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RAT SOLEUS MUSCLE DOES NOT ACT INDEPENDENTLY FROM SURROUNDING MUSCLES

Chris Tijs*, Jaap H. van Dieen and Huub Maas
Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands
*Correspondence should be addressed to Chris Tijs, c.tijs@vu.nl

SUMMARY

Although *in situ* studies have shown that muscle force can be transmitted to the skeletal system via myofascial pathways [1], an *in vivo* study [2] reported a contradicting outcome for cat soleus (SOL) muscle. To investigate SOL independence in the rat, ankle joint plantar flexion moments exerted during SOL excitation were assessed for different positions of ankle and knee joints. Increasing knee angle imposed length changes on the inactive gastrocnemius (GA) and plantaris (PL) muscles, while SOL muscle-tendon complex (MTC) length was not changed. SOL active plantar flexion moment was significantly affected by knee angle, indicating mechanical interaction between SOL and GA-PL and, hence, showing that rat SOL does not act independently from surrounding muscles.

INTRODUCTION

Although biomechanical models represent muscles as independent units which are connected to the skeleton exclusively via their tendons of origin and insertion, *in situ* studies have shown that, in addition to the myotendinous junction, muscle force can be transmitted to the skeleton system via myofascial pathways [1]. Maas & Sandercock [2] investigated whether effects of epimuscular myofascial force transmission play also a role *in vivo* by investigating the effects of knee angle, to change the length of GA and PL muscles in the cat hind limb, on the ankle moment exerted by SOL. They found that SOL active ankle moment was not affected by length changes of its synergists, indicating no mechanical interaction between one-joint SOL and surrounding two-joint muscles. This different outcome compared to previous studies may be explained by a difference in species (cat versus rat) or by the fact that the effects of knee angle on SOL ankle moment were measured only at one ankle angle. The purpose of this study was to investigate to what extent SOL is interacting mechanically with adjacent synergistic muscles in the rat.

METHODS

Data from 12 male Wistar rats were obtained (309.5±10.3 gr.). In the deeply anesthetized animal, the skin and the biceps femoris of the left hind limb were removed. The sciatic nerve was exposed and a cuff-electrode was placed around it. The sciatic nerve divides into several nerves including a combined branch for the SOL, PL and lateral gastrocnemius (LG) [3]. All nerves, except the combined LG-SOL-PL branch were cut. Individual nerve branches for LG and PL were identified using stimulation with a bipolar hook electrode and were cut, thus, leaving only the SOL branch intact.

The femur was clamped and the plantar surface of the foot was attached to a 6-degrees-of-freedom (DOF) load cell by clamping the calcaneus and dorsal surface of the foot. In addition, knee and ankle joint centers were marked and aligned with the axes of rotation of the set-up (Fig. 1). The load cell was used to measure the applied forces (3 DOF) and moments (3 DOF), and via inverse dynamics sagittal plane ankle joint moments were calculated. Ankle joint moments exerted on supramaximal (0.4 mA) stimulation of SOL nerve (100 Hz, 500 ms) were assessed for different positions of ankle and knee joints. First, knee angle was varied from 60^0 to 130^0 while the ankle joint was kept at a constant position (either at 90^0 *(n=10)* or at 140^0 *(n=6)*). In addition, ankle angle-moment characteristics were assessed by measuring SOL ankle moments for various positions of the ankle joint (from 150^0 to 70^0) with the knee angle kept at 90^0 *(n=12)*. Two minutes rest periods were allowed between trials.

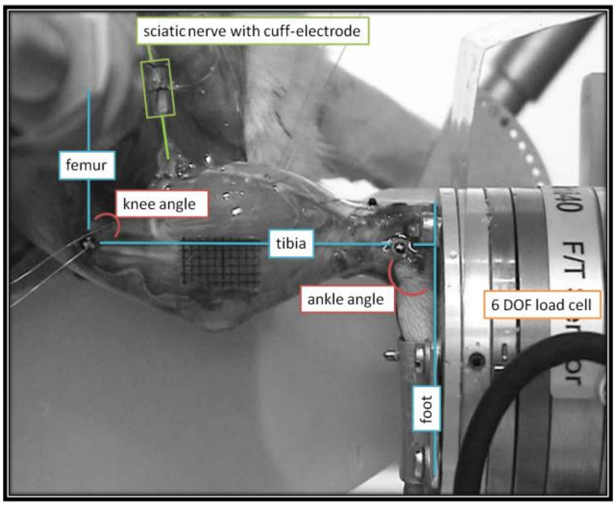

Figure 1: Lateral view of the rat left hind limb in the set-up with both ankle angle and knee angle set to 90^0.

Passive ankle joint moments were assessed by calculating the mean moment for a 50 ms time window just before the tetanic SOL contraction. Active ankle joint moments as a result of SOL excitation were calculated by subtracting passive joint moments from total joint moments, which were assessed by calculating the mean moment of the last 50 ms of the contraction. Repeated measures ANOVAs were used to test for effects of knee joint angle and to test for differences between ankle positions.

