The Effect of Fixed Ankle and Knee Joints on Postural Stability and Muscle Activity

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Abstract. [Purpose] This study examined postural stability and muscle activity when limitations were placed on the ankle and knee joints. [Subjects] Forty-eight healthy young adults were randomly assigned to one of three groups: a fixed-ankle group (6 males, 9 females), a fixed-ankle-and-knee group (9 males, 7 females), and a non-fixed group (7 males, 10 females). [Methods] The fixed-ankle subjects were limited using orthopedic fiberglass casting tape and elastic bandages and the fixed-ankle-and-knee subjects were additionally limited using a knee immobilizer. There were no limitations on the ankle and knee joints of the non-fixed group subjects. We measured postural stability and muscle activities of the ankle and knee muscles. [Results] There were differences in the muscle activities of the tibialis anterior, median gastrocnemius, and rectus femoris between the groups. The greatest muscle activity in the tibialis anterior was shown by the non-fixed group, and the fixed-ankle group showed the greatest rectus femoris and gastrocnemius activities. There were significant differences in the overall stability index, anterior-posterior stability index, and medial-lateral stability index. All three indices were the lowest for the non-fixed group. [Conclusion] A fixed ankle or knee reduces muscle activity which in turn lowers postural stability.

Key words: Ankle and knee joint, Muscle activity, Postural stability

INTRODUCTION

The ability to maintain and recover balance during everyday activities is related to factors such as sensation, motor skills, cognitive function, psychosocial function, and environment. A normal adult chooses an appropriate postural response strategy in reaction to external stimuli. Through anterior-posterior stability, medial-lateral stability, and multidirectional instability, perturbation is properly controlled. In controlling balance for body stability, the hip and ankle joints play an important role. Balance is maintained by using an ankle strategy, a hip strategy, or both strategies at the same time. In particular, exercise strategies for improving anterior-posterior stability can be classified into ankle strategies, hip strategies, and stepping strategies. When body sway is large, the hip strategy is used, and when body sway is small, the ankle strategy is used. Ankle joint muscles not only control the specific functions of the ankle joint but also provide stability, propulsion and shock absorption during movement.

The knee joint, one of the lower limb joints, is at greater risk of damage than other joints, and supports weight load and provides mobility at the same time. It is responsible for weight load in function and a wide range of mobility in dynamics. In addition, when ankle and hip strategies are used to control body sway, the knee joint located between them is a part of a kinetic chain. Back-and-forth motion induces contractions of the ankle joint muscles, and the cooperative reaction of muscles near the knee joint provides body stability. Power applied to a part of the kinetic chain is absorbed by other parts of the chain as well as by the open part of the chain. However, if the power is too great, it damages the body. For this reason, pain decreases muscle strength, and limits range of motion impairing balance ability. When the ankle and knee joints cannot react properly, the hip strategy plays an important role in controlling posture and balance.

In the case of individuals participating in leisure activities that require fixed feet (e.g., inline skating, snowboarding, and skiing) or elderly individuals who have chronic ankle pain, knee arthritis, or limited range of motion, the ankle or knee strategy plays an important role in body stability. Even though there have been many studies of the influence of the ankle or hip strategy on postural stability, few studies of the posture-control strategies that can be used when ankle or hip strategies cannot be used have been conducted. Therefore, the present study examined postural stability and muscle activities when limitations were placed on the ankle and knee joints. The results of this study will be applied to postural stability training for patients with limited range of motion of the lower-limb joints.
SUBJECTS AND METHODS

Forty-eight healthy young adults, 23 males and 25 females, ranging in age from 21 to 26 years (average age: 23.3±4.7 years old; body weight: 62.4±11.3 kg; height: 169.9±8.7 cm) with no known visual or balance pathology, gave their written informed consent and were included in this study. All the subjects were students in the physical therapy program at Y University in Korea. Subjects were randomly assigned to one of three groups: a fixed-ankle group (6 males, 9 females; average age: 22.6±1.1; average height: 165.5±7.7 cm; average weight: 60.9±8.4 kg), a fixed-ankle-and-knee group (9 males, 7 females; average age: 23.5±7.3; average height: 166.6±10.2 cm; average weight: 62.7±13.2 kg), and a non-fixed group (7 males, 10 females; average age: 22.7±0.6; average height: 168.0±9.3 cm; average weight: 63.4±12.6 kg). The movement of both ankle joints of the fixed-ankle subjects was limited using orthopedic fiberglass casting tape and elastic bandages. The movement of both knee joints of the fixed-ankle-and-knee group subjects was limited using a knee immobilizer. There were no limitations on ankle or knee joints of the non-fixed group subjects. In the fixed-ankle condition, the taping applied to limit ankle joint movement was taped around the sole. To exclude the effect of changes in somesthesis in the soles, the same width of taping was applied to the soles of both the fixed-ankle-and-knee and non-fixed groups.

