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Journal of Electromyography and Kinesiology xxx (2008) xxx–xxx

JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY

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Effects of knee joint angle on the fascicle behavior of the gastrocnemius muscle during eccentric plantar flexions

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Received 29 January 2008; received in revised form 18 April 2008; accepted 29 May 2008

Abstract

The present study aimed to clarify the effects of knee joint angle on the behavior of the medial gastrocnemius muscle (MG) fascicles during eccentric plantar flexions. Eight male subjects performed maximal eccentric plantar flexions at two knee positions [fully extended (K0) and 90° flexed (K90)]. The eccentric actions were preceded by static plantar flexion at a 30° plantar flexed position and then the ankle joint was forcibly dorsiflexed to 15° of dorsiflexion with an isokinetic dynamometer at 30°/s and 150°/s. Tendon force was calculated by dividing the plantar flexion torque by the estimated moment arm of the Achilles tendon. The MG fascicle length was determined with ultrasonography. The tendon forces during eccentric plantar flexions were influenced by the knee joint angle, but not by the angular velocity. The MG fascicle lengths were elongated as the ankle was dorsiflexed in K0, but in K90 they were almost constant despite the identical range of ankle joint motion. These results suggested that MG fascicle behavior during eccentric actions was markedly affected by the knee joint angle. The difference in the fascicle behavior between K0 and K90 could be attributed to the non-linear force–length relations and/or to the slackness of tendinous tissues.

Keywords: Achilles tendon force; Tendinous tissues; Ultrasonography

1. Introduction

Length changes of muscle fibers (fascicles) have been shown to be not always the same as those of a muscle–tendon complex (MTC) due to the elasticity of tendinous tissues (external tendon and aponeurosis) (Griffiths, 1991; Fukunaga et al., 2001; Kawakami et al., 2002). Since the force generating potential of a fascicle is dependent on its length (Gordon et al., 1966) and velocity (Hill, 1938), earlier studies have focused on the fascicle behavior of major exercising muscles in various movements such as walking (Fukunaga et al., 2001; Ishikawa et al., 2005), running (Ishikawa et al., 2007; Lichtwark et al., 2007) and jumping (Kurokawa et al., 2001, 2003; Sousa et al., 2007).

In the previous studies cited above, length changes of the fascicles have been demonstrated to be different between synergists [medial gastrocnemius (MG) and soleus (SOL)] during the lengthening phase of MTC in walking (Ishikawa et al., 2005) and drop jumping (Sousa et al., 2007). For example, during the late-stance phase of walking, MG fascicle was maintained at a near-constant length, while SOL fascicle was elongated (Ishikawa et al., 2005). The different fascicle behavior between MG and SOL may be related to the anatomical difference; i.e., MG crosses the knee and ankle joints, but SOL crosses only the ankle joint. Actually, Kawakami et al. (1998) have reported that the shortening of MG fascicles during maximal static plantar flexions is decreased at flexed knee positions, whereas that of SOL fascicles is similar at different knee joint positions. In addition, our recent study has demonstrated that the length and shortening velocity of MG

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1050-6411/$ - see front matter
doi:10.1016/j.jelekin.2008.05.008

Please cite this article in press as: Wakahara T et al., Effects of knee joint angle on the fascicle behavior of the ..., J Electromyogr Kinesiol (2008), doi:10.1016/j.jelekin.2008.05.008

fascicle during maximal concentric plantar flexions are markedly influenced by the knee joint angle, despite identical ankle joint actions (Wakahara et al., 2007). However, it is unclear whether the MG fascicle behavior during eccentric plantar flexions is affected by the knee joint angle.

It has been shown that the plantar flexion torque (Herzog et al., 1991; Cresswell et al., 1995; Pinniger et al., 2000; Kawakami et al., 1998; Maganaris, 2003) and Achilles tendon force (Arndt et al., 1998) during maximal static plantar flexions are smaller at the flexed knee position than at the extended position. If the Achilles tendon force during eccentric actions is also reduced by knee flexion, this change will affect MG fascicle behavior, because the tendinous tissues are lengthened with applied force (Trestik and Lieber, 1993). On the other hand, the force during eccentric actions has been shown to be less influenced by changes in the velocity as compared with that during concentric actions (Westing et al., 1990; Reeves and Narici, 2003). Hence, the velocity of eccentric actions may not have a substantial effect on the fascicle behavior.

The purpose of the study is to investigate the effects of knee joint angle on the fascicle behavior of MG during eccentric plantar flexions. We hypothesized that the length changes in the MG fascicle during eccentric actions are influenced by the knee joint angle, but not by the angular velocity.

2. Methods

2.1. Subjects

Eight healthy men [age, 25.6 yrs (SD 3.0); height, 172.9 cm (SD 6.2); and body mass, 66.9 kg (SD 7.3)] voluntarily participated in the present study. Written informed consent was obtained from each subject. This study was in accordance with the Declaration of Helsinki and approved by the Human Research Ethics Committee in the Faculty of Sport Sciences, Waseda University. The subjects were highly motivated and had previously attended the laboratory on at least one occasion to become familiarized with the testing procedures.

