Ultrasonographic observation of stretched flexor digitorum in forced dorsiflexion

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Abstract

In this study, we examine a behavior of muscle-tendon complexes of the forearm during dorsiflexion of an index finger, using ultrasonography. When an external force is applied to a fingertip for dorsiflexion, a corresponding tendon is stretched by both muscular strength and the applied external force. The stretched tendon exerts elastic forces, which work as a restoring torque of the finger joint. In our previous works, a large hysteresis in the restoring force when the dorsiflexion angle is increased and decreased, and this seems to be caused by the behavior of the muscle-tendon of the forearm. In this paper, we investigate the behavior of the muscle-tendon, a.

1. Introduction

Motion of human body is brought by the transmission of muscular strength to the skeleton through tendons. Then, the tendon has elastic properties, and is usually not extended / shortened only by muscular strength, but it is stretched by applying external forces, and is shortened when these external forces are unloaded. This mechanism is called as Stretching-shortening cycle (SSC) [1] and contributes to the instantaneous body movement. Many studies on the muscle-tendon complex (MTC) have been conducted, and most of them employ ultrasonographic images or fMRI to observe directly MTCs in vivo [2][3]. In addition, these studies often focus on lower limbs, with which dynamic motion such as running and jumping are performed, and studies on upper limbs are a few.

Our previous works focusing on fingers of hand investigated the relationship between joint angles and fingertip forces, in order to estimate the elastic performance of fingers without above clinical equipment [4]. As for the measured fingertip forces caused by restoring torque of joints, a large hysteresis between elevation and reduction of the external forces applied to the fingertip for dorsiflexion is observed. We assume that it is caused by the behavior of the corresponding muscles because the hysteresis is quite larger than that expected by tendon-only specification reported by Ker et al. [5]. To reveal the mechanism of exerting restoring torques of finger joints during dorsiflexion by external forces, we analyze, with ultrasonographic images, a behavior of MTCs in the forearm which includes flexor digitorum.

2. Method

2.1. Measurement Procedure

When applied external forces push up a fingertip for dorsiflexion, the flexor digitorum is mainly stretched, but other muscles are also involved. We observe a behavior of the MTCs of forearm during dorsiflexion of wrist with the following procedure.

First of all, a player places their palm down on the measurement table (Fig.1), and lifts their index finger up with maximum muscle tension to a joint angle where they can reach. We call it “the initial angle”. Next, we apply an external force to the fingertip in the direction of dorsiflexion and increase the joint angle by 5 degrees from the initial angle (load-elevation, LE). Once the finger joint reaches the limitation of movement, the applied external force is reduced to decrease the joint angle by 5 degrees (load-reduction, LR) to the initial angle. During the procedure, the muscle and tendon of flexor digitorum in vivo are observed by using ultrasonography [SP7.5MHz, Interson Corp.].

The subjects of this study are five healthy participants (5 males, the average age is 22 years). The tendon of flexor digitorum during extension is observed with ultrasonographic images at the point shown in Fig. 2. Changes of displacement of the observed tendon corresponding to joint angles of the finger in extension can be estimated from the ultrasonographic images. Note that we estimate displacement of the tendon instead of extension of tendon in dorsiflexion due to angle of visibility of the probe.

2.2. Image Processing for Ultrasonographic Analysis

A reference point of the tendon in the image is determined and its displacement is measured every 5 degrees of the joint angle in dorsiflexion (Fig. 3). In addition, number of high luminance pixels in the binarized ultrasonographic image is also counted, in order to estimate muscular activities in forced dorsiflexion, with changing a threshold of binarization. According to our preliminary experiments, increasing high luminance pixels illustrates somewhat activation of muscles.

