

Ankle Evertor Strength of Healthy Subjects in Different Ankle and Toe Positions

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Abstract

Background: Ankle evertor muscles are important for preventing lateral ankle sprain. Since, the evertor muscles cross the ankle and toe joints, the position at which the ankle evertor muscle strength is measured is important. However, no studies have previously investigated the effect of ankle and toe positions on the strength of the ankle evertor muscle.

Objects: This study is aimed to determine the effect of various ankle and toe joint positions on the strength of the ankle evertor muscles in healthy subjects.

Methods: Eighteen healthy subjects participated in this study. Isometric ankle evertor strength of the dominant leg was determined in each subject in different ankle and toe positions (dorsiflexion (DF) with toe extension (TE), DF with toe flexion (TF), plantar flexion (PF) with TE, and PF with TF). A 2 by 2 repeated analysis of variance (ANOVA) was used to determine the difference in the evertor strength between the ankle positions (PF and DF) and toe positions (TE and TF).

Results: The results indicate that there was no significant ankle position by toe position interaction effect ($p=.83$). However, the ankle evertor strength was significantly increased in the ankle DF position than in the PF position ($p<.01$), and the ankle evertor strength during eversion with TE was significantly higher than eversion with TF ($p<.01$).

Conclusion: The findings of this study suggest that clinicians should consider the ankle and toe positions when measuring the muscle strength and during performance of selective muscle strengthening exercises of the ankle evertor muscles.

Key Words: Ankle evertor; Extensor digitorum longus; Isometric strength; Measurement position.

Introduction

Lateral ankle sprain is one of the most common injuries in young athletes, with symptoms, such as pain, swelling, dysfunction, and instability of the ankle joint (Hertel 2000; Lorenzo-Sánchez-Aguilera et al, 2018; Nelson et al, 2007; Willems et al, 2002). The majority of the individuals who experience lateral ankle sprain, approximately 70~80%, progress to chronic ankle instability with symptoms persisting for more than 1 year (Santilli et al, 2005; Schmidt et al, 2011; terrier et al, 2017). Ankle biomechanics during

an ankle sprain show increased ankle inversion and internal rotation (Fong et al, 2009; Kristianslund et al, 2011). Additionally, previous studies investigated the biomechanics at the moment of ankle injury. They reported that ankle injury was found in dorsiflexion (DF) position in contrast to the theoretical hypothesis that ankle injury occurs in plantar flexion (PF) position (Fong et al, 2009; Kristianslund et al, 2011).

Appropriate control of the ankle muscles is necessary to prevent sudden ankle movement. Researchers have focused on the ankle evertor muscles in particular, a group of muscles that are involved in a

movement that is antagonistic to inversion. Willems et al (2002) and Donnelly et al (2017) reported that ankle evtor strength was significantly decreased in individuals with chronic ankle instability compared to healthy subjects (Donnelly et al, 2017; Willems et al, 2002). However, several other studies found no significant difference in ankle evtor strength in subjects with chronic ankle instability compared to healthy control subjects (Sierra-guzmán et al, 2018; Terrier et al, 2017). Despite the many studies conducted on ankle evtor muscles, the effect of ankle evtor strength on lateral ankle injury is still undetermined.

The muscles that cross the lateral side of ankle joint can contribute to eversion movement. The main muscles involved in ankle eversion are the peroneus longus (PL) and peroneus brevis (PB) (Donnelly et al, 2017; Webster and Nussbaum 2016). These muscles produce eversion and PF movements because they cross the ankle joint posterolaterally (Muscolino 2016). Other muscles that cross the lateral side of the ankle joint are the peroneus tertius and extensor digitorum longus (EDL) (Muscolino 2016; Rourke et al, 2007; Yammine and Eric 2017). The peroneus tertius is sometimes missing and homologous to the EDL. The main function of the EDL is ankle DF and toe extension (TE), but it can also contribute to eversion as this muscle crosses the ankle joint anterolaterally (Muscolino 2016). As the PL and PB cross the ankle joint while the EDL crosses the ankle joint, toe metatarsophalangeal (MTP) joint, and interpalangeal (IP) joint, the length of the muscles varies according to the position of the ankle and toes (Muscolino 2016).

