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Surface Electromyogram Analysis of Toe Exercises : a Comparison of Toe Function

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Abstract. [Purpose] This study analyzed toe exercises using surface electromyograms. [Subject and Methods] The subjects were 26 feet of 16 participants, whose mean age was 25.7 ± 7.2 years old. The participants did three toe exercises, which were isometric contractions (about 5 sec) of the first toe flexor, 2nd-to-5th toe flexors and 3rd-to-5th toe flexors. An electrode was attached to four muscles: the longus peroneal, supinator muscles, and the medial and lateral gastrocnemius muscles. [Results] In the first toe flexor exercise, the peroneus longus muscle activity increased significantiy more than the other muscles. In 2nd-to-5th toe flexor and 3rd-to-5th toe flexor exercise, the supinator muscle activity increased significantly compared to the peroneus longus muscle, and the peroneus longus muscle activity decreased significantly compared to the medial head of the gastrocnemius muscle. [Conclusion] The first toe flexor exercise affected the long peroneal muscle as well as the flexor hallucis longus. On the other hand, the 2nd-to-5th toe flexor and 3rd-to-5th toe flexor produced the opposite result to that of the first toe exercise.
Key words: Toe function, Surface electromyogram, Painful accessory navicular

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INTRODUCTION

The accessory painful navicular presents with loss of the medial longitudinal arch (MLA) and produces pain and tenderness along the MLA. Chen Y et al. have pointed out that the relationship between loss of function of the tibialis posterior tendon (TPT) and the painful accessory navicular. The primary complaints of patients are caused by TPT insufficiency[1)]. Kiter E reported that the painful accessory navicular is caused by TPT being directly inserted in the accessory navicular bone, without any continuity to the sole of the foot. In addition, a thin slip of tissue was observed between the TPT and the other tendon originating from the accessory navicular bone.

Kiter E considered that the TPT has no supinator function without its distal attachments[2)]. It is well known that dysfunction of the TPT, from tenosynovitis to complete rupture, might result in severe flatfoot[3,4)].

Harris and Beath[5)] wrote that the normal foot is supported both by passive factors (bones and ligaments) and by active factors (muscles). They stated that, in the average or strong foot, most of the support is provided by passive factors, with little load being supported by the muscles.

However, recent research has shown that blocking tibial nerve transmission to the intrinsic foot muscles produces a significant increase in pronation[6)]. Headlee DL et al. reported that after subjects performed sets of 75 repetitions of isotonic flexion contractions of the intrinsic foot muscles against a 4.44 kg weight on a custom pulley system, a loss of MLA was showed[7)].

From the above, in the MLA of foot, we consider that not only passive factors (bones and ligaments) also active factors (muscles) are important, and developed three toe muscles exercises. The three toe exercises are of the first toe flexor, the 2nd-to-5th toe flexors and the 3rd-to-5th toe flexors (Fig. 1).

We previously reported that for the painful accessory navicular, exercises of the 2nd-to-5th toe flexors and 3rd-to-5th toe flexors resulted in significant pain reductions compared to before exercise for more than 70% of the subjects. On the other hand, first toe flexor exercise did not result in significant pain reduction and more than 60% of the subjects reported no alteration in pain[8)]. In the first-flexor exercise, subjects can flex only the hallux, and it is clear that the flexor hallucis longus muscle is affected. This muscle is one of the supinator group. Therefore, we expected that the first toe flexor exercise would show an effect of pain reduction because of antipronation. Nevertheless, this exercise did not happen.

There are two distinct functional groups of plantar flexors: the triceps surae and the perimalleolar muscles. The soleus and gastrocnemius (medial and lateral) have the advantage of large size and a full calcaneal lever. In contrast, the perimalleolar muscles are relatively small and wrap closely around the medial and lateral malleoli as their tendons turn from a vertical alignment along the leg to a horizontal path for action on the foot[9)].