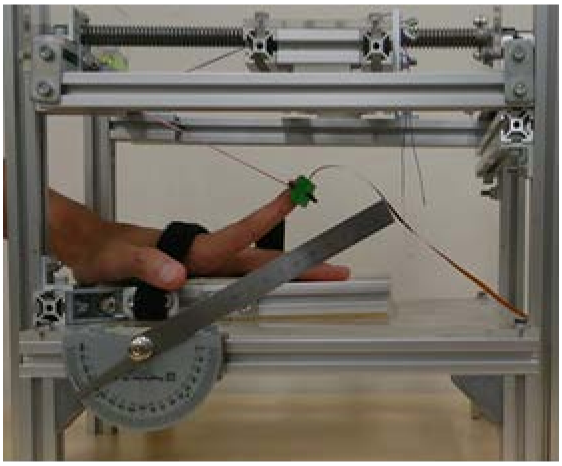

Fig.1 measurement environment

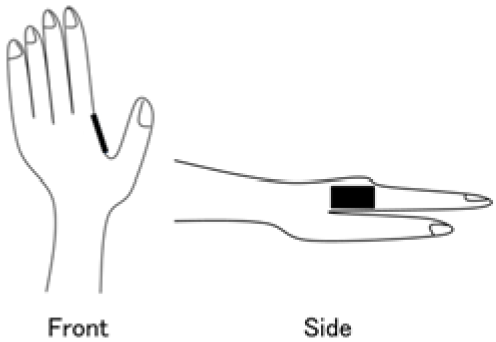

Fig.2 Observation part

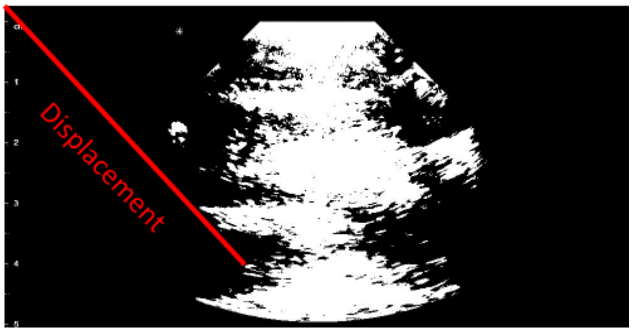

Fig.3 Displacement of muscles from finger direction

3. Results

3.1. Relationship between joint angles and fingertip forces during forced dorsiflexion

As [1], we estimate a relationship between joint angles of finger in dorsiflexion and fingertip forces.

Fig. 4 shows that the external forces are exponentially proportional to the joint angles at the phase of load elevation (LE), and a hysteresis is present between elevation and reduction of joint angle, that is, LE and load reduction (LR) phases. Fig. 5 shows the relationship between the displacement of a reference point of the observed tendon in the ultrasonographic images and joint angles. The displacement, which may be related to extension of the tendon, is proportional to joint angle in dorsiflexion at LE phase. Moreover, a hysteresis between LE and LR is also observed. The hysteresis in the relationship between joint angles and fingertip forces reported in Fig.4 seems to be larger than what is expected from the study of isolated tendon [4]. Hence we consider a factor decreasing fingertip forces in LR phase as a behavior of muscles in the forearm.

Considering that elongation of tendon is proportional to changes of joint angle [6], Fig. 5 illustrates that the measured displacement is correlated with the elongation of the tendon. With this hypothesis, the tendon of flexor digitorum is shortened in LR phase, even if the value of joint angle is equal. Shortening length of the tendon may be caused by breaking force equilibrium between tension of the tendon and muscular strength of corresponding muscles, and this breaking may be occurred with relaxation of the muscles.