In this study, postural stability and activities of the lower limb muscles were measured. To measure postural stability, the Biodex Balance System was used. This system consists of a circular platform that moves freely along the anterior-posterior axis and medial-lateral axis on a stable floor, a handrail for the subjects’ safety, and a screen. This system works similar to video games that use joysticks. The subject’s location and movement information on the circular platform are shown on a screen. The system has four testing protocols, including fall risk, athletic single leg stability, postural stability, and limits of stability. The protocol of the postural stability test, used to evaluate the ability to maintain center of balance, was used. The stability index provided as a result of the test and a lower score indicates a stable posture. The postural stability test measures the gradient of the anterior-posterior axis and medial-lateral axis of the stable circular platform and calculates the overall stability index (OSI), anterior-posterior stability index (APSI), and medial-lateral stability index (MLSI).

A four-channel wireless surface electromyography system (MP150 system, BIOPAC System Inc., Santa Barbara, USA) was used to measure changes in the muscle activities of the ankle and knee muscles. Analog signals of surface electromyography recorded by the four channels are sent to the MP150 system and transformed into digital signals. Then, they are saved and analyzed using Acqknowledge 4.1 software on a personal computer. To reduce measurement error, participants’ body hair was removed the placement locations were wiped using medical alcohol before attaching the electrodes. The electrodes were attached to the subjects’ rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius. The subjects were asked to stand upright on the Biodex Balance System with their arms by their sides and their feet placed 10 cm apart from each other. They were measured three times for one minute per measurement, and they were asked to take 30 seconds of rest, lying flat on the ground, between each measurement. The sampling rate of the electromyogram signal was set to 1,000 Hz, and a 30~500 Hz bandwidth notch filter was used. The amplified analog electromyogram was transformed into 1,000 digital signals per second using an analogue-digital converter and recorded. The active electrodes consisted of two stainless steel pads, their diameter was 11.4 mm, and the distance between the electrodes was 20 mm. The surface electromyogram analog signals recorded by the four channels were sent to the MP150 system to be transformed to digital signals and were saved and analyzed on a personal computer using Acqknowledge 4.1 software (BIOPAC System Inc., Santa Barbara, USA). To standardize the electromyogram signals, muscle contraction of comfortable standing on a stable floor was set as the standard contraction (the %RVC method).

To examine differences in postural stability and muscle activities between the groups, one-way ANOVA and a post-hoc test (Scheffe test) were conducted. The collected data were analyzed using SPSS version 18.0 for Windows with significance accepted for values of p<0.05.

RESULTS

The purpose of the present study was to examine the effect of fixing the ankles and knees of normal adults on muscle activities and postural stability. The results were as follows. There were differences in the muscle activities of the tibialis anterior, gastrocnemius, and rectus femoris between the groups. In the case of the tibialis anterior, the non-fixed group showed the greatest muscle activity followed by the fixed-ankle-and-knee and fixed-ankle groups (p<0.01). The
The present study examined the effect of fixing ankle and knee joints in a static upright position on a dynamic platform on postural stability and muscle activities. The group without fixed lower limbs showed the highest muscle activity in the tibialis anterior followed by the gastrocnemius. This result is similar to that reported by Almeida et al. (8), who indicated that the ankle joint strategy is used the most when maintaining balance on a dynamic platform. They showed that the tibialis anterior and gastrocnemius are activated rotationally when there is back-and-forth movement, the medial gastrocnemius is activated before the body falls in front of the vertical line, and the tibialis anterior starts to activate before the body returns to the original position. In addition, ankle joint muscles go through efferent contraction and afferent contraction in turn to provide postural stability through the activities of the muscles activating the knee and hip joints (9). The ankle strategy is used to keep balance on a translational platform, with a large base of support for the body (10).