2.2. Experimental protocols

The subjects lay prone on a bench of an isokinetic dynamometer (CON-TREX, CMV AG, Switzerland) with the knee fully extended (K0) and 90° flexed (K90) (Fig. 1). In K0, the trunk was tightly fastened to the bench with belts. In K90, wooden blocks were placed in front of the thigh to prevent knee joint movements. The rotation axis of the right ankle was aligned with that of the dynamometer, and the foot was firmly strapped to a footplate. After a warming-up period, maximal voluntary static and eccentric plantar flexions were performed at each of the two knee joint positions mentioned above in a randomized order. The ankle joint angle in the static action was set at slightly dorsiflexed position (−10° to −3°) from the anatomical neutral position (0°), so that it would reach 0° at the time of peak torque, since the plantar flexion torque causes some ankle joint displacements (Muramatsu et al., 2001; Karamanidis et al., 2005). The extent of dorsiflexion was previously determined for each subject in the familiarization session. Indeed, angular displacements of 9.8° (SD 3.4) and 3.9° (SD 1.9) occurred in K0 and K90, respectively. As a result, the ankle joint angles measured by a goniometer were 0.1° (SD 3.4) in K0 and −0.4° (SD 2.2) in K90 at the time of peak tendon force. In the eccentric actions, the range of ankle joint motion was from 30° (plantar flexion) to −15° (dorsiflexion). However, the ankle joint angles did not reach −15° due to heel lift from the footplate during maximal plantar flexions. The angular velocities of the ankle were set at 30°/s (slow) and 150°/s (fast). Eccentric actions were preceded by about 2 s of static phase with the ankle at 30°. The subjects were instructed to sustain their maximal effort from the static phase to the end of the movement. Two trials were conducted for each action, and a 2-min rest period was provided between the trials. In each of the test conditions, the trial with the greater peak torque was chosen for subsequent analyses. In K0, the maximal voluntary static dorsiflexion was performed at ankle angle of 0°.

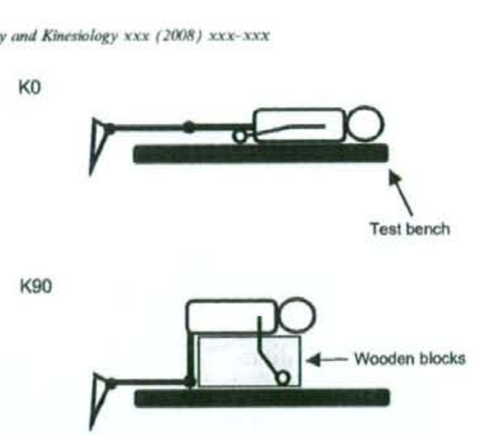

Fig. 1. Schematic illustrations of the two testing positions. The subjects performed static and eccentric plantar flexions with the knee fully extended (K0, upper) or 90° flexed (K90, lower).

2.3. Torque and joint angle measurements

Plantar flexion torque was measured with the dynamometer. The ankle and knee joint angles were determined with electrical goniometers (ankle joint, SG110/A; knee joint, SG150; Biometrics, UK). Torque and joint angle signals were sampled at 2 kHz using a 16-bit A/D converter (PowerLab/16SP, ADInstruments, Australia) and stored on a computer. These data were processed by using a low-pass filter (Butterworth type fourth-order zero-lag filter) with a cutoff frequency of 17 Hz to reduce high-frequency noise. The cutoff frequency was determined by a

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residual analysis (Winter, 1990). The torque produced by the weight of the attachment was subtracted from the measured torque to compensate for gravity. Tendon force was computed by dividing the plantar flexion torque by the moment arm of the Achilles tendon. The moment arm was estimated as the first derivative of the length change in MG MTC, which was derived from a previous report (Grieve et al., 1978), with respect to ankle joint angle (radians). The equation for estimating the length change of MG MTC is as follows:

$$\begin{aligned}\Delta L = {} & 0.30141(90-\theta_a) - 0.00061(90-\theta_a)^2 - 0.07987\theta_k \\ & + 0.00011\theta_k^2 - 15.72217\end{aligned}$$

where ΔL (%) is the length change of MG MTC relative to the lower leg length of each subject, θ_a (°) is the ankle joint angle and θ_k (°) is the knee joint angle.

2.4. Ultrasonographic measurements

Longitudinal sectional images of MG were obtained using a B-mode ultrasound apparatus (SSD-6500, Aloka, Japan) with a linear-array probe (10 MHz wave frequency, UST-5712, Aloka, Japan) (Fig. 2). The field of view of the ultrasound image was 60 × 60 mm. Since the fascicle length during eccentric actions was not so long (Fig. 1), almost all the length of fascicle was visualized in the image. The probe was placed over the midbelly of MG and fixed to the skin using elastic tapes. Ultrasound images were stored on computer memory of the apparatus at 36 Hz in the static and slow eccentric actions, and at 96 Hz in the fast eccentric actions. An electrical signal was superimposed on the images to synchronize them with other data [torque, angle and electromyogram (EMG)]. The MG fascicle length was measured as the distance between the intersection points of fascicle and aponeuroses. The pennation angle was determined as the angle between fascicle and deep aponeurosis. The length and pennation angle of one fascicle were manually measured on each frame using an image processing program (ImageJ, National Institute of Health, USA). The measurements were performed two times for each frame, and the mean values were used for further analyses. The data extracted at nearest 10° of ankle joint angle were indicated in the figures and used for statistics. The coefficients of variation of the two measurements were less than 3.6% and 5.5% for fascicle length and pennation angle, respectively. The intraclass correlation coefficients of the measurements were more than 0.962 and 0.939 for fascicle length and pennation angle, respectively.