Due to a length-tension relationship, the length of the muscles affects the force produced by their contraction. Therefore, the position at which muscle strength is measured can affect the outcome of muscle strength measurements (Ahn et al, 2018). Donnelly et al (2017) studied ankle evtor strength in the neutral and PF positions (Donnelly et al, 2017). His results indicates that evtor strength was

higher in the neutral ankle position than PF position. However, there have been no studies that incorporated the positioning of both the toes and the ankle during ankle evtor strength measurements. Investigating how ankle evtor strength of a healthy subject is affected by ankle and toe joint positions may result in improved clinical guidelines for strength measurement and training of ankle evtor muscles. Therefore, the purpose of this study was to investigate the effect of various ankle and toe joint positions on ankle evtor strength in healthy subjects. Although the main function of EDL is DF and TE, EDL also function as evtor. Therefore, the hypothesis of this study is that the ankle evtor strength would be higher in the DF position than in the PF position, and the evtor strength in the TE position would be higher than that in the TF position due to the action of EDL.

Methods

Subjects

The G*Power software ver. 3.0.10 (Franz Faul, Kiel University, Kiel, Germany) was used to estimate sample size in a pilot study of 3 subjects. From a priori analysis, a power of .95, set of .05 and the effect size of .56 indicated that at least 14 subjects were needed. Eighteen healthy subjects (males: 12, females: 6) participated in this study (age=23.6±2.2 years; height=170.2±7.5 cm; weight=68.8±9.8 kg). The subjects recruited were healthy, and those with prior experience of ankle sprain, prior surgery in the lower extremities, limited ankle joint range of motion and neurological disorders were excluded (Cho et al, 2018). All subjects who volunteered to participate in this study signed a written consent form describing the procedure and the purpose of this study before the commencement of the experiments.

Instrumentation

The Smart KEMA strength sensor (KOREATECH,



Figure 1. Ankle evtor measurement position and the Smart KEMA sensor position.

Inc., Seoul, Korea) was used to measure the isometric ankle evtor strength. This sensor is a tensiometer that measures the force at which both ends are pulled and the measuring range is 0~1960 N (Ahn et al, 2018; Kim et al, 2017). To measure muscle strength, a 5-cm wide strap, which is attached to one end of the sensor is applied on the subject's forefoot, and the length-adjustable belt attached to the opposite side of the sensor is fixed to the floor (Ahn et al, 2018). For all subjects, the tension at the starting position was adjusted to 2 kgf in order for all subjects to start at the same tension (Ahn et al, 2018). The Smart KEMA strength sensor has a high intra-rater reliability (ICC=.85~.98) (Kim et al, 2017).

The measured data were collected at a sampling frequency of 10 Hz and transmitted via Bluetooth to the Smart KEMA application on a tablet. The transmitted strength data can be monitored in real time and analyzed through the application (Ahn et al, 2018; Kim et al, 2017).

Procedure

Evtor strength of the dominant foot was measured in each subject. The dominant leg was the preferred leg for kicking a ball (Webster and Nussbaum 2016). During the measurement, the subject took a side-lying position on the opposite of the measured ankle. Then the measuring leg was pushed forward by flexing the hip and knee, allowing the forefoot of the measured leg to come out of the table. Pillow support was applied under the knee to prevent pelvic, femur and tibia rotation. The investigator fixed the subject's distal tibia to prevent the compensation of tibia external torsion and instructed the subject to evert the ankle with maximum effort for 5 seconds (Figure 1). The subjects everted their ankle in the following four ankle and toe positions: (1) dorsiflexion with toe extension (DFTE) (Figure 2A); (2) dorsiflexion with toe flexion (DFTF) (Figure 2B); (3) plantarflexion with toe extension (PFTE) (Figure 2C); and (4) plantarflexion with toe flexion (PFTF) (Figure

