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ORIGINAL ARTICLE

Shin-ya Kuno · Tetsuo Fukunaga

Measurement of muscle fibre displacement during contraction by real-time ultrasonography in humans

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Abstract The contact point (P) made by both the echoes of the aponeurosis and from interspaces among fascicles of the tibialis anterior muscle was detected by real-time ultrasound scanning in 12 adults. Movement in the location of P was observed during muscle contraction and its displacement was related to changes in ankle joint angles ($r=0.81$, $P<0.01$), i.e. P shifted proximally when the ankle joint was dorsiflexed. There was also a significant positive correlation between the degree of dorsiflexion and the velocity related to the change in location of P ($r=0.84$, $P<0.01$). Ultrasound measurements of the displacement and the velocity of P were reproducible as there was no variation noticed among measurements on different days. It is suggested from these results that the displacement of P reflected changes in muscle length during contraction and that this amount of change corresponded to changes in joint angles.

Key words Muscle fibre · Ultrasonography
Muscle contraction

Introduction

From an anatomical viewpoint skeletal muscles can be divided into roughly two categories: parallel muscles whose muscle fibres are parallel to the tendon, which is attached to the bone, and pennate muscles whose fibres are connected to the tendon at the same angles as the fibres themselves. It has been shown that the difference in the angle of the fibres in relation to the tendon (referred to as the pennation angle) affects the force exerted outside the body by way of joints (Maughan et al. 1984; Narici et al. 1989). The measurement of pennation angles has so far been made using cadavers (Alexander and Vernon 1975; Amis et al. 1981; An et al. 1981; Wickiewicz et al. 1983), but recently the possibility of measuring human pennation angles by an ultrasound method has been shown (Henriksson-Larsen et al. 1992; Kawakami et al. 1993; Rutherford and Jones 1992). Such studies have adopted a method of image-processing the ultrasound echoes from the bundles of tissue binding muscle. It has been recognized that the pennation angle obtained by this ultrasound method corresponds well to results of measurements taken from a cadaver, and when repeated on the same person is quite reproducible (Henriksson-Larsen et al. 1992; Kawakami et al. 1993; Rutherford and Jones 1992). The results of these studies have seemed to indicate the possibility of measuring anatomical information of fibre orientation by the ultrasound method.

On the other hand, muscles contract and become shorter, producing a change in the joint angle. Since the relationship between a change in the joint angle and the corresponding amount of muscle contraction is affected by the length of the moment arm, it may be expected that the amount of muscle contraction (contraction rate) will vary among individuals even if their joints undergo the same angular change due to differences in their moment arms. Thus, when identifying the muscle force-rate relationship in a living human body, it is of vital importance to determine the contraction speed of the muscles themselves.

Therefore, we tried to measure noninvasively the displacement (rate) of human muscles while they were contracting to determine the relationship with the corresponding change (rate) in the joint angles.

Methods

Subjects

Six adults were tested in this study, with a further 6 subjects who participated to confirm the reproducibility of the method use. Informed consent to participate in the study was obtained from all subjects.

S. Kuno (✉) · T. Fukunaga
Laboratory of Sports Sciences, Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Komaba, Meguro-ku 153, Japan