Length changes of the tendinous tissues from the static phase were obtained by subtracting changes in the horizontal component of the fascicle length (fascicle length × cosine of the pennation angle) from the changes in MTC length (Fukunaga et al., 2001).

2.5. EMG recordings

Surface EMGs were recorded from the MG, lateral gastrocnemius (LG), SOL and tibialis anterior (TA) muscles. After careful preparation of the skin, pairs of Ag/AgCl electrodes (Blue Sensor P-00-S, Ambu A/S, Denmark, measuring area: 154 mm^2) were placed over the belly of each muscle with an inter-electrode distance of 20 mm. Whereas the electrodes for MG were close to the ultrasound probe, the EMG signal recorded was not affected by this configuration. A reference electrode was placed on the medial malleolus of the left foot. The EMG signals were collected telemetrically (WEB-5000, NIHON KOHDEN, Japan; input impedance > 10 MΩ, common mode rejection ratio > 80 dB, time constant: 0.03 s, hi-cut filter: off) with a sampling frequency of 2 kHz. After full-wave rectification, EMGs were averaged during a 0.5-s period

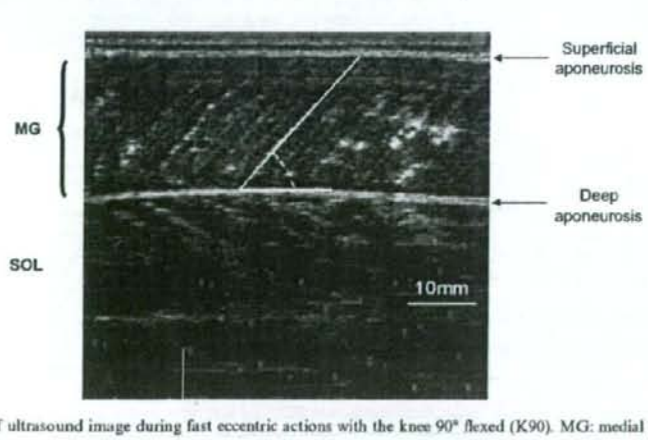

Fig. 2. A typical example of ultrasound image during fast eccentric actions with the knee 90° flexed (K90). MG: medial gastrocnemius, SOL: soleus.

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around the peak tendon force for the static actions, and over the entire range of motion for the eccentric actions, respectively.

2.6. Statistics

A three-way ANOVA (2 knee joint angles × 4 ankle joint angles × 2 angular velocities for the tendon force, fascicle length and pennation angle; 2 knee joint angles × 3 ankle joint angles × 2 angular velocities for the elongation of tendinous tissues) with repeated measures was used to determine the effects of the knee joint angle, ankle joint angle and angular velocity of the ankle. For the tendon force at an ankle angle of 0° and EMGs, a two-way ANOVA (2 knee joint angles × 3 angular velocities, in which the static action was included as 0°/s) with repeated measures was used to test the effects of the knee joint angle and angular velocity. The ANOVAs were followed by Tukey's post hoc tests. Statistical significance was set at $P < 0.05$. All the analyses were performed with a statistical software (SPSS 12.0J).

3. Results

The three-way ANOVA revealed that the knee and ankle joint angles had a main effect on the tendon force ($P < 0.01$), although the angular velocity did not (Fig. 3). An interaction between knee and ankle joint angles ($P < 0.05$) indicated that the tendon forces were not different between knee joint angles at the ankle angle of 30°, but were higher in K0 than in K90 at 0°, 10° and 20°. Also, an interaction between ankle joint angle and angular velocity ($P < 0.05$) indicated that the tendon forces were higher in the slow eccentric actions than in the fast eccentric actions at 0° in K0, whereas tendon forces at the other ankle joint angles were not different between angular velocities. The two-way ANOVA demonstrated that the tendon force at the ankle angle of 0° was decreased in K90 than in K0 ($P < 0.01$), but not affected by angular velocity with no interaction (Table 1).

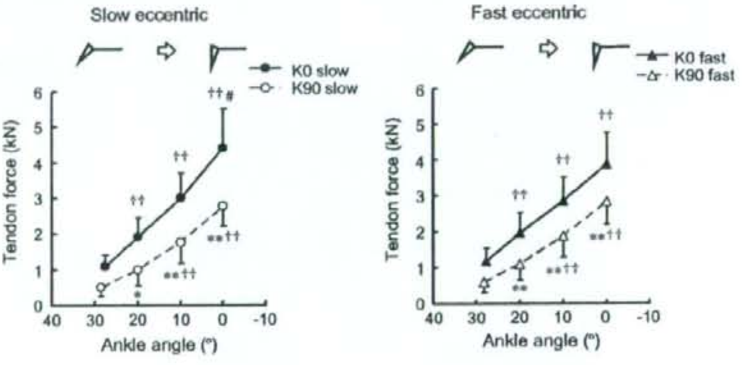
Table 1
Tendon force at the ankle angle of 0° and EMG amplitude of each muscle