RESULTS AND DISCUSSION

Varying knee angle affected active SOL ankle moment significantly, both when the ankle was at 90^0 ($p<0.001$) and at 140^0 ($p<0.001$), indicating mechanical interaction between SOL and GA-PL (Fig. 2). The effects of knee angle were significantly different between the two ankle positions ($p=0.021$). With the ankle kept at 90^0, increasing knee angle from 60^0 to 80^0 resulted in an increase of 0.6±0.4 mNm to a maximum SOL ankle moment of 7.7±0.9 mNm, followed by a decrease of 0.7±0.6 mNm when the knee was extended further to 130^0. In contrast, with the ankle kept at 140^0, increasing knee angle resulted in a decrease in SOL ankle moment from 7.8±1.2 mNm at 60^0 to 5.6±0.8 mNm at 115^0.

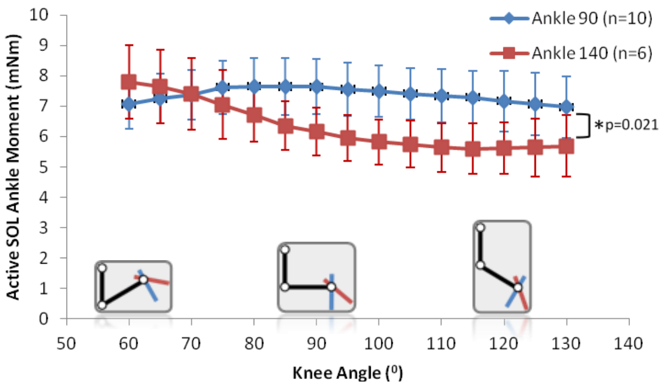

Figure 2: Effect of knee angle on active soleus (SOL) plantar flexion moment (mean ± SD) for ankle kept to 90^0 (n=10) and 140^0 (n=6).

Ankle angle-moment characteristics are shown in Fig. 3. Increasing ankle angle (i.e. lengthening SOL) from 150^0 to 120^0 resulted in an increase in active SOL ankle moment, followed by a large plateau phase between ~120^0 and ~90^0. Maximal active SOL ankle moment was 8.1±1.0 mNm, which was found at 100^0.

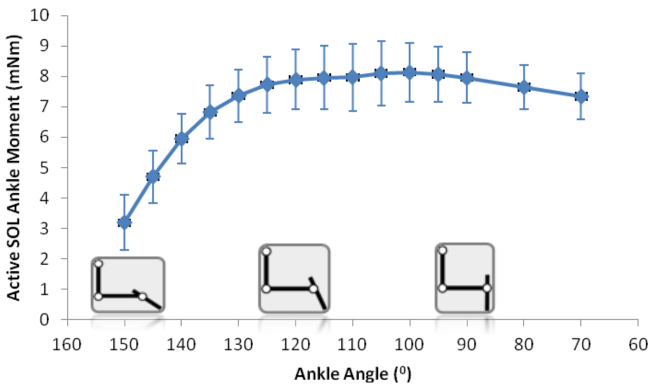

Figure 3: Ankle angle-plantar flexion moment characteristics (mean ± SD) for soleus muscle (SOL) with knee angle set to 90^0.

These results show that MTC length changes of the passive two joint GA-PL muscles affect the active ankle joint moment of one-joint SOL muscle, indicating mechanical interaction between these muscles. As shown in Fig. 2, the effect of increasing knee angle on active SOL ankle moment is dependent on ankle angle. With the ankle at 140^0, it was expected that increasing knee angle would result in an increase of the active SOL moment due to epimuscular myofascial effects. Since increasing knee angle will lengthen GA and PL muscles proximally, it also changes their position relative to SOL muscle. Previous research suggests that a proximally directed load could decrease the length of proximally located sarcomeres and increase the length of distally located sarcomeres within the same muscle fiber, even if global length of a muscle fiber remains constant [4]. Depending on the optimum sarcomere length, lengthening distally located sarcomeres could therefore increase/decrease distal tendon force. Because SOL is at a relatively short MTC length when the ankle is at 140^0 (sarcomeres would be below their optimum length), we expected an increase of active SOL moment. This would also be in accordance with the ankle angle-moment characteristics (Fig. 3).

In contrast, our results showed that increasing knee angle mainly resulted in a decrease of active SOL ankle moment, indicating that distally located sarcomeres within SOL muscle fibers were more likely shortened. It should be noted that an additional pathway for mechanical interactions between SOL and GA-PL is present. Besides interaction via connective tissue linkages between the SOL, GA and PL muscle bellies, these muscles can also interact via the shared Achilles tendon [5]. If increasing knee angle results in a higher length of the Achilles tendon, SOL muscle fibers may attain lower lengths. This would decrease active SOL ankle moment, as found in the present study. Thus, these different pathways of intermuscular interaction can have opposite effects on active SOL ankle moment. However, based on the present data, we cannot distinguish between the contributions of each pathway.

CONCLUSIONS

The active moment exerted at the ankle on excitation of SOL is affected by the position of the knee joint, despite the fact that this muscle only spans the ankle joint. Therefore, we conclude that rat SOL does not act independently from surrounding synergistic muscles.

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