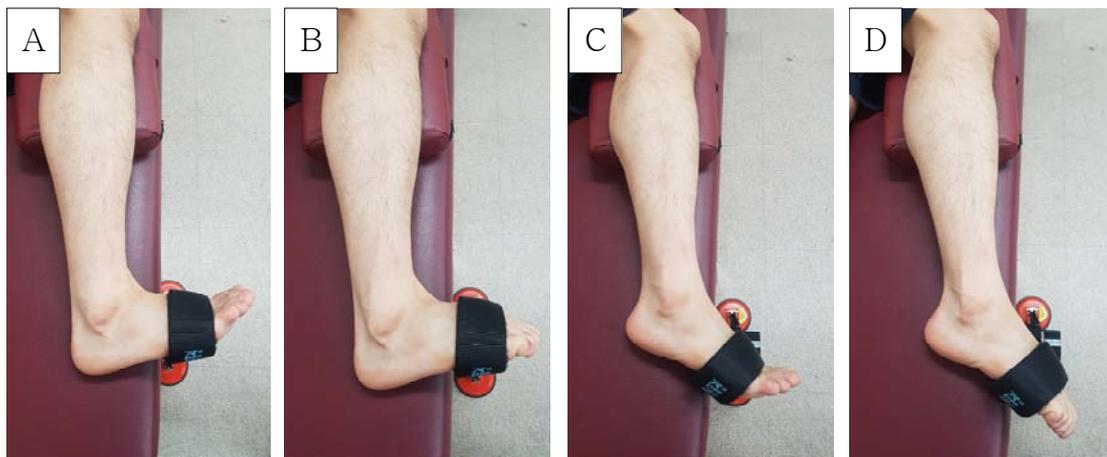


Figure 2. Ankle and toe positions for measuring the ankle evtor strength (A: dorsiflexion with toe extension, B: dorsiflexion with toe flexion, C: plantarflexion with toe extension, D: plantarflexion with toe flexion).

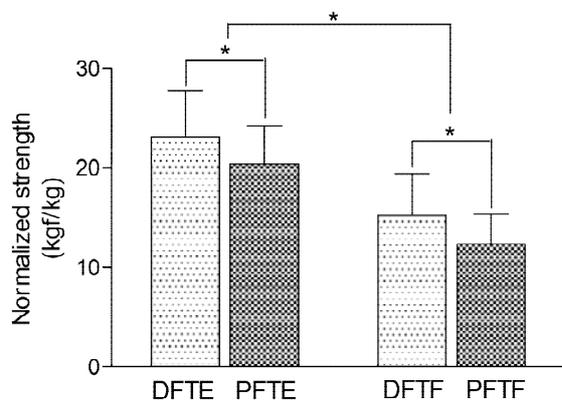


Figure 3. Ankle eversion strength in different ankle and toe positions (DFTE: dorsiflexion with toe extension, PFTE: plantarflexion with toe extension, DFTF: dorsiflexion with toe flexion, PFTF: plantarflexion with toe flexion, * $p < .01$).

2D). The ankle DF position was set at 10° while the ankle PF position was set at 50° (Donnelly et al, 2017; Kisner and Colby 2012). The investigator confirmed the ankle position using a standard goniometer at the starting position. Before the measurement, the subjects practiced to maintain the ankle angle in starting position while measuring eversion strength. In addition, the investigator monitored that if there is any DF or PF during measurement. The angle of toe flexion and extension were set at the maximum possible angle of the subject. The order of measurement of the four positions was randomized using www.randomized.com. Before the strength measurement, the subjects practiced performing eversion with maximum force in each ankle and toe position, and then took a 5-minute rest before commencing with the experiment. The eversion strength was measured twice in each position, with a 3-minute rest period between measurements to prevent muscle fatigue.

Data analysis

The measured ankle eversion strength was processed through the Smart KEMA application. The mean value of the middle 3 seconds of the collected 5-second ankle eversion strength data was calculated. The average of the two measured values was calcu-

lated and saved. The strength data of each subject was divided by the subject's body weight for normalization (Donnelly et al, 2017).

Statistical analysis

Statistical analysis was conducted using SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to confirm the normal distribution of the data. A 2 by 2 repeated model analysis of variance (ANOVA) was used to determine the difference in eversion strength between the ankle position (DF and PF) and toe position (TE and TF). The significance level was set at $p = .05$. If any significant interaction or effect was observed between groups and factors, the simple effect was compared by paired t-test or independent t-test using Bonferroni corrections ($p = .05/4 = .013$).

Results

All data were normally distributed. The 2 by 2 repeated ANOVA showed that there was no significant interaction effect between the ankle position and toe position ($F = .05$; $p = .83$) on the ankle eversion strength. However, there was a significant difference in the main effect of each ankle position and toe position. The strength of the ankle eversion was higher in the ankle DF (DFTE = 23.1 ± 4.7 kgf/kg; DFTF = 20.4 ± 3.8 kgf/kg) than in the PF position (PFTE = 15.3 ± 4.2 kgf/kg; PFTF = 12.3 ± 3.0 kgf/kg) ($F = 24.0$; $p < .01$). The strength of the eversion muscles during eversion with TE was significantly higher than that during eversion with TF ($F = 44.55$; $p < .01$) (Figure 3).