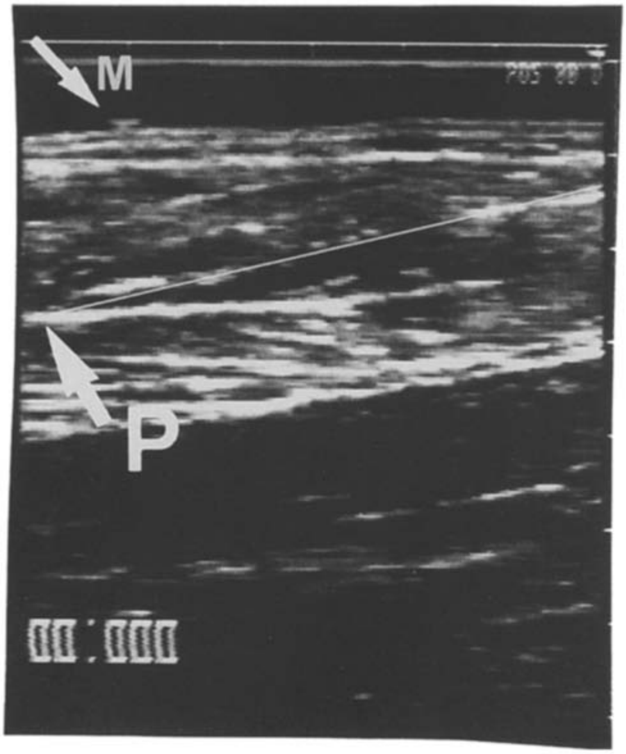

Fig. 1 A point of contact (*P*) between the echoes of the aponeurosis of tibialis anterior muscle and the echoes from interspaces among fascicles by ultrasonography. A *small arrow* shows the standard position (*M*)

Ultrasonography

The ultrasound equipment (SSD-500, AloKa, Japan) used was of type B-mode (Kawakami et al. 1993). An ultrasound probe was placed on the widest part of the right-leg tibialis anterior muscle, to determine the position (point P) where the contact point between the fascia and the bundles of tissue binding muscle was visible on the real-time image (Fig. 1). After the probe was firmly positioned, a specially-designed placement marker (M) was set between the body and the probe so that the marker would not move.

At a signal the subjects executed voluntary ankle-joint dorsiflexion movements. The ultrasound image during this muscle contraction was recorded on videotape simultaneously with a time mark every 1/1000 s and the angle through which the ankle joints moved (Fig. 2) as measured by a goniometer. To confirm good reproducibility, each person was measured twice.

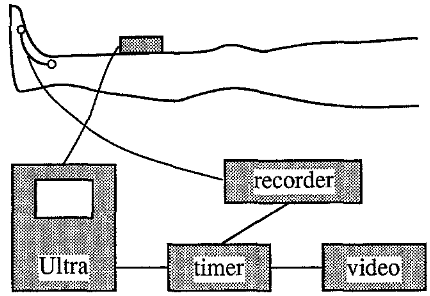

Fig. 2 Diagram of the experimental setup

Measurement of displacement of muscle fibre

From the ultrasound images of dorsiflexion on video tape, five or six frames were randomly selected to be printed out. Using these images, point P between the fascia and the bundles of tissue binding the muscle within the tibialis anterior muscle was identified to determine the distance from set on the placement marker. The amount of muscle displacement and time were calcualted using the point P obtained from two different consecutive images. The fibre displacement rate was also calculated in this manner from the amount of muscle displacement obtained and the time taken. The angle of the ankle-joint and angular speed were obtained by measuring the angle with the goniometer and realting these angles to point P using the synchronized ultrasound images.

Statistics

We used the comparison of two regression parameters to confirm the reproducibility of the measurements.

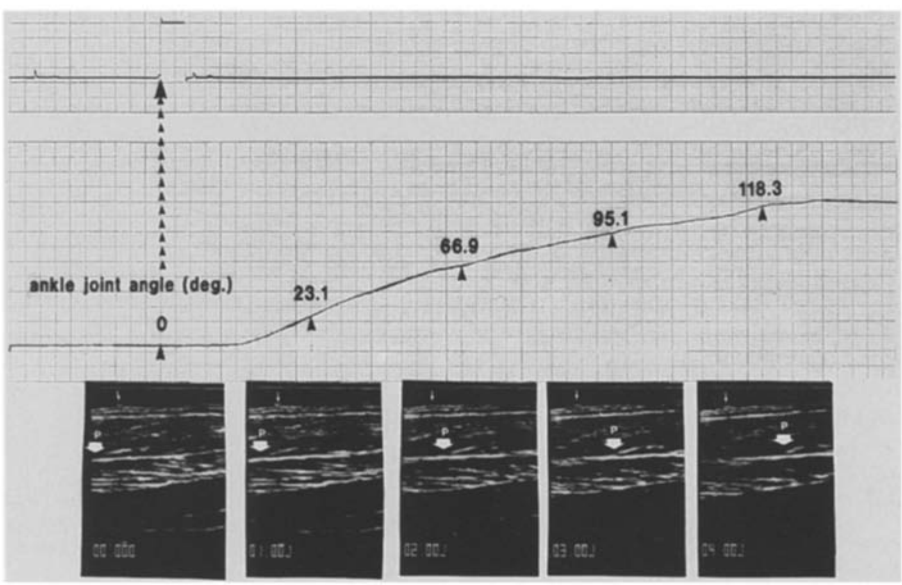

Fig. 3 Photographs changes of ankle joint angle and displacement of *P* (see definition Fig. 1)

