped around the proximal phalanx of the third, fourth, and fifth finger. Before the test, the examiner instructed the subjects to practice the intrinsic plus position so as to familiarize them with the position and to prevent IP and wrist flexion. The subjects were instructed to perform the intrinsic plus position, that is isolate MCP flexion and IP extension and to maintain the intrinsic plus position against the resistance provided by the strap applied around the proximal phalanx during the measurement of maximal isometric strength of lumbrical muscle. The data of lumbrical muscle strength were collected during a five-second period for each finger. The initial one and final one were excluded, and data for three periods was used for statistical analysis. The CSA data of lumbrical muscles were collected with the hand in resting position. The lumbrical CSA was measured when US captured the outline of the lumbrical muscle border as it became distinct, and enabled off-line analysis by tracing around the muscle border using on-screen calipers to measure CSA (Figure 1). A one-minute resting period was provided between measurements to prevent muscle fatigue.

Statistical Analysis

The data were expressed as mean±standard deviation (SD) values. Data were found to be normally distributed using the Kolmogorov - Smirnov test, one-way analysis of variance (ANOVA) was used to compare maximal isometric strength and the CSA between lumbrical muscles. A Bonferroni's correction was used for multiple comparisons. Pearson correlation coefficients were used to test for relations between maximal isometric strength and CSA of lumbrical muscles. The data were interpreted according to the following modification of the criteria proposed by Portney and Watkins (2000): r=.50~.75; moderate to good; r>.75; good to excellent. Data analysis was performed using SPSS version 18.0 software, and the level of statistical significant was set at .05.

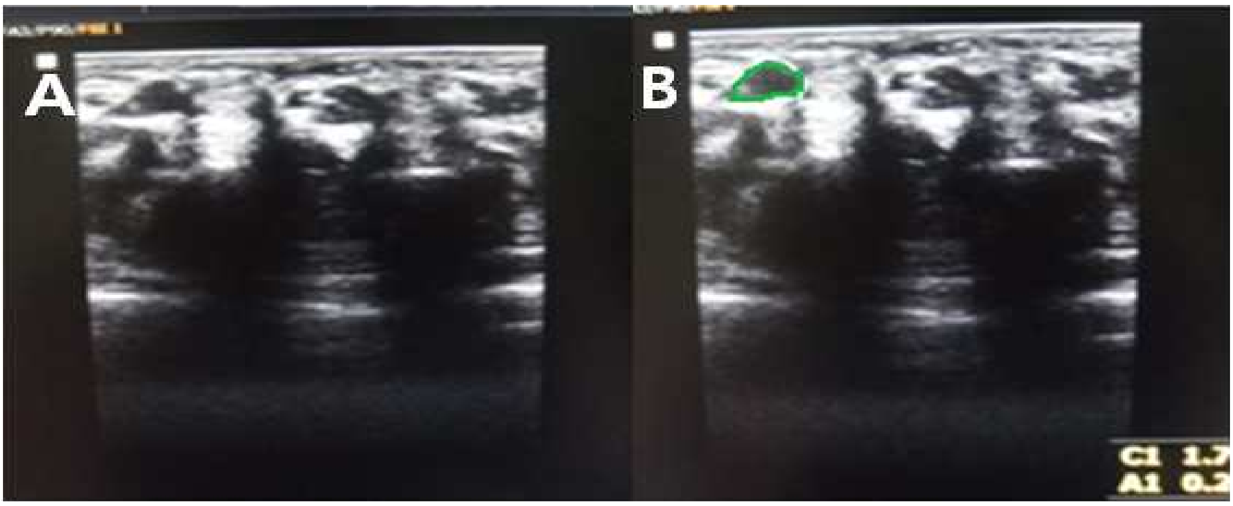

Figure 1. Lumbrical muscle captured by US (A) and the CSA measurement of the lumbrical muscle (B).

Results

Maximal isometric strength of the lumbrical muscle

Maximal isometric strength of the lumbrical muscle was not significantly different in each finger ($p>.05$). The fourth lumbrical muscle was not significantly stronger than the other lumbrical muscles (Table 2).

The CSA of the lumbrical muscle

The CSA of the lumbrical muscle was significantly different in each finger ($p<.05$). Post-hoc testing revealed that the CSA of the fourth lumbrical muscle was significantly larger than the second lumbrical muscle (Table 3) (Figure 2).