		Static	Slow eccentric	Fast eccentric	
Tendon force (kN)	K0	4.5 ± 1.2	4.4 ± 1.1	3.7 ± 0.8	*
	K90	3.0 ± 0.7	2.8 ± 0.6	2.7 ± 0.6	
EMG amplitude (mV)					
MG	K0	0.21 ± 0.07	0.18 ± 0.05	0.17 ± 0.04	*
	K90	0.13 ± 0.03	0.12 ± 0.04	0.13 ± 0.03	
LG	K0	0.23 ± 0.14	0.19 ± 0.09	0.19 ± 0.08	*
	K90	0.15 ± 0.08	0.15 ± 0.07	0.15 ± 0.06	
SOL	K0	0.20 ± 0.09	0.14 ± 0.05	0.13 ± 0.04	
	K90	0.16 ± 0.04	0.15 ± 0.03	0.17 ± 0.06	
TA	K0	0.05 ± 0.05	0.03 ± 0.01	0.03 ± 0.01	
	K90	0.04 ± 0.05	0.02 ± 0.01	0.03 ± 0.01	

Values are means and SDs.

[*] Significant main effect of knee joint angle.

The MG fascicle length and pennation angle during the eccentric actions were presented in Fig. 4. The behavior of fascicle was markedly different between K0 and K90. This result was surprising because the ankle joint actions were the same for these positions. The fascicle length and pennation angle were affected by knee and ankle joint angles ($P < 0.01$). However, no main effect of angular velocity was found on either of the fascicle length or pennation angle. There was a significant interaction between knee and ankle joint angles ($P < 0.01$), indicating that the



* and ** denote significant difference between knee joint angles at P < 0.05 and P < 0.01, respectively.

†† denotes significant difference from ankle joint angle at 30° at P < 0.01.

# denotes significant difference between angular velocities at P < 0.05.

Fig. 3. Means and standard deviations (SDs) of the tendon forces during slow (left) and fast (right) eccentric actions. Closed and open symbols show data at the knee joint angle of 0° (K0) and 90° (K90), respectively.

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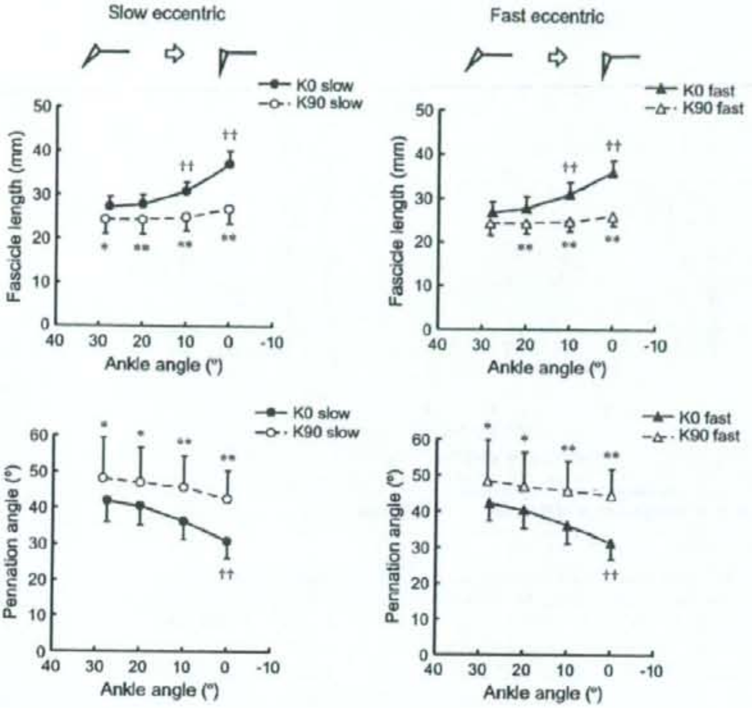

* and ** denote significant difference between knee joint angles at $P < 0.05$ and $P < 0.01$, respectively.
†† denotes significant difference from ankle joint angle at 30° at $P < 0.01$

Fig. 4. Means and standard deviations (SDs) of the fascicle lengths (upper) and pennation angles (lower) of MG during slow (left) and fast (right) eccentric actions. Closed and open symbols denote data at the knee joint angle of 0° (K0) and 90° (K90), respectively.

fascicle lengths and pennation angles in K0 were elongated and decreased with the ankle dorsiflexed, respectively, while those in K90 did not show any difference among the ankle joint angles.

The elongation of MG tendinous tissues during the eccentric actions was influenced by knee and ankle joint angles ($P < 0.01$) (Fig. 5). The angular velocity did not have an effect on the tendinous tissue elongation. An interaction between knee and ankle joint angles ($P < 0.01$) indicated that the tendinous tissue elongations were not different between knee angles at the ankle angle of 20°, whereas those at 0° and 10° were less in K0 as compared with K90 ($P < 0.01$).

The mean EMGs of MG ($P < 0.01$) and LG ($P < 0.05$) were higher in K0 than in K90, but were not affected by angular velocity with no interaction (Table 1). On the other hand, neither the knee joint angle nor the angular velocity had an effect on SOL EMGs. The mean EMGs of TA were not different between knee joint angles. The relative values of TA EMGs to those during maximal dorsiflexion were 10.2% (SD 3.5) and 9.5% (SD 2.9) in slow and fast eccentric actions in K0, and 7.4% (SD 2.7) and 8.3% (SD 3.1) in slow and fast eccentric actions in K90, respectively.