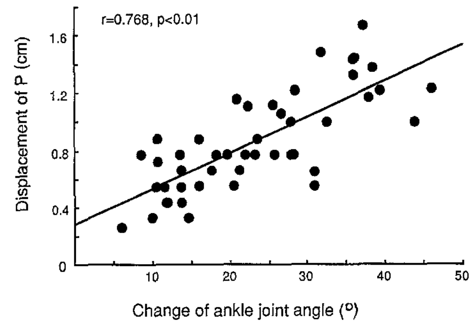

Fig. 4 Relationship between changed of ankle joint angle and displacement of *P* (see definition Fig. 1)

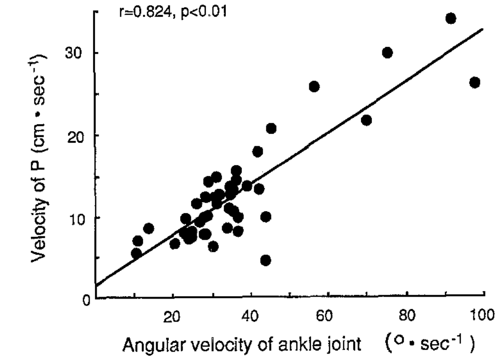

Fig. 5 Relationship between angular velocity of ankle joint and velocity of *P* (see definition Fig. 1)