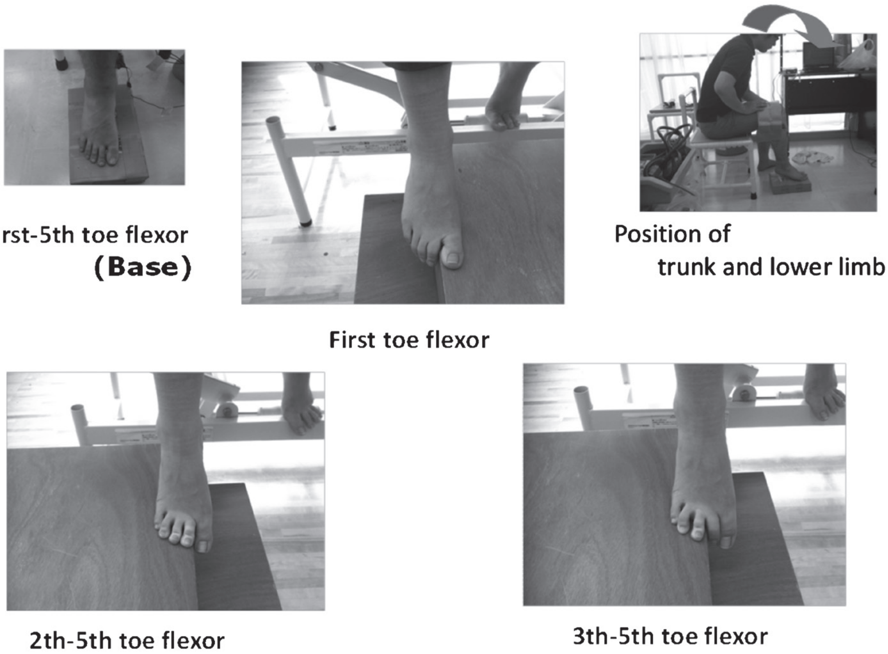

Fig. 1. Each experimental condition

Ankle plantar flexor torques, relative to the soleus (100%) , are 68% for the gastrocnemius, 1.8% for the tibialis posterior, 1.8% for the flexor digitorum longus, 6.1% for the flexor hallucis longus, and 2.4% for the longus peroneal muscle[9]. The tendon of the flexor hallucis longus has the advantage of a longer lever from the ankle axis, as its tendon passes behind the posterior margin of the tibia rather than the more anterior malleoli. Therefore, among the perimalleolar muscles, the flexor hallucis longus generates the greatest plantar flexor torque.

On the other hand, in inversion muscles, relative to the tibialis posterior (1) , the torque of the tibilalis anterior is 0.63, that of the flexor hallucis longus is 0.51, and that of the soleus is 0.43[9]. In the order of their inverting leverage: the tibialis posterior, tibialis anterior, flexor digitorum long, flexor hallucis longus, and soleus. The flexor hallucis longus has the disadvantage of a longer lever from ankle axis.

The results of previous studies, suggest that the flexor hallucis long muscle is advantageous in plantar flexor torques, whereas it is disadvantageous in inversion. This may explain why our first toe flexor exercise did not show a pain reduction compared to before exercise in our previous study. However, we consider that theory alone is not enough to show scientific evidence. This study analyzed the toe exercises we developed using surface electromyograms. The aim was to examine why the first toe flexor exercise did not show a pain reduction effect while the 2nd-to-5th toe flexors and 3rd-to-5th toe flexors exercise did.

SUBJECTS AND METHODS

The subjects of this study were 16 participatnts, 26 feet (12 males 22 feet, 4 females 4 feet), mean age 25.7 ± 7.2 years old. Subjects were excluded from the study if they had current or previous foot pain, previous foot surgery, osteoarthritis affecting the foot, or other major medical conditions. This study was performed with the consent of the Ethics Committee for Human Research of Waseda University and Gumma Paz College

While the toe exercises were being performed, surface electromyograms (EMG) were recorded by a small data logger system, picoFA-DL-2000 (S&ME, Inc.). This was accomplished by using preamplified electrodes. The EMG data was recorded by using software (m-BioLog). Data were sampled at 1 K Hz, and a bandwidth of 5–500Hz.

The electrods were attached to four places: the long peroneal muscle of just below the fibula head, the supinator muscles posterior and inferior to the medial malleolus, and the belly muscles of the medial head of the gastrocnemius muscle and the lateral head of the gastrocnemius muscle. The distance between the electrodes set was about 10 mm.

