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Research Article

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Altered Kinematics and Muscle Activity during Heel Rise in Individuals with or without Functional Ankle Instability

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Abstract

Background: The purpose of this study was to investigate the differences in the kinematics of the ankle joint and the activity of the lower leg muscles in subjects with functional ankle instability (FAI) during a double-leg heel rise.

Methods: Ten male athletes with FAI (age=19.9 ± 1.4 years; height=1.71 ± 0.04 m, weight=66.5 ± 3.6 kg) and ten male control athletes (age=20.1 ± 1.1 years; height=1.74 ± 0.03 m, weight=67.1 ± 4.5 kg) performed the heel rise on a force plate. The kinematic data and the electromyography (EMG) activity of the tibialis anterior (TA), gastrocnemius lateralis (GL), peroneus longus (PL), peroneus brevis (PB) and tibialis posterior (TP) muscles during the heel rise were recorded. Ankle movement was divided into two phases, a heel rise phase and a pause phase, and the data collected for each motion was compared between the two groups.

Results: During the pause phase, subjects with FAI tended to present a more abducted position and a less inverted position compared with that of the controls, which was accompanied by decreased peroneus brevis activity during the same period. An altered movement of the ankle joint due to deficits of muscle function was observed in subjects with FAI. The kinematic and kinetic differences observed in subjects with FAI may lead to recurrent ankle sprain.

Keywords: Functional ankle instability; Electromyography; Motion analysis

Introduction

Ankle sprains are among the most common injuries experienced by athletes involved in sports [1,2]. After an initial ankle sprain, it is estimated that about 70% of athletes will suffer from a recurrent ankle sprain [3,4]. Symptoms of residual ankle instability develop in 15–60% patients after an ankle sprain [5,6]. Traditionally, it is postulated that there are two types of ankle instability: mechanical ankle instability and functional ankle instability (FAI) [7]. FAI is characterized by recurrent ankle sprains and a feeling of "giving way" [6]. FAI might be a factor in deficits of ankle proprioception [8,9], neuromuscular response times [9], and inverted strength [10,11]. It has been reported that FAI is associated with deficits of dynamic postural control.

Delahunt et al. [12] have reported that subjects with FAI have a less everted position of the ankle joint than controls during a lateral hop task for the period pre and post-initial contact of the foot with the ground. Individuals with FAI exhibit a more inverted foot position pre and post-initial contact during the gait cycle [13]. It has also been reported that subjects with FAI exhibit altered muscle activity patterns, including reduced peroneus longus (PL) muscle activation time at the pre-initial contact during gait [14] and decreased PL muscle activity at the post-initial contact during gait [13]. In a study of landing activity, subjects with FAI demonstrated a significant reduction in the pre-initial contact PL activity compared with the activity of the controls [15,16]. Thus, it can be said that subjects with FAI have altered movement patterns and altered muscle activity during walking and landing. However, the previous studies did not provide sufficient analysis of the movement patterns of subjects with FAI.

The heel rise has been used to assess calf muscle function [17]. This exercise involves the muscle action of plantar flexion and it can be used reliably [18]. After an acute ankle sprain, this exercise has also been used for ankle sprain rehabilitation, especially during neuromuscular training [19,20]. By assessing the maximum number of rises [21], the maximum plantar flexion angle [22] and the lower leg muscle activity [22], it has been possible to evaluate lower leg muscle function. A previous study has shown that subjects with stage II posterior tibial tendon dysfunction exhibit significantly smaller plantar flexion angle at the ankle joint than that of the controls during the heel rise [22]. In a study evaluating heel rise in subjects with a history of lateral ankle sprain, the endurance of the ankle plantar flexor muscles was measured through repetitive heel rises [21]. It was reported that the subjects with a history of lateral ankle sprain performed a lower number of heel rises than healthy subjects. Because heel rises are easy to perform, it is possible to evaluate the condition of FAI by comparing certain nuances within the movement, such as the lift height of the heel. However, to our knowledge, there has been no study to date that has analysed subjects with FAI using the heel rises. The purpose of this study was to compare the kinematics and ankle joint muscle activity during heel rises, between athletes with and without FAI.