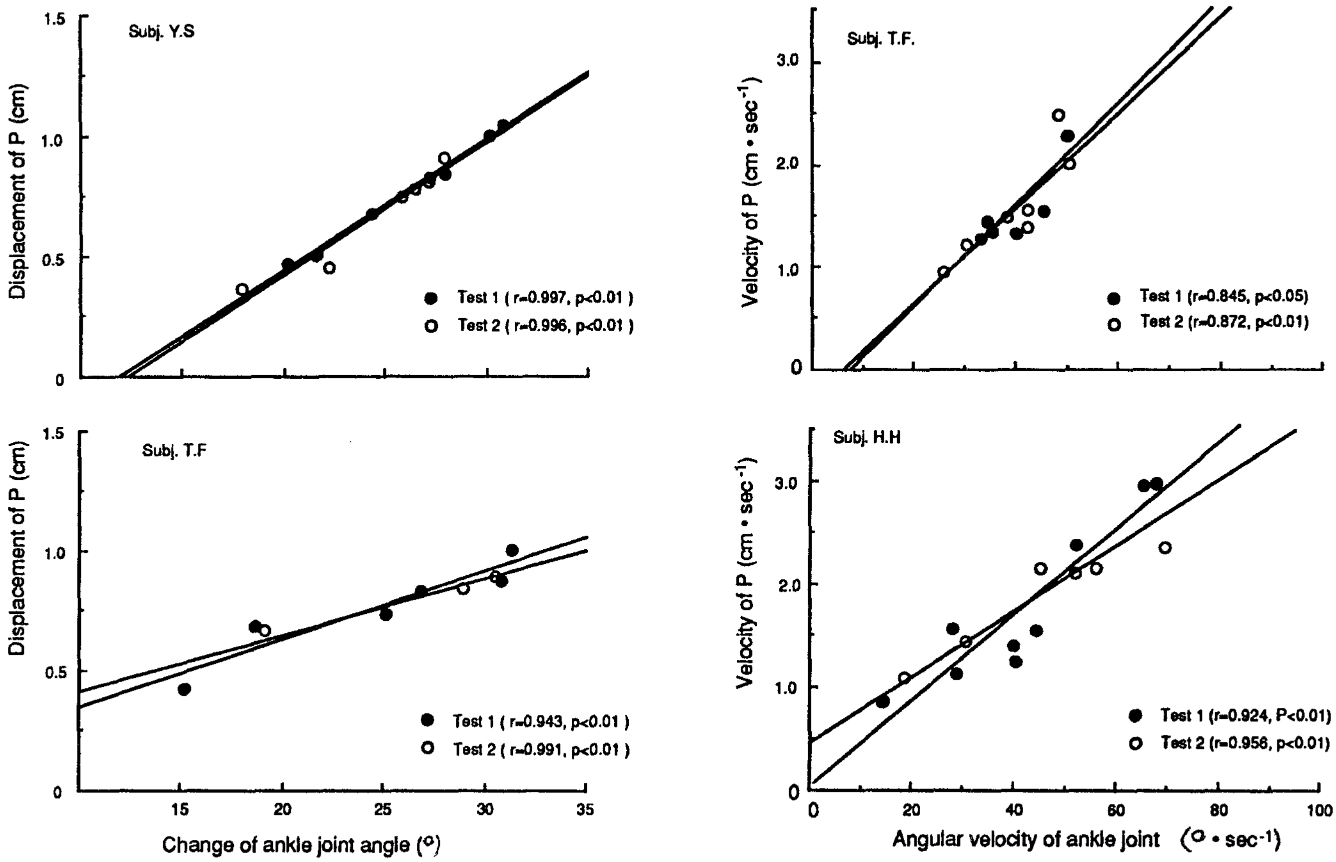

Fig. 6 Correlations for scans of tibialis anterior muscle repeated on separate days. For definition of *P* see Fig. 1

Results

Figure 3 shows an example of analysis during one round of dorsiflexion within the tibialis anterior muscle. A comparison of P, where the fascia and the bundles of tissue binding the muscle meet with M showed a relationship such that the larger the joint angle, the farther right the position of P moved. Figure 4 shows the relationship between the change in the angle of the ankle-joint and the corresponding displacement of P. A significant positive relationship betwen the angle and displacement ($r = 0.768$, $P < 0.01$) was observed, indicating that, in any of the subjects, the larger the change in angle of the ankle-joint, the greater the displacement of P. Figure 5 shows the relationship between the angular speed of leg joints and the corresponding rate of displacement in P. A significant positive relationship ($r = 0.824$, $P < 0.01$) was also observed here.

Figure 6 shows examples of reproducibility of both the relationship between the change in the angle of the ankle-joint and the amount of displacement in P and between angular speed of the ankle-joint and the displacement rate of P. This figure shows both the most reproducible test (upper 2 panels) and the least reproducible test (lower 2 panels). These are quite similar indicating the excellent reproducibility of both relationships. None of the results of any subject showed a significant difference when comparing the two regression parameters.

Discussion

According to recent ultrasound studies (Henriksson-Larsen et al. 1992; Rutherford and Jones 1992) designed to identify noninvasively the direction in which muscle fibres run, the angle betwen the echoes considered to be the ultrasound reflection waves from the fascia and those from the tissue binding the muscle bundles has been assumed to be the angle at which muscle fibres run. This was checked for reproducibility of measurements and with the results of measurement using a cadaver and was found to be excellent agreement. In the present study also, the reproducibility was tested using the same subject on a different day, and satisfactory results were obtained. We have also reviewed the reproducibility of measurements and combination with the results of actual measurement using a cadaver (Kawakami et al. 1993). Therefore, it may be assumed that the ultrasound image-shown displacement of P studied here indicated some positional information about muscle fibre contraction.

In this study, a significant relationship was obtained between the amount of change in the angles of the ankle-joint and the corresponding displacement of P as well as a relationship between the angular speed of leg joints and the corresponding rate of P displacement. These results indicated that a change in angle of the ankle-joint is regulated by muscle displacement (Henriksson-Larsen et al. 1992). A change of 10° in the ankle-joint corresponded to approximately a 5-mm displacement of the muscle (Fig. 4). The magnetic resonance imaging method and cadaver measurements of leg dorsiflexion have shown the moment arm to be 37 mm (Rugg et al. 1990) or 24 mm (Wickiewicz et al. 1984). Using these values, the displacement of the muscle attachment point due to a change of 10° in the ankle joint can be geometrically determined to be 4.2 or 6.5 mm. Considering that the length of the moment arm differs among individuals, the results of this study may well be within acceptable limits.

We found a high correlation between the muscle displacement and the change of ankle joint ($r=768$, $P<0.01$). It might therefore be suggested that an estimate of the displacement of muscle could be effected by the measurement of the ankle-joint angle.

In conclusion, these results would seem to suggest not only that the movement of point P by real-time ultrasonography gives information on changes in muscle fibre orientation due to muscle concentration, but also that the amount of change in the angle of the ankle joint is regulated by the displacement of muscle.

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