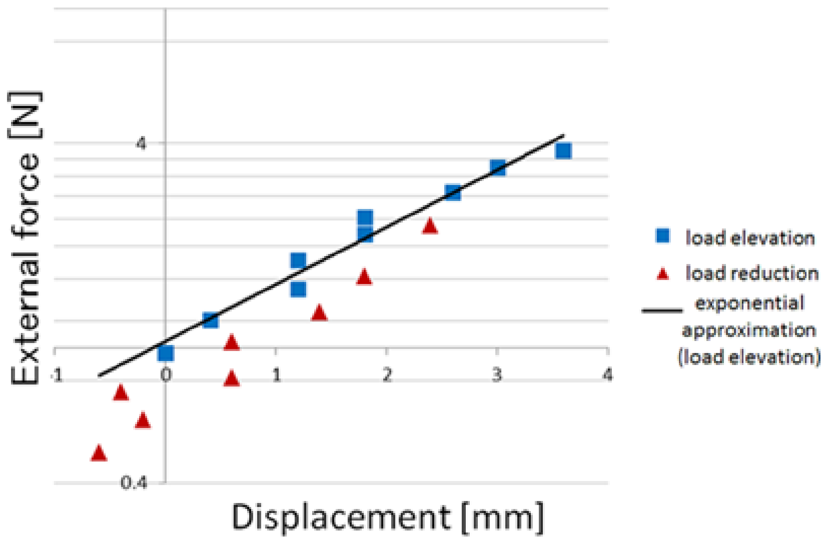

Fig.4 External force applied to the fingertip vs. displacement of the tendon in SSC

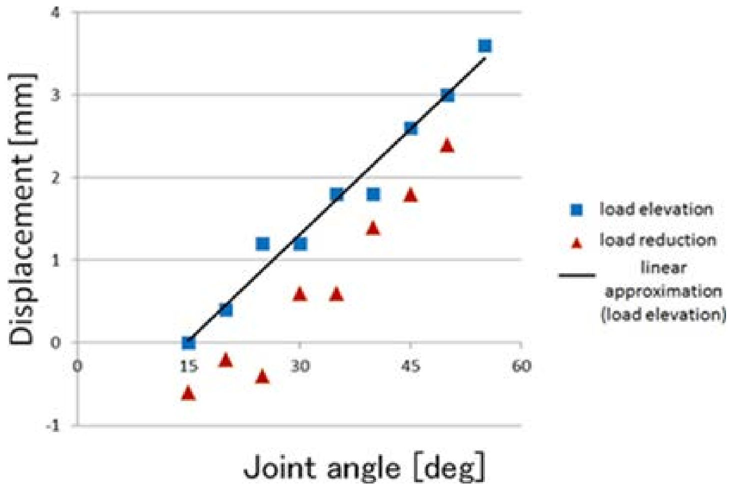

Fig.5 Displacement of the tendon vs joint angles in SSC

3.2. Displacement of muscles of forearm

From above consideration, we also observe behavior of the muscles in the forearm. Both parts of muscles and tendons seem to contract as increasing joint angles in dorsiflexion since the measured displacement is decreasing in contrast (Fig. 6, 7). In LR phase, each displacement of the muscles and tendons is largest at the limitation angle, and decreases as the joint angle shifts to the initial angle.

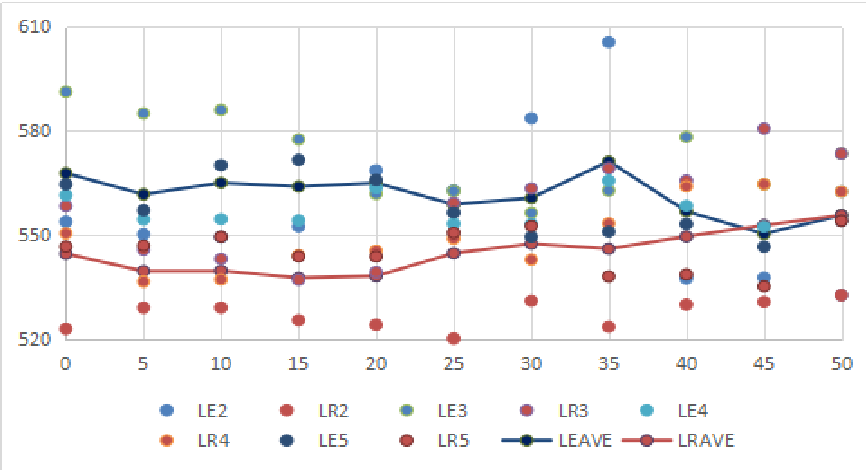

Fig.6 Displacement of muscles (in muscle-rich areas)