Correlations between maximal isometric strength and the CSA of the lumbrical muscle in each finger

There was no significant and moderate correlation between maximal isometric strength and the CSA of the second lumbrical muscle. However, there were significant and high correlations between maximal isometric strength and the CSA of the third and fourth lumbrical muscle, respectively (Table 4) (Figure 3).

Discussion

The purpose of this study was to identify the measurement method of the CSA of the lumbrical muscle using US and to examine the correlation between maximal isometric strength and the CSA of the lumbrical muscle. The results of this study show that there was moderate to good correlation between maximal isometric strength and the CSA of the lumbrical muscles. The larger the CSA of the lumbrical muscle, the greater the force generation capacity in each finger. This result agrees previous studies that muscle strength was positively correlated to the CSA (Dons et al, 1979; Ichinose et al, 1998; Maughan et al, 1983). In this study, maximal isometric strength of the lumbrical muscles shows a tendency to increase from the second to fourth lumbrical muscle, however, there was no significant difference in each finger and there was no significant and moderate correlation between maximal isometric strength and the CSA of the second lumbrical muscle. However, the interosseous muscles, while controlling finger abduction, contributes to the intrinsicplus position. We could not demonstrate interosseous muscle action because it is difficult to find interosseous muscle using US. This is considered

Table 2. Comparison of maximal isometric strength of the lumbrical muscle (N=9)

	Mean±SD (㎏)	95% confidence interval (CI)	F	p
second lumbrical	2.94±.88	2.26～3.61		
third lumbrical	3.03±.90	2.34～3.73	.063	.94
fourth lumbrical	3.09±.96	2.34～3.83		

Table 3. Comparison of the CSA of the lumbrical muscle during rest (N=9)

	Mean±SD (㎠)	95% confidence interval (CI)	F	p
second lumbrical	.11±.03	.09～.13		
third lumbrical	.13±.04	.10～.16	3.357	.04
fourth lumbrical	.15±.04	.13～.18		

Table 4. Correlations between maximal isometric strength and the CSA of the lumbrical muscle in each finger

	Pearson's r	p
second lumbrical strength × CSA	.55	.06
third lumbrical strength × CSA	.80	<.01
fourth lumbrical strength × CSA	.77	<.01

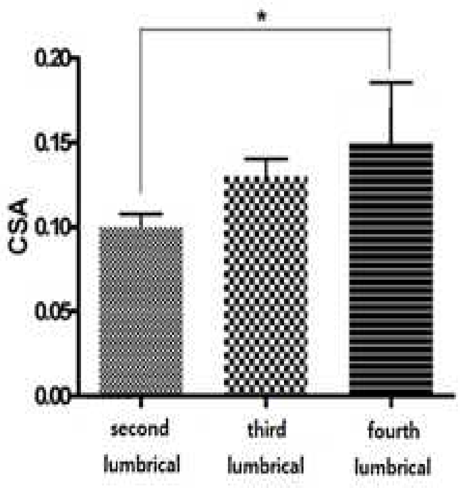

Figure 2. Comparison of the CSA of the lumbrical muscle during rest (*p<.05).

because we recruited only nine subjects, which is a small sample group, and would need a larger sample group for further studies.

To the best of our knowledge, this is the first and novel study to demonstrate that an US can provide measurements of the CSA of the lumbrical muscles, which are deep intrinsic muscles, in healthy male participants and no previous studies reported this method of measuring the CSA of lumbrical muscles using US. This CSA measurement of the lumbrical muscle is important to provide easy and convenient indirect measurement of the strength of the lumbrical muscle. Particularly, our study can explain that the relationship of maximal isometric strength and the CSA of the lumbrical muscles.

Although biomechanical and functional importance of lumbrical muscles was emphasized from the literature, only a few studies measured lumbrical muscles and lumbrical muscle activity using a small wire electrode to analyze the relative contribution of the intrinsicmuscles using cadavers (Koh et al, 2006). In recent studies, there were strength measurements of intrinsic muscles in children and in patients with neurological disease, however not for lumbrical muscles (Schreuders et al, 2004; Molenaar et al, 2008).