Discussion

This study investigated the effect of several ankle and toe joint positions on the ankle eversion strength in healthy subjects. The results indicate that the eversion strength during eversion in the DF position

was significantly higher compared to eversion in the PF position while the evertor strength during eversion with TE was significantly higher compared to that during eversion with TF.

A previous study investigating the effect of the ankle positions on the evertor strength (Donnelly et al, 2017) showed that the evertor strength in a neutral position was significantly higher compared to that in the PF position (PF position: 1.73 Nm/kg; neutral: 2.10 Nm/kg) (Donnelly et al, 2017). The results of this study also showed that the evertor strength in the ankle DF position was higher than the PF position as in the previous study. This is related to the functions of PL and PB, the prime movers of eversion. Both PL and PB act as evertor and plantarflexor. Thus the PL and PB muscles are shortened in the PF position during eversion due to the direction of muscle action (Muscolino 2016; Santilli et al, 2005). It is difficult for shortened muscles to generate maximal tension due to active insufficiency caused by an overlap of actin and myosin (Jeon et al, 2016; Sahrman 2001). Therefore, the evertor strength may have increased in the DF position where the PL and PB can produce evertor force effectively compared to PF position.

Some of the muscles that contribute to eversion also cross the toe joints, meaning the position of the toes can also affect the evertor strength. However, previous studies on the ankle evertor strength did not consider the impact of toe positions on strength measurements. The results of this study showed that evertor strength during TE was significantly stronger than TF. The EDL muscle contributes to the eversion motion in the TE position. Thus, TE led to an increase in the evertor strength (Muscolino 2016). In contrast, the flexor digitorum longus (FDL) and flexor hallucis longus (FHL) are synergistically involved in ankle inversion in the TF position because they cross the medial side of the ankle joint. While maintaining the toe flexion position during the measurement of evertor strength, FDL and FHL may act as an antagonist to evertors causing a decrease in

evertor strength in the TF position (Muscolino 2016). In addition, since EDL activation is inhibited at the TF position, the contribution of the EDL to eversion is reduced, thus, affecting the evertor strength.

Many previous studies have investigated the relationship between the ankle evertor weakness and chronic ankle instability. However, the results of these studies are still conflicted. Several studies have reported the evertor muscle weakness in individuals with chronic ankle instability, but some other studies have reported no significant difference between individuals with ankle injury and healthy subjects (Donnelly et al, 2017; Terrier et al, 2017; Willems et al, 2002). The evertor muscles cross the ankle joint, and some of the evertor muscles also cross the toe joint. In addition, the ankle joint has a complex articular surface and the movement in the ankle joint occurs on three axes. For this reason, muscles across the ankle joint simultaneously contribute to the various movements of the ankle. Therefore, the ankle and toe joint positions and length of the muscles involved should be considered when measuring the ankle evertor muscle strength in clinics and on sports fields. In this study, we examined the change of evertor strength according to joint position of the ankle and toes of healthy subjects, and there was a significant difference in the strength of the evertor muscle according to the ankle and toe position. Therefore, based on these results, we conclude that it is necessary to consider the ankle and toe positions when measuring ankle muscle strength and during selective muscle strengthening exercise. In particular, clinicians apply evertor strength exercises for intervention to patients with lateral ankle sprain. At this time, we recommend eversion in ankle PF with TF position to inhibit the compensation of EDL and selectively strengthen injured PL and PB based on the results of this study.

There are several limitations of this study. The generalization of the results is limited because only the young population were samples in this study. However, because lateral ankle sprains are more

common in young and active individuals (Hertel 2000; Lorenzo-Sánchez-Aguilera et al, 2018), the results of this study would help effective intervention for most patients with lateral ankle sprain. Further study is needed to investigate the effect of the ankle and toe position changes on the ankle evtor muscles in subjects with lateral ankle sprain. Activation of the muscles involved in ankle eversion was not measured. Hence, further studies are needed to determine the effect of the ankle and toe position on the ankle evtor muscle activation.

Conclusion

This study measured the effects of various ankle and toe positions on the strength of evtor muscles in healthy subjects. The results indicate that the evtor strength during eversion in DF was significantly higher compared to eversion in PF while the evtor strength during eversion with TE was significantly higher compared to eversion with TF. The muscles that contribute to the ankle eversion cross the ankle and toe joints; therefore, changes in the position of the ankle and toe joints can cause a change in evtor strength. Therefore, based on these results, clinicians will need to consider the ankle and toe joint positions when measuring the ankle evtor strength and providing selective training for patients.

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