4. Discussion

The present results support the hypothesis that the length change in MG fascicle during eccentric actions is influenced by knee joint angles, but not by angular velocities. In K0, the MG fascicle length was elongated as the ankle was dorsiflexed, but it was almost constant in K90 (Fig. 4). The results essentially agree with our recent report (Wakahara et al., 2007), in which the effects of knee joint angle on the MG fascicle behavior during concentric actions were investigated. Namely, the length change (velocity) of MG fascicle was less at the flexed knee position than at the extended position. The present study clarified that, not only in maximal concentric but also in eccentric plantar flexions, knee joint positions greatly influenced the fascicle behavior of MG. Our findings suggest that the angles of each joint that the bi-articular muscle crosses have complex effects on its fascicle behavior. The

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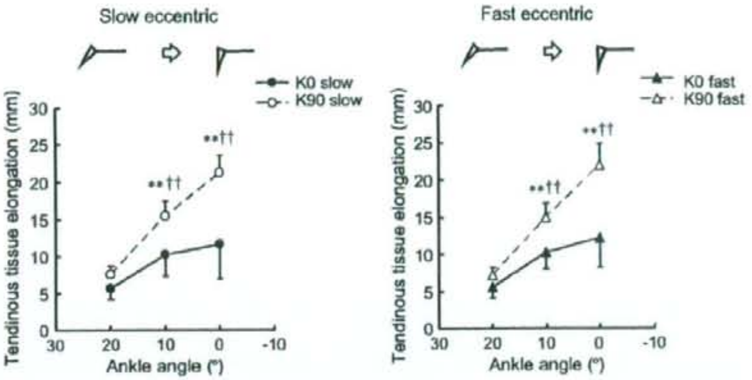

** denotes significant difference between knee joint angles at P < 0.01.
†† denotes significant difference from ankle joint angle at 20° at P < 0.01.

Fig. 5. Means and standard deviations (SDs) of the tendinous tissue elongations during slow (left) and fast (right) eccentric actions. Closed and open symbols denote data at the knee joint angle of 0° (K0) and 90° (K90), respectively.

effects would have to be taken into account to properly understand the mechanics of bi-articular muscle during multi-joint movements.

The tendon forces during the eccentric actions were lower in K90 than in K0 (Fig. 3). Both MG and LG cross the knee joint, but the physiological cross-sectional area of LG is only about 40% of that of MG (Fukunaga et al., 1992). Hence, the decrease of tendon force with knee flexion is mainly attributable to the lower force of MG in K90 according to the following three factors; (1) fascicle length, (2) pennation angle and (3) activation levels. Firstly, MG fascicle lengths were shorter in K90 as compared to K0 (Fig. 4). These length ranges corresponded to the ascending limb of the length–force relation of MG fascicle for both knee positions, on the assumptions that the number of sarcomeres in series within MG fascicle is 17,600 (Huijing, 1985), and that the optimal length of the human sarcomere ranges from 2.64 to 2.81 μm (Walker and Schrodt, 1974). Thus, it is most likely that the shorter MG fascicle in K90 had lower potential for generating force than in K0. Secondly, the pennation angles of MG were different between knee positions throughout the range of motion (Fig. 4). The higher pennation angles in K90 reduced the force transmitted to the tendinous tissues. Thirdly, the MG EMGs were lower in K90 than those in K0 (Table 1). Taken together, it is reasonable to assume that the lower tendon forces in K90 compared to K0 would be due to the decrease in the force exerted by MG.

During eccentric plantar flexions, the amount of lengthening in MG fascicle was different between K0 and K90 (Fig. 4), despite the identical range of ankle motion. In K90, the fascicle behaved almost isometrically. A possible explanation for this phenomenon is the non-linear force–length relations of tendinous tissues, because the tendinous tissues are more compliant at low force levels and gradually become stiffer as applied force increases (Trestik and Lieber, 1993). The force developed by MG was reduced with knee flexion, and thus a slight increase in the force would result in the greater deformation of compliant tendinous tissues in K90. On the other hand, it is possible that higher levels of force in K0 limited the tendinous tissue elongation, and consequently the fascicle was lengthened. Unfortunately, we could not demonstrate the force–length relation of MG tendinous tissues from present data, because the tendon force included the force produced by the antagonists and agonists other than MG. Another explanation is that the slackness of tendinous tissues was not fully taken up by the force during the pre-static phase in K90. Although the plantar flexion task was performed with maximal effort, if the fascicles of MG are close to their active slack length, a greater amount of slack could not be removed at the extremely shortened MTC length. In any case, the considerable length changes in the tendinous tissues in K90 would be related to their mechanical properties at smaller force levels.

The angular velocity of eccentric actions did not affect the behavior of fascicle (Fig. 4) and tendinous tissues (Fig. 5). It has been suggested that the tendinous tissue elongation is partly dependent on the strain rate (Hubbard and Soutas-Little, 1984; Danto and Woo, 1993), because of their viscoelastic properties. In addition, animal experiments have shown that the eccentric force increases up to 1.7–2.0 times as high as static force with increasing lengthening velocity (Lombardi and Piazzesi, 1990; Krylow and Sandercock, 1997). These findings imply that the angular velocity of eccentric actions influences the length changes of fascicle and tendinous tissues. However, the effects of strain rate on the tendinous tissue elongation are still

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controversial (Wren et al., 2001). Some studies (Hubbard and Soutas-Little, 1984; Danto and Woo, 1993) found significant effects of strain rate on the elastic modulus of tendinous tissues, while others (Herrick et al., 1978; Ker, 1981; Wren et al., 2001) did not. On the other hand, the increment of eccentric force with angular velocity has been reported to be of a minor degree, if any, when the action is performed with volitional effort (Dudley et al., 1990; Westing et al., 1990). Indeed, the present results indicated that the tendon forces were not altered with angular velocities (Fig. 3). Therefore, similar tendon forces would have resulted in the analogous behavior of fascicle and tendinous tissues between the slow and fast eccentric actions.