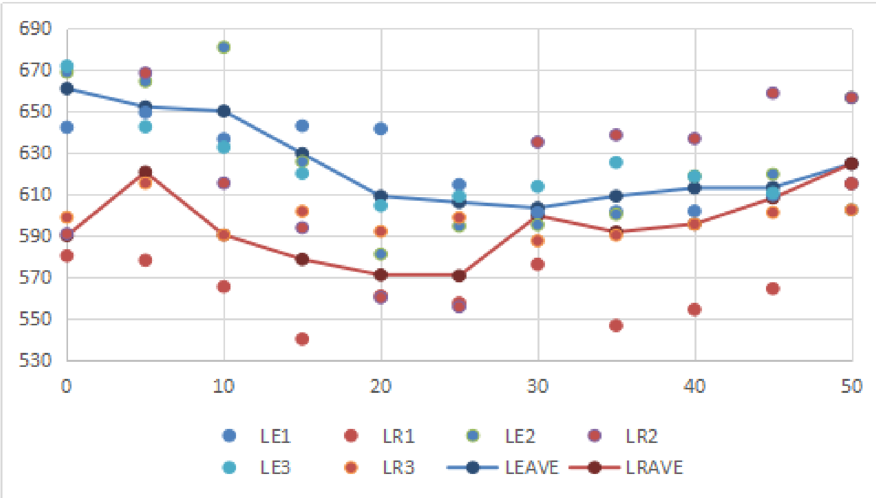

Fig.7 Displacement of muscles (in the area with many tendons)

3.3. Estimation of muscular activities

Another approach to investigate a behavior of the MTCs using number of high luminance pixels in the ultrasonographic images illustrates as Fig.8 and Fig.9 that the size of MTCs changes corresponding to the joint angles in forced dorsiflexion. As for the part around the wrist (Fig. 8), where tendons are present rather than muscles, the changes have no significance to the joint angle. On the other hand, as for the part in the forearm (Fig. 9), these muscles seem to be more relaxed in LR phase than LE phase. This result may describe our hypothesis that the relaxed muscles in LR phase do not support stretching of tendons, as addressed in the previous study [4], although further verification with more subjects should be considered.

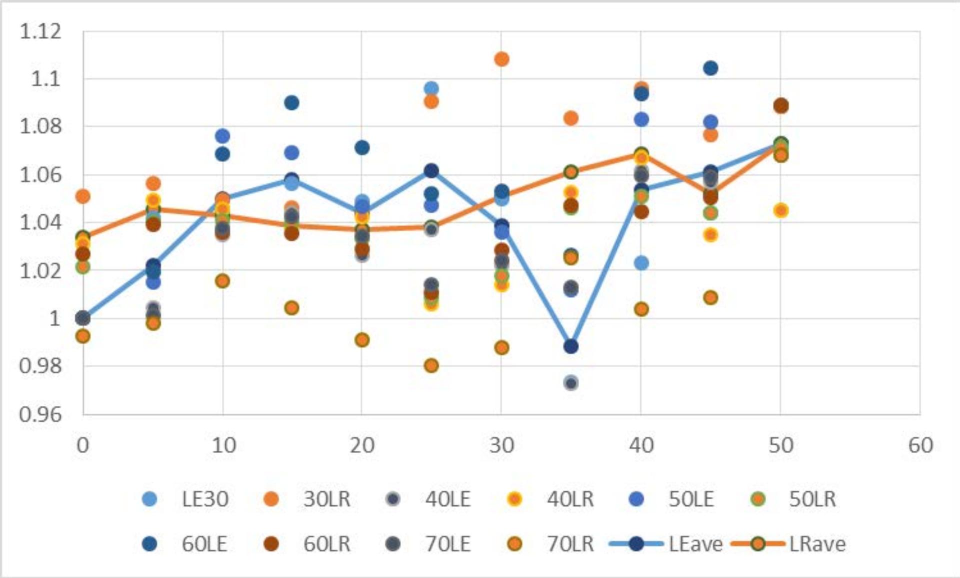

Fig.8 Change in the size of MTC when the joint angle is changed (around the wrist), normalized to LE30, which represents "the initial angle"