Three exercises were perdormed in this study has three conditions, first toe flexor, 2nd-to-5th toe flexor and 3rd-to-5th toe flexor exercises. All subjects randomly performed the three exercises (3 times each). The subjects were seated and weight of 3 kg was placed on their distal thigh. All subjects tilted their trunks forward until their heads were directly above their knees as per Fig. 1. The subjects tried to raise their heel with their toes to performe the flexor exercises (isometric contraction of about 5 seconds). The subjects were allowed to practice the exercises practiced around five times before the experiment began.

Among isometric contraction of 5 seconds, 2 seconds of the median as data was adopted. The first-to-5th toe flexor exercise (all toes flexor) was as a baseline in IEMG. Each condition was done a normalization, relative to the first-to-5th toe flexor exercise (100%), was done a normalization (integrated electromyogram%: IEMG%).

For statistical analysis we performed the Kruskal Wallis

Table 1. IEMG of subjects during the different exercises

First-Toe Flexor	Pero	141.2 ± 6.3
	Sup	103.4 ± 7.1
	GL	102.4 ± 10.6
	GM	96.5 ± 7.5
2-5Toe-Flexor	Pero	68.2 ± 4.4
	Sup	120.5 ± 10.6
	GL	90.2 ± 7.8
	GM	94.9 ± 5.5
3-5Toe-Flexor	Pero	58.3 ± 5.7
	Sup	121.5 ± 15.1
	GL	77.9 ± 7.6
	GM	91.8 ± 6.0

Mean±SEM. *stastically significant, p<0.05, n:26. KruskalWallis, Mann-Whitney. Pero:peroneus longus. Sup: supinator muscles. GL:gastrocnemius longus. GM: gastrocnemius medialis.

and Mann-Whitney tests using SPSS 11.0. Results were considered significant at values of p<0.05.

RESULTS

In the first toe flexor exercise, IEMG (%) of the peroneus longus muscle, the supinator muscles, the medial head of the gastrocnemius muscle, and the lateral head of the gastrocnemius muscle were 141.2 ± 6.4%, 105 ± 4.5%, 89.0 ± 8.1 %, 89.0 ± 8.1 %, respectively (Table1-A). The peroneus longus muscle activity was significantly higher than that of the other muscles.

In the 2nd-to-5th flexor exercise, IEMG (%) of the peroneus longus, the supinator muscles, the medial head of the gastrocnemius muscle, and the lateral head of the gastrocnemius muscle were 67.0 ± 4.4 %, 102.7 ± 10.6%, 86.0 ± 7.8%, 92.8 ± 5.5%, respectively (Table1-B). The supinator muscles activity increased significantly compared to the peroneus longus muscle, and the peroneus longus muscle activity decreased significantly compared to the medial head of the gastrocnemius muscle.

In the of 3rd-to-5th flexor exercises, IEMG (%) of the peroneus longus, the supinator muscles, the medial head of the gastrocnemius muscle, and the lateral head of the gastrocnemius muscle were 53.8 ± 5.7%, 102.2 ± 15.1%, 85.9 ± 7.6%, 91.8 ± 6.0%, respectively (Table1-C). The supinator muscles activity increased significantly compared to the peroneus longus muscle, and the peroneus longus muscle activity decreased significantly compared to the medial head of the gastrocnemius muscle.

The results of the 2nd-to-5th and 3rd-to-5th flexor exercises (Table1-B,C) are similar. On the other hand, the first toe flexor exercise (Table1-A) gave contrary results.

DISCUSSION

This study analyzed and compared the surface EMG of toe exercises we developed. In the first toe flexor exercise, the peroneus longus muscle activity increased significantly more than those of the other muscles. In contrast, in the 2nd-to-5th and 3rd-to-5th flexor exercises, the supinator muscles activity increased significantly compared to that of the peroneus longus muscle, while the triceps surae muscles, and the medial and lateral gastrocnemius muscles, did not show significant differences.

In our previous clinical research on the painful accessory navicular[8], the subjects were around 20 years old. In this study, the participants were also all around the same age.