The tendon force calculated in the present study could be affected by the activity of antagonists and agonists other than MG. The EMG activities of TA during the eccentric plantar flexions were low as compared with those during maximal dorsiflexion and were not different between knee joint positions. Hence, the force exerted by TA would not have a significant effect on the present results. The EMGs of mono-articular SOL, which has the largest physiological cross-sectional area among the plantar flexors (Fukunaga et al., 1992), were not influenced by knee joint angles (Table 1). This suggests that the contribution of SOL to the tendon force was not substantially different between the two knee joint positions. On the other hand, SOL forms a common tendon with the gastrocnemius muscles (Bojsen-Moller et al., 2004). Since the elongation of MG tendinous tissues were different between the extended and flexed knee positions (Fig. 5), the length and velocity of SOL fascicles may also be altered by knee joint angles. Further studies that examine the behavior of SOL fascicles are necessary to fully understand the relation between the MG fascicle behavior at different knee positions and mechanical outputs.

In the present study, the fascicles were traced on the assumptions that these are straight and behave homogeneously within their muscle belly. Muramatsu et al. (2002) have determined curvature of MG fascicle in vivo using ultrasonography. They showed that measurement of fascicle length by a straight line led to an underestimation by ~6%, which is corresponding to 1–2 mm in the present study. On the other hand, MG fascicle lengths and pennation angles at different sites were examined at rest and during static actions by Maganaris et al. (1998) and Kawakami et al. (2000). In both studies, the fascicle lengths were similar within the muscle belly. The pennation angles were homogeneous (Maganaris et al., 1998) and inhomogeneous (Kawakami et al., 2000) among measured sites. Also, Lichtwark et al. (2007) have reported that the MG fascicle lengths and pennation angles measured at three different sites changed in a similar way during walking and running. Taken together, the assumptions of linearity and homogeneity of MG fascicles would not have a substantial effect on our results.

In conclusion, the present study showed that knee joint angles and corresponding differences in the force have an influence on the MG fascicle behavior during maximal eccentric plantar flexions. The results were probably due to the non-linear force–length relations and/or the slackness of tendinous tissues.

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練馬区－早稲田大学　共同研究プロジェクト

メタボリックシンドローム対策・予防を目的に、

『歩く』を増やすお手伝い！

通信ウォーキングプログラム

参加者募集

メタボリック
シンドローム気味の
中年男性、
夫婦での参加は
大歓迎

募集要項

■内容

メタボリックシンドローム対策が叫ばれるなか、多くの人々にとって、特別に時間を割いて運動を行うこと、また「辛い」思いをしながら頑張り続けることはきわめて難しいことです。本研究プロジェクトでは、3ヵ月間、提供された歩数計、ウォーキング冊子、その他の資料を使って、日常生活において「歩く」を中心とする身体活動量をご自分で増加させていくことを目指して私たちが「お手伝い」を行います。

■募集対象者

- 20歳～65歳までの練馬区在住・在勤の方
- 運動習慣がなく、現在、運動不足気味である、また将来の健康に不安を感じている方
- 本年4月18日（土）から7月18日（土）までの約3ヵ月の間、本研究プロジェクトに参加でき、質問紙やモニタリングシートの郵送など、本研究プロジェクトの課題に協力できる方
- 4月18日（土）午前中に練馬区役所多目的会議室で開催する説明会に参加できる方（代理出席も可）

※現在、慢性疾患、生活習慣病などの疾患を保持しているために運動を禁止されている方は対象外

■日程

申込方法・問い合わせ先　3月1日（日）～4月5日（日）

申し込みに際しては、実施要領および質問調査を早稲田大学応用健康科学研究室ホームページ（http://takenaka-waseda.jp/）から直接閲覧、または04-2947-6874に郵便番号、住所、氏名を記入してファックスにて請求し、所定の質問回答用紙および申込書をそえて郵送にてお申し込みください。

決定通知

募集条件を満たす方の中から抽選で90名を決定し、4月7日（火）までに郵送で通知します。

プログラムのスケジュール

4月18日（土）	開始式、説明会（必ず参加すること、代理も可） ウォーキング冊子、セルフモニタリングシート、歩数計（3ヵ月継続者にはそのまま進呈）を配布し、プログラムの説明、採血（希望者のみ）を行います。
プログラムの実践	セルフモニタリングシート（歩数記録表）への記入および郵送いただきながら自身で実践してもらいます。
7月18日（土）修了式	修了証の配布、聞き取り調査（個人の成果については後日通知）