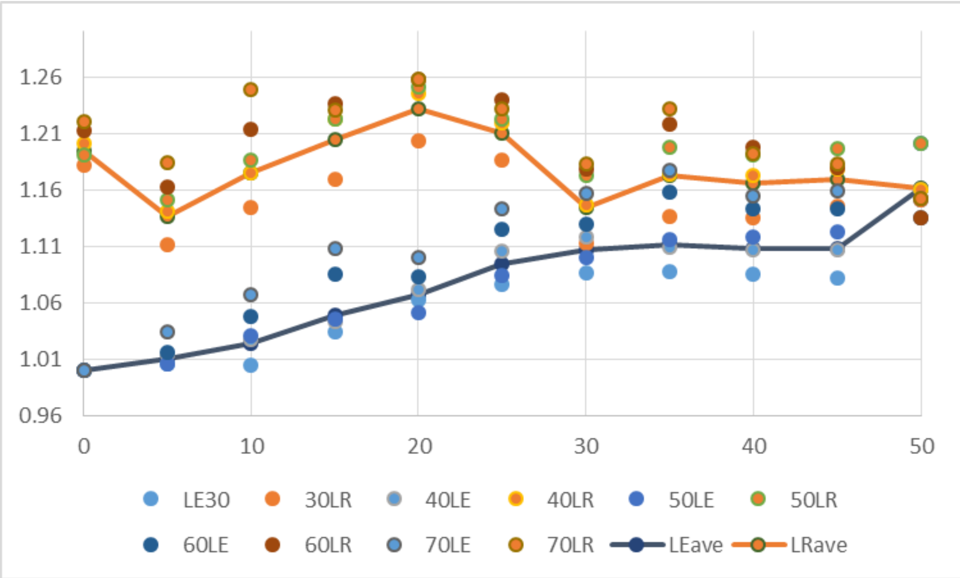

Fig.9 Change in the size of MTC when the joint angle is changed (forearm), normalized to LE30

4. Discussion

In this study, focusing on extension of flexor digitorum in forced dorsiflexion, we aim to reveal the factors causing a hysteresis between elevation and reduction of forces applied to the fingertip, which is referred in our previous work [4]. Ultrasonography helps us to measure changing displacement of MTCs in vivo with respect to changes of joint angle in dorsiflexion. As a result, measured series of displacement of tendon in the hand shows correlation with changes of the joint angle (Fig. 5, 7). In addition, those of muscles in the forearm have no significance (Fig. 6). Although there was no change in the muscle tendon according to the joint angle change, hysteresis occurred between LE and LR phases (Fig. 4). This reason may be described by relaxing the muscles in the LR phase shown in Fig. 8 and 9 because the relaxed muscles cannot be support the stretched tendon and its restoring force. It may cause shortening the tendon and decreasing amount of strength of MTCs.

5. Conclusions and Future Works

In this paper, performance of fingers in forced dorsiflexion, which is attributed to the stretched muscle-tendon complexes in the forearm including flexor digitorum, was measured and analyzed with ultrasonography in vivo. Fingertip forces being exponentially proportional to joint angles in dorsiflexion is mainly exerted by tension of tendons, and its hysteresis to joint angles between load elevation and reduction for pushing up the finger was observed. By analyses with ultrasonography, it may be caused by behavior of the muscles that are relaxed in the phase of load reduction. The relaxed muscles exert less muscular strength to support the stretched tendons. As the result, the tendons are also relaxed and shortened.

For further verification of our hypothesis, more measurement and analyses for many participants in the experiment should be conducted. In addition, applications for robots and prosthetics with the mechanism of human hand will be considered.

Acknowledgements

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