Furthermore, in this study, the CSA of the lumbrical muscle measurement was conducted by measuring on the palmar aspect of the metacarpal head with a transverse view. This is based on the suggestion by Caine et al (2009) whotested soft tissue structures of canines in the transverse view of US images, and confirmed the lumbrical muscle by the movement of MCP flexion with PIP extension. Although US is a noninvasive, easy, and cost-effective measure, no previous study measured the CSA of the lumbrical muscles. Therefore, our study

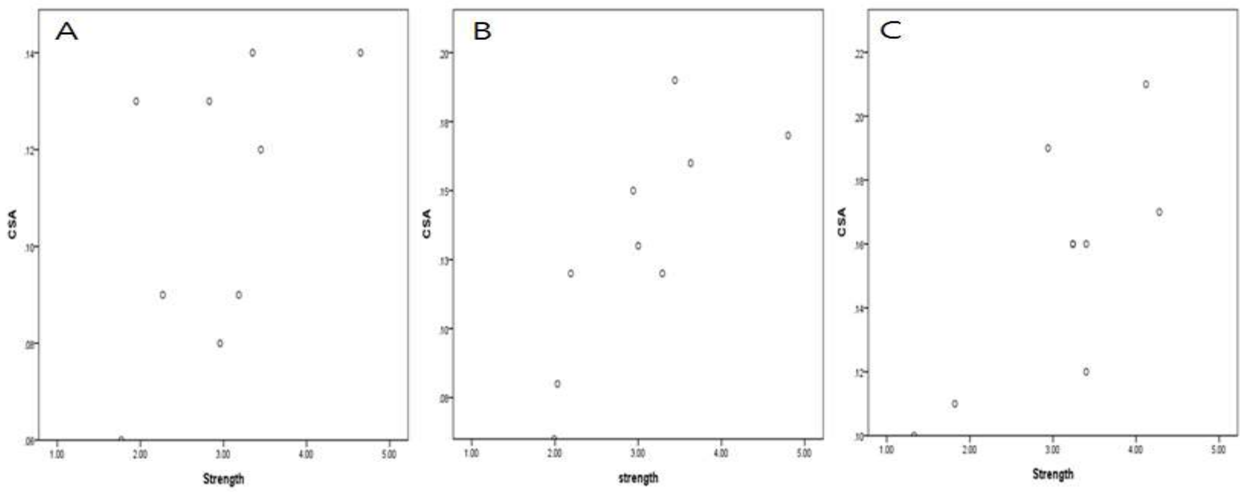

Figure 3. Correlations between maximal isometric strength and the CSA of the lumbrical muscle. A: second lumbrical, B: third lumbrical, C: fourth lumbrical.

suggests that the measurement method of the CSA of lumbrical muscles and standardized guidelines using US can be considered as an alternative method for wire electromyography. Particularly, this study could suggest an effective measurement for symptomatic groups such as neurological problems, muscle weakness, or pain for clinical evaluation and diagnosis.

However, there are limitations in this study. First, this study recruited only nine subjects, so further study needs to larger sample groups. Second, the measurement of the CSA of lumbrical muscles was conducted only with a hand in resting position, thus the degree of the CSA of the lumbrical muscle change during muscle contraction cannot be identified. Third, as has been mentioned, while the interosseous muscle's main action is finger abduction, it also contributes to the intrinsic plus position. However, it is difficult to find the interosseous muscle using US. Thus, further study is needed to identify the contribution of interosseous muscle in the intrinsic plus position. Fourth, on the basis of the present study, further study is needed to obtain intra- and inter-rater reliability and validity of the CSA of the lumbar muscle using a gold standard.

Conclusion

The purpose of this study was to establish the measurement method of the CSA of the lumbrical muscles using US and to examine the correlation between maximal isometric strength and the CSA of the lumbrical muscles. Maximal isometric strength of the lumbrical muscles show a tendency to increase from the second to fourth lumbrical muscle, but no significant difference in each finger. The CSA of the lumbrical muscles was significantly different in each finger. Additionally, there was moderate to good correlation between maximal isometric strength and the CSA of the lumbrical muscles. Therefore, we conclude that maximal strength of the lumbrical muscles was positively correlated to the CSA of the lumbrical muscles in each finger, and the US protocol used in this study was useful for the measurement of the CSA of the lumbrical muscles which can provide clinician with valuable information.

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