All participants performed the three exercises mentioned above in a random order so as not to allow the order to influence the results of the experiment. Furthermore, the experimental conditions were the same as those of our earlier study[8] : all participants tilted their trunks forward until their heads were above their knees in the sagittal plane in order to prevent the participants from using their knee or hip joint, while in the frontal plane, the participants set their hip and knee joints to maintain right position. Moreover, in the first-toe flexor, exercise, subjects flexed their interphalangeal joint set. In the 2nd-to-5th and 3rd-to-5th toe flexors exercises, they flexed their proximal interphalangeal joints set and extended their distal interphalangeal joints set as much as possible in order to use their toes.

In the 2nd-to-5th and 3rd-to-5th flexors exercises (Table1-B,C), the supinator muscles activity increased, and that of the peroneus longus decreased. In spite of the exercise with the lesser toe (lateral toe), activity of the peroneus longus (lateral muscle group) decreased. However, in the first-toe flexor exercise, the peroneus longus muscle activity increased (Table1-A). In the latter exercise, subjects flex only the hallux, and it is clear that the flexor hallucis longus muscle is affected. Moreover, this muscle is one of the supinator muscle group. Therefore, we expected that the activity of the supinator muscles would also increase in this exercise. However, this did not occur. The tendon of the peroneus longus muscle courses distally a remarkable distance, and attaches to the plantar-lateral aspect of the first tarsometatarsal joint. The muscle attaches to the plantar side of the base of the distal phalanx of the first toe[10]. Hence, we consider that the peroneus longus was affected by this first toe flexor exercise that also affects the medial toes.

Regarding the role of the medial longitudinal arch of the peroneus longus muscle, Basmajian and Stecko[11] performed electromyographic studies of the tibialis anterior, the peroneus longus, the tibialis posterior and the instrinsic muscles of the foot to determine which provide support for the medial longitudinal arch of the foot. They reported that the only muscle to play an important role in the normal static support of the foot is the posterior tibialis. In contrast, the peroneus longus was quite inactive in almost all subjects. Franettovich M et al[12] analyzed electromyograms during walking before and after the application of an antipronation taping. They reported a reduction in the peak activation of the tibialis posterior and the tibialis anterior. However, the peroneus longus changed very little. We deduce from the results cited above that, the peroneus longus is not greatly associated with the role of the MLA. On the other hand, it is well known that the peroneus longus muscle is an important muscle in the prevention and the treatment of ankle sprain[13,14].

If the therapist facilitates eversion, exercise of the peroneus longus muscle might be effective. However, when the therapist attempts to facilitate the medial longitudinal arch of the foot, it is necessary to increase the activities of the tibialis posterior and the flexor digitorum longus muscle while inhibiting that of the peroneus longus muscle. In other words, in our opinion, it is necessary to inhibit exercise of the hallux. This is additional evidence explaining why the first toe flexor exercise did not reduce pain in painful accessory navicular. We already stated that 2nd-to-5th and 3rd-to-5th toe flexor exercises might be a comparatively better treatment for increase of the MLA and strengthening of TPT[8].

The electromyograms of the posterior tibialis, the flexor digitorum longus and the flexor hallucis longus muscles were included in the supinator muscle electromyogram in this study. Which muscles, and their respective contribution were unclear. For example, it is clear that the peroneus longus muscle was involved in the first-toe flexor exercise. However, in the 2nd-to-5th and 3rd-to-5th flexors exercises, it is not clear which muscles, the posterior tibialis or the flexor digitorum longus, are involved. This is a limitation of surface EMG. Therefore, this study was not able to establish why the lessor toe flexor exercises resulted in pain reduction.

In conclusion, for painful accessory navicular, we reported that the first toe flexor exercise was not effective, with more than 60% of the subjects reporting no pain reduction. In our present study, we showed that the first-toe flexor exercise affects the peroneus longus muscle as well as the flexor hallucis longus, suggesting why the first-toe flexor exercise does not reduce pain in painful accessory navicular[8]. Further studies are required to understand why the 2nd-to-5th and 3rd-to-5th toe flexor exercises gave results contrasting with that of the first toe flexor exercise and reduced pain in painful accessory navicular[8]. We will research these points in the near future.

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