健康づくり講演会

3月15日（日）午前・・・健康づくり講演会　練馬区役所交流会場
4月　5日（日）午前・・・健康づくり講演会　練馬区役所多目的会議室

主催：早稲田大学応用健康科学研究室
共催：練馬区

※本プログラムは特定保健指導とは異なります。

練馬区－早稲田大学　共同研究プロジェクト

通信ウォーキングプログラム

スモールチェンジ

早稲田大学応用健康科学研究室

contents

わかっちゃいるけどねえ・・・

竹中 晃二
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本冊子は、皆さんにウォーキングという行動を始め、継続してもらうための「道具」として使ってもらうものです。運動すると生活習慣病予防になる、メタボの解消になる、最近太り過ぎなので運動しないと、と多くの人が考えています。また世間では、はやりの ×× 運動、×× エクササイズをすればこんなによい効果があるというように、ダイエット法と同じくらい運動を勧める情報が溢れています。しかし、皆さんは、運動が健康によいということをわかっちゃいるけど、なかなか始めることができません。また、簡単に始めたとしてもしばらくすると止めてしまいます。その理由はなぜでしょうか。

●「やる」か「やらない」かという 2 者択一の考えが始めることを妨げている

私たちは運動を行おうと考える場合、「やる」か「やらない」かの「イチかゼロかモード」で考えてしまいがちです。仕事が忙しい、時間がない、自信がない。こういう状況では、「やる」という敷居があまりにも高いために開始することもままなりません。まずは「始める」ことに集中し、「何もやらないよりはわずかなことでもやった方が健康づくりにつながる」という考えを持つことが重要です。本冊子では、いきなり運動を行うというよりは、いつもより少し余分に歩いてみる、通勤でいつも通る階段を 1 つだけ上ってみる、少し速めに歩いてみる、夫婦で会話しながら歩いてみるなど、「やる」という敷居を低くして、まずは日常生活の様々な状況の中で「歩く」という活動を増やしていくことを勧めています。

● 健康づくりはもともと「続かない」

どのような健康行動でもそうですが、動機づけの高さや意志の力が強いのは始める時だけで、数ヵ月、数年も継続し続けることはきわめて難しいことです。「続く」ということを前提にすれば、続かなければ自分は意志が弱い人間だと思ってしまいます。果たして皆さんは意志の弱い人なのでしょうか。そんなことは決してありません。おいしい物を食べないダイエットが永遠に続かないように、「やらなくっちゃ」という禁欲生活にはもともと無理があるのです。それよりも、運動はもともと「続かない」と考えて、続けるための工夫を行うことの方が大事なことです。たとえば、歩数など記録することで行動実践の拘束力は増し、目標を達成すれば友人と食事をするなど自分にご褒美を与える、目につくところにウォーキングシューズを置いておく、時間・場所を一定に決めることで継続しやすくなります。また、せっかく身に付けたウォーキングの習慣が悪天候や残業などで少しずつ遠ざかることはよくあることです。そのため、あらかじめどういう状況で逆戻りが起こりやすいのかを考えておき、その時や状況に「備える」ことが逆戻りの予防となります。

本冊子は、皆さんが楽しみながらウォーキングを行っていけるように、いろいろな仕掛けを考えています。いくら効果が期待できるウォーキングであったとしても続かなければ効果は得られません。つまり、継続なくして健康行動の成果はあり得ません。さて、とぼとぼ歩きでもかまわないので、まずは「始める」ことから始めてみましょう。

1 本冊子の目的・使い方

現在、健康づくりに果たす運動の役割が注目されています。その背景には、交通手段の発達、あらゆる場所におけるエスカレーターやエレベーターの設置、労作業を軽減する機械の普及、さらにコンピューターを中心とする仕事や日常生活があるのです。1 日の大半を動かない、また座りっぱなしで過ごす生活が増加していくと1日のエネルギー消費量が低下し、循環器・筋・神経の活動も鈍るようになります。また、私たちは、座位中心の生活によって全体の身体活動量が減少しているにもかかわらず、一方では、高カロリー、高脂質の食品を手軽に食べることができるようになりました。そのため、現在では、肥満傾向になる人も多くなってきており、現代人においてメタボリックシンドロームや生活習慣病が大きな問題となっていることは皆さんもご存じのはずです。

皆さんは、「最近、お腹の周りが気になる」、「生活習慣病にならないようにしたい」、「痩せたい」などと思いつつ、しかし「やらなくっちゃ」という敷居の高さに負けて実行にうつすことができていません。本冊子では、誰にでも簡単に、しかも手軽に行うことができる「歩く」という行動の増強を推奨しています。

「健康のために運動を行う必要があることはわかってはいるけれど、運動は疲れるし、仕事が忙しいから時間が取れない」と思っていませんか。健康を維持するためには、たしかに運動を行う必要がありますが、特別に時間を取ってスポーツや運動を行わなくても日々の生活の中で身体活動量（生活活動量）を増やすだけで十分健康を維持することができます。ここで述べる身体活動とは、階段の上り下りや家事など身体の動きを包括し、日常生活におけるあらゆる身体活動を指します。もちろん、ウォーキングは、生活活動に含まれ、最もよい活動です。ウォーキングは、自分のペースで行うことができ、時間も 1 日に合計 30 分以上行うだけで十分であり、費用などもかからないのですぐに始められます。

この冊子では、まずはウォーキングの効果について簡単に紹介し、次に生活習慣病予防のためにどのくらい動いたらよいかを述べます。次にウォーキングを始めるにあたってメディカルチェックをしてもらいます。その後、簡単な質問に答えていただき、あなたにとって現在の身体活動量がどれくらいであるのかを測定します。この測定からあなたのこれからの目標を、1) もっと頻繁に歩こう、2) もっと長く歩こう、3) もっと速く歩こう、の3つのSTEPに分けてウォーキングを勧めています。あなたが今どのSTEPから始めたらよいのか、それぞれのSTEPに応じて週あたりにどのくらい歩いたらよいのか、続けるためにはどうしたらよいのかを提案をしていきます。STEP別の提案の他に、ウォーキングについての簡単な知識も添えてあります。

