Three-dimensional determinations of the Achilles tendon moment arm and orientation of the talocrural joint axis, in vivo, during submaximal muscle contraction

1 Satoru Hashizume, 2Soichiro Iwanuma, 3Ryota Akagi, 4Hiroaki Kancheisa, 5Yasuok Kawakami, 5Toshimasa Yanai
1 Graduate School of Sport Sciences, Waseda University, 2Research Fellow of the Japan Society for the Promotion of Sciences
3Department of Sports Sciences, Japan Institute of Sports Sciences, 4National Institute of Fitness and Sports in KANOY,
5Faculty of Sport Sciences, Waseda University; email: s.h-strive-for@moegi.waseda.jp

SUMMARY

The purposes of this study were to determine the Achilles tendon moment arm and the orientation of the talocrural joint axis, in vivo, at rest and during muscle contraction in three-dimensions and to compare them between two conditions. At rest and during 60% maximal voluntary contraction (MVC) of plantar-flexor muscles, a series of coronal ankle images were obtained using a magnetic resonance imaging (MRI) at ankle joint angles of -10º (dorsiflexed position), 0º (neutral position), +10º (plantarflexed position). The talocrural joint axis was determined by rotation of the talus to the tibia from -10º to +10º of ankle joint angle. The Achilles tendon moment arm was determined as the shortest distance from the talocrural joint axis to the line of action of the Achilles tendon force at 0º of ankle joint angle projected to the orthogonal plane of the talocrural joint axis. The Achilles tendon moment arm determined for the 60% MVC condition was 4.8 cm and that determined for the rest condition was 4.0 cm. The Achilles tendon moment arm during 60% MVC was significantly greater by 0.8 cm (about 20%) from that at rest. This indicates that the muscle contraction of triceps surae influences the Achilles tendon moment arm and the relationship between the ankle joint motion and the function of the triceps surae muscle. On the transverse plane, the deviation between the talocrural joint axis and medial-lateral axes altered from 21.8º at rest to 8.1º during 60% MVC. It is one of the factors that increase the Achilles tendon moment arm increased with muscle contraction. Furthermore, this orientation change of the talocrural joint axis results in the orientation of the joint moment of the Achilles tendon force to change.

INTRODUCTION

A moment arm is defined as the shortest distance between the axis of rotation and the line of action of the force [1]. In a musculoskeletal system, a moment arm of a muscle force governs the relationship between the joint moment generated by the muscle force and the muscle force and between the joint rotation angle and length change of the muscle tendon unit [2]. A moment arm, therefore, is essential parameter for musculoskeletal model.

Traditionally, a two-dimensional method was applied to determine a moment arm on an anatomical plane [3]. A previous two-dimensional study [4] showed the Achilles tendon moment arm during muscle contraction was greater than that at rest. The reasons for the finding were listed as the displacement of the talocrural joint center of rotation (COR) and the changing orientation of the line of action of the Achilles tendon force due to the triceps surae muscle contraction. The displacement of the talocrural joint COR determined in two-dimensions indicates that the position and/or orientation of the talocrural joint rotation axis should be altered by the muscle contraction of the triceps surae. On the transverse view, the talocrural joint axis inclined to lateral-posterior direction [5]. The orientation change of the talocrural joint axis such as decreasing deviation between the talocrural joint axis and medial-lateral axis produces an increase in the Achilles tendon moment arm. Furthermore, this orientation change of the talocrural joint axis should result in the orientation of the joint moment of the Achilles tendon force to change.

Musculoskeletal models were widely used to understand human locomotion, to simulate orthopedic procedures and so on [6]. Because human joint motion occurs in three-dimensions, human locomotion also occurs in three-dimensions. The three-dimensional musculoskeletal model that accounts for the effect of muscle contraction is required to simulate human motion correctly. To construct such a model, the three dimensionally determined Achilles tendon moment arm and the orientation of the talocrural joint axis during muscle contraction are necessary. The purpose of this study, therefore, were to determine the Achilles tendon moment arm and the orientation of the talocrural joint axis, in vivo, at rest and during submaximal muscle contraction in three-dimensions and to compare them between two conditions. It is hypothesized that the deviation between the talocrural joint and the medial-lateral axes decreases with muscle contraction and it produces an increase in the Achilles tendon moment arm.

