IN VIVO ESTIMATION OF HUMAN ACHILLES TENDON MOMENT ARM
BASED ON ULTRASONOGRAPHY

Yasuo Kawakami¹, Keiko Nakai¹, Constantinos N. Maganaris²,
Toshiaki Oda¹, Kentaro Chino¹, and Tetsuo Fukunaga¹

¹Department of Life Science, University of Tokyo, Japan
²Department of Sport and Exercise Science, Manchester Metropolitan University, UK
E-mail: kawakami@idaten.c.u-tokyo.ac.jp

INTRODUCTION

Recent studies have attempted estimation of moment arm (the distance between joint center of rotation and muscle line of action) for in vivo human muscles, by two-dimensional morphometrics using X-ray or MRI (Marshall et al. 1990; Rugg et al. 1990) and tendon travels using ultrasound (Ito et al. 2000; Maganaris et al. 2000). The latter method overcomes the uncertainty of determining joint center of rotation inherent in the former method, and can take a functional aspect of muscles into consideration. However, the major drawback of this method is a possible error of tendinous movement determination due to concurrent occurrence of tendon elongation (Maganaris et al. 2000). Here we propose a novel approach to take advantage of this tendon elongation for moment arm estimation.

METHODS

The relationship between joint moment (M), moment arm (r), and muscle force (F) is expressed as

\[ M = rF \]

If we assume constant moment arms at different muscle force levels, then

\[ \Delta M = r \Delta F \]

The elongation of tendinous tissues (\( \Delta L \)) is a function of muscle force, i.e.

\[ \Delta F = k \Delta L \]

where \( k \) is stiffness of the tendinous tissues at a linear region of the length-force curve where tendon elongation is linearly related to applied force. It thus follows that

\[ \Delta M = rk \Delta L \]

\[ r = \frac{\Delta M}{k \Delta L} \]

Consequently, the moment arm is a linear function of the ratio of changes in muscle force and tendon length. Therefore, once we obtain this ratio for different joint positions, we can estimate the relative moment arms for those positions.

We applied this procedure to human Achilles tendon moment arm estimation in vivo. Subjects were six healthy men (23-46 yr, 172 ± 4 cm, 67 ± 8 kg, means ± SD). The subject lay prone with the knees fully extended, and the right foot was secured to a foot plate of an electrical myometer with the ankle joint set either at -15, 0, 15, and 30° (0°: anatomical position, positive values for plantar flexion). At each ankle position, the subject performed constant-level, submaximal and maximal plantar flexions isometrically. The torque levels were selected so that they were scattered over the whole range of torque from rest to maximal voluntary contraction. During contraction, B-mode real-time ultrasonogram (Aloka, Japan) was obtained for the distal attachment site of the gastrocnemius muscle fibers onto the Achilles tendon. At each ankle position, the attachment site moved proximally as the torque level increased, which was regarded as elongation of the Achilles
tendon. From the relationships between Achilles tendon elongation and torque at four ankle positions (Fig. 1), the linear regions were determined and slopes (torque / elongation) over these regions were calculated, and values relative to that of 0° were obtained. The absolute moment arm at 0° was derived from the length change of the whole gastrocnemius muscle-tendon unit (determined by 3D ultrasonogram, Aloka, Japan) for an angle change of 15° arc around 0°, from which, absolute moment arms at other positions were estimated.

RESULTS AND DISCUSSION

Moment arms varied from 2.3 ± 0.7 to 4.1 ± 0.9 cm, and peaked at 0° (Fig. 2). These values were slightly smaller than, and the changes with respect to ankle positions were different from, those reported previously using MRI morphometrics (Rugg et al. 1990). These results might be related to the possible error in determination of joint center in the previous study, since the present values were similar (both for absolute values and their variations for ankle joint positions) to the measurements on cadaver specimens using the tendon travel method (Spoor et al. 1990). However, the present method might also have sources of errors inherent in the assumptions. For example, the moment arm can increase by muscle contraction (Ito et al. 2000; Maganaris et al. 2000) although we assumed constant moment arms at different torque levels. The contribution of other muscles than the gastrocnemius to plantar flexion torque might change at different ankle positions, as pointed out by Kawakami et al. (2000). These concerns should be clarified in further studies.

Muscle force estimation from joint moment relies greatly on the accuracy of moment arms. Considering anatomical variations, in vivo determination of moment arms as proposed in this study should be done for each individual.

REFERENCES