2 ウォーキングの効果

ウォーキングには様々な効果があります。以下にそのいくつかを紹介します。

■ 減量効果

ウォーキングを行うと脂肪がエネルギーとして使用されます。ウォーキングは、有酸素運動であり、この種の運動は脂肪を効果的に燃焼させることができます。

■ 生活習慣病の予防

ウォーキングを効果的に行うと肥満や運動不足が原因となる生活習慣病が予防できます。運動を継続すると血液の循環がよくなり、HDL（善玉）コレステロールが増え、動脈硬化が予防されます。

■ 心肺機能が高まる

ウォーキングを行うと心拍数が増加し、体内の酸素を取り込む能力が増大し、心臓や肺の機能が高まります。そのため、仕事や日常生活で疲れにくくなります。

■ 骨が強くなる

ウォーキングを行うと骨に刺激を与え、骨を強化することができます。歩くことは重力という負荷が骨にかかると同時に、骨にカルシウムが吸収されて丈夫になるといわれています。骨粗しょう症の予防にも効果的です。

■ 脳の活性化

ウォーキングを行うと脳に酸素を取り込み、そのことによって脳の働きを活発にすることができます。

■ 筋力の低下を防ぐ

ウォーキングを行うと筋肉に刺激を与え、足腰の筋力低下を防ぐことができます。

■ 血行がよくなる

ウォーキングを行うと血管が刺激されて血行がよくなります。

■ 持久力が高まる

ウォーキングを行うと持久力が高まり、疲れにくい身体をつくることができます。

■ ストレス解消に役立つ

適度な運動は、ストレスを解消するのに役立ちます。血液の循環がよくなり、脳が刺激され、自律神経のバランスがよくなります。

特にウォーキングでは、周りの景色を楽しみながら行え、友達や家族をを誘って一緒に話をしながら行えるので、一層、ストレス解消に役立ちます。

■ 不安、抑うつ気分を解消できる

長期的に行うことにより、不安や抑うつ気分を低減させることができます。

などなど、いつでも、どこでも、わずかな時間でも行える
ウォーキングには効果がいっぱい！

3 どのくらい動かないといけないのか？

健康づくりや生活習慣病予防のためには、どのくらい身体を動かす必要があるのでしょうか。平成 18 年 7 月に厚生労働省が発表した「エクササイズガイド 2006」には、日頃どのくらい身体を動かせばよいのかという身体活動量の目標が示されています。このガイドラインを簡単に紹介します。

身体活動量とは、日常生活において身体を動かす労働、家事、通勤･通学、趣味などの**「生活活動」**と体力の維持･向上などの意図を持って行う**「運動」**があります。

「エクササイズガイド2006」では、身体活動の強さと量を表す単位として、身体活動の強さについては**「メッツ」**を用い、量については「メッツ × 時間」とし、これを**「エクササイズ」**と呼んでいます。

①「メッツ」（強さの単位）

身体活動の強さを、安静時に比べて何倍に相当するかを表す単位です。座って安静にしている状態が1メッツ、歩行が3メッツに相当します。

②「エクササイズ (Ex)」（量の単位）　Ex= メッツ × 時間

身体活動の量を表す単位です。身体活動の強さ（メッツ）に身体活動の実施時間をかけたものです。

例）3メッツの身体活動を1時間行った場合：3メッツ × 1時間=3エクササイズ
6メッツの身体活動を30分行った場合：6メッツ×0.5時間=3エクササイズ

目標とは、生活習慣病予防のために必要な身体活動量、または運動量のことです。

1 週間に必要な身体活動量の目標：4＋19＝23 エクササイズ
（4 は運動、19 は生活活動）

内臓脂肪を減らしたい人は、週 23 エクササイズのうち、運動を 10 エクササイズ以上にすることが求められます。

運動習慣のない人は、週に 2 エクササイズから始めてみましょう。

1エクササイズに相当する活発な身体活動

厚生労働省「エクササイズガイド2006」から引用

ウォーキングにあてはめると…

エクササイズの目的身体活動量を歩数に換算すると、1日あたりおよそ8,000～10,000歩くらいになります。週に4エクササイズの運動は、6km/hほどの速さの速歩なら週に約60分に相当します。毎日60分と聞くと意外と多いと思われるかもしれませんが、一度に60分も歩かなくてもよいのです。30分を2回、15分を4回、10分を6回というように合計時間が一日に60分になるようにすれば、あなたにもできるような気がしてきませんか？

まずは、あなたの生活を振り返ってみて、どれくらい身体を動かしているかを確認しましょう。もしあなたの活動量が少ない場合は、すぐに23エクササイズを目指すのではなく、無理しない程度に少しずつ活動量を増やしていきましょう。

簡単に活動量を増やすことができる活動形態は、ウォーキングです。ウォーキングの特徴は、**いつでも、どこでも、特別な技術がいらない、お金がかからない、身体への負担が少ない、老若男女を問わない**でできることです。簡単に手軽にできるところがよいですね。