METHODS

Eight males (age: 26.4 ± 3.4 years, height: 171.3 ± 5.1 cm, body mass: 62.6 ± 7.4 kg) voluntary participated in this study. At rest and during 60% maximal voluntary contraction (MVC) of plantar-flexor muscles, a series of coronal ankle images were obtained using a magnetic resonance imaging (MRI) at ankle joint angles of -10º (dorsiflexed position), 0º (neutral position), +10º (plantarflexed position). All MRI scans were performed with the following scan parameters:
Fast gradient echo, 21.7 ms for time to echo, 1400 ms for repetition time, 3 mm of slice thickness, 0 mm of interspaced distance, 300 mm×300 mm of field of view, 256×256 pixels of matrix. The plantar flexion torque was measured by a custom made torque-meter constructed by non-magnetic materials and optic fibers, and the measured torque was displayed on a goggle type monitor to provide the subject with the visual feedback of the torque output.

The algorithm proposed by Spoor and Veldpous [7] was used to calculate the talocrural joint axis. The finite helical axis was determined by rotation of the talus to the tibia from -10º to +10º of ankle joint angle. The calculated finite helical axis represents the instantaneous talocrural joint axis at 0º of ankle joint angle. The Achilles tendon moment arm was determined as the shortest distance from the talocrural joint axis to the line of action of the Achilles tendon force at 0º of ankle joint angle projected to the orthogonal plane of the talocrural joint axis.

RESULTS AND DISCUSSION

The Achilles tendon moment arm determined for the 60% MVC condition was 4.8 cm and that determined for the rest condition was 4.0 cm. The Achilles tendon moment arm during 60% MVC was significantly greater by 0.8 cm (about 20%) from that at rest (p<0.05) (Figure 1). Therefore, if the Achilles tendon moment arm at rest was applied to simulate the motion involving the plantar-flexor torque, estimated parameters must be contaminated by the error associated with ignoring the increase in the Achilles tendon moment arm associated with the triceps surae muscle contraction. This indicates that the effect of the muscle contraction on the Achilles tendon moment arm influences the relationship between the ankle joint motion and the function of the triceps surae muscle.

On the transverse plane, the deviation between the talocrural joint and medial-lateral axes altered from 21.8º at rest to 8.1º during 60% MVC. It is one of the factors that the Achilles tendon moment arm increased with muscle contraction. Furthermore, this orientation change of the talocrural joint axis results in the orientation of the joint moment of the Achilles tendon force to change. This occur the increasing ground reaction force of the anterior direction at given joint moment of the Achilles tendon force. This result indicates that the triceps surae muscle contraction influences not only on the Achilles tendon moment arm, but also on the orientation of the joint moment of the Achilles tendon force.

Another factor influencing the Achilles tendon moment arm could be suggested. A previous study [8] showed that the soleus muscle thickness increased with contraction. The increased soleus muscle thickness makes the line of action of the Achilles tendon shift posteriorly. This makes the Achilles tendon moment arm increase.

The present study showed the triceps surae muscle contraction makes the Achilles tendon moment arm increased and the deviation between the talocrural join and medial lateral axes decreased. These results should be applied to improve the accuracy of the three-dimensional musculoskeletal model for simulate human locomotion and orthopedic disease.

CONCLUSIONS

The Achilles tendon moment arm determined for the 60% MVC condition was 4.8 cm and that determined for the rest condition was 4.0 cm. The Achilles tendon moment arm during 60% MVC was significantly greater by 0.8 cm (about 20%) from that at rest. On the transverse plane, the deviation between the talocrural joint and medial-lateral axes altered from 21.8º at rest to 8.1º during 60% MVC.

ACKNOWLEDGEMENTS

This study was partly supported by the Waseda University Global COE program entitled “Sport Sciences for the Promotion of the Active Life”.

REFERENCES