The fixed-ankle group showed the greatest muscle activity in the rectus femoris. When the range of motion of the ankle is reduced, other joints compensate for the limitation (11). It seems that the increased activity of the rectus femoris, a knee extensor, compensated for the limited range of motion of the ankles. The quadriceps femoris is the most important muscle among the muscles around the knee joint. It is an agonistic muscle of knee extension, and provides lower limb stability when standing or walking (12). The ankle strategy is used in quiet stance and during small perturbations, and that the ankle plantar flexors/dorsiflexors alone act to control the inverted pendulum. In large perturbations, or when the ankle muscles cannot act, a hip strategy is used to flex the hip, in order to move the center of mass (COM) posteriorly, or to extend the hip in order to move the COM anteriorly (13). The fixed-ankle-and-knee group showed the highest muscle activity in the biceps femoris, while the muscle activities in general were lower than in the other groups. The biceps femoris is a muscle of two joints and seems to be involved knee joint and hip joint strategies.

In this study, the non-fixed group showed the highest postural stability. This result is in line with the dynamic multi-segment model (14), that shows that postural stability is controlled by active combination of the ankle, knee, and hip joints. The non-fixed group could use the combination of joints more effectively than the fixed-ankle group and the fixed-ankle-and-knee group. Fixation of the ankle and knee reduced the muscle activities, which in turn lowered postural stability. When the ankle is fixed, other parts of the body (especially the knee) may be damaged when compensating for the ankle joint’s limited range of motion. Therefore, elderly individuals who suffer from chronic pain in the ankle or knee or have a limited range of motion in the joints have lower postural stability, which in turn can cause falls. Moreover, individuals who perform leisure activities that involve fixing the feet in boots (e.g., inline skating, snowboarding, or skiing) seem to use the knee joint strategy excessively, raising the risk of knee injury. To prevent knee injuries and falls, it seems necessary to exercise to strengthen the knee extensors and flexors and use the upper limbs.

The present study examined the effect of fixing ankle and knee joints in a static upright position on a dynamic platform on postural stability and muscle activity. Further studies should be performed to examine the level of trunk muscle activity required to compensate for lower limb limitations on joints and the timing of each muscle activity.

### DISCUSSION

The present study examined the effect of fixing lower limb joints in a static upright position on a dynamic platform on postural stability and muscle activities.

The group without fixed lower limbs showed the highest muscle activity in the tibialis anterior followed by the gastrocnemius. This result is similar to that reported by Almeida et al. (8), who indicated that the ankle joint strategy is used the most when maintaining balance on a dynamic platform. They showed that the tibialis anterior and gastrocnemius are activated rotationally when there is back-and-forth movement, the medial gastrocnemius is activated before the body falls in front of the vertical line, and the tibialis anterior starts to activate before the body returns to the original position. In addition, ankle joint muscles go through efferent contraction and afferent contraction in turn to provide postural stability through the activities of the muscles activating the knee and hip joints (9). The ankle strategy is used to keep balance on a translational platform, with a large base of support for the body (10).

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### Table 2. Postural stabilities of the between groups

<table>
<thead>
<tr>
<th></th>
<th>non-fixed group&lt;sup&gt;a&lt;/sup&gt; (n=17)</th>
<th>ankle-fixed group&lt;sup&gt;b&lt;/sup&gt; (n=16)</th>
<th>ankle and-knee-fixed group&lt;sup&gt;c&lt;/sup&gt; (n=15)</th>
<th>post-hoc</th>
</tr>
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<tbody>
<tr>
<td>OSI&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.81 ± 0.86</td>
<td>3.96 ± 1.61</td>
<td>4.38 ± 1.28 **</td>
<td>b=c &gt;a</td>
</tr>
<tr>
<td>APSI&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1.19 ± 0.66</td>
<td>2.79 ± 1.37</td>
<td>3.15 ± 0.88 **</td>
<td>b=c &gt;a</td>
</tr>
<tr>
<td>MLSI&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.09 ± 0.45</td>
<td>2.27 ± 0.82</td>
<td>2.35 ± 1.00 **</td>
<td>b=c &gt;a</td>
</tr>
</tbody>
</table>

<sup>a</sup>overall stability index, <sup>b</sup>anterior/posterior stability index, <sup>c</sup>medial/lateral stability index, <sup>p</sup>*<0.05, **<0.01

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