Methods

Twenty male athletes participated in this study. The study group consisted of ten athletes with FAI (age=19.9 ± 1.4; height=1.71 ± 0.04 m, weight=66.5 ± 3.6 kg). The inclusion criteria for the FAI group were (1) having experienced at least one ankle sprain and (2) having a Cumberland Ankle Instability Tool (CAIT) (Japanese version) score ≤ 25 [23]. The control group consisted of ten athletes without FAI (age=20.1 ± 1.1; height=1.74 ± 0.03 m, weight=67.1 ± 4.5 kg). The inclusion criterion for the control group was exhibiting a CAIT Japanese version score ≥ 28. Control group were matched according to height and weight.

All the subjects read and signed an informed consent form approved by the University Institutional Review Board prior to participation [No.27-155]. During the study, subjects were instructed to perform a double-leg heel-rise test. They stood on both legs barefoot on the force plate (type 9286B; Kistler Instrument Corp., Winterthur, Switzerland). Upon commencing the exercise, the subjects were instructed to rise up on their heels as high as possible and as quickly as possible. Following a two second pause at the top position, the subjects were then instructed to lower their heels back to the starting position immediately. In this study, the heel rise cycle was divided into two phases, the heel rise phase and the pause phase.

Data collection and processing

The motion capture system (OptiTrack Motion Capture Systems, USA) was used to provide information about three-dimensional (3D) segment angular displacement. Markers were placed on the lateral and medial aspect of the knee joint, the lateral malleolus, the medial malleolus, the first metatarsal head, the fifth metatarsal head and the second toe. Marker positions were sampled at a frequency of 100 Hz. Time-averaged profiles for ankle joint 3 D angular displacements were calculated for each subject. Mean profiles of each group were subsequently calculated. In the heel rise phase, foot kinematic angles at the point of peak ankle plantar flexion were analysed. The average foot kinematic angles were calculated during the pause phase. In this study, we recorded information from the tibialis anterior (TA), gastrocnemius lateralis (GL), PL, peroneus brevis (PB), and tibialis posterior (TP) muscles for subjects in each group. Electromyography (EMG) activity was recorded using pre-amplified electrodes (SX230-1000; Biometrics Ltd., UK) applied to lightly abraded skin over the respective muscle belly. The signals were amplified, and filtered by a band pass filter (at 20 and 500 Hz) and sampled at 1,000 Hz.

The signal was then full-wave rectified. Data between the period of 80 ms pre-maximum plantar flexion velocity and 80 ms post-maximum plantar flexion velocity were extracted from the EMG records for each muscle on each participant. The root mean square EMG (RMS EMG) was calculated for each muscle during the heel rise phase and the pause phase. After extraction of the relevant data, EMG records were normalized with respect to maximal voluntary contraction (MVC) EMG amplitude for each subject.

Statistical analysis

All statistical analysis was performed using SPSS Statistics (version IBM Corporation, Armonk, USA). The Kolmogorov-Smirnov tests were performed as the test of normality. Differences between the FAI and control groups were tested for statistical significance using independent two-sided t-tests for the variables that had a normal distribution. The muscular activities of the PB during the heel rise phase were not normally distributed, so they were evaluated using the Mann-Whitney U test. Effect sizes (ES) and mean differences with 95% confidence intervals (CI) were calculated to determine the clinical relevance of a significant difference. For the variables that had a normal distribution, ES was based on the report of Cohen's d as small (0.2), medium (0.5) or large (0.8) [24]. The effect sizes were interpreted as small (0.1), medium (0.3) or large (0.5), for the variables that had a not normal distribution [25]. A p-value <0.05 was considered statistically significant.

Results

No significant differences were found between the FAI group and the control group in terms of age (years), height (m), or weight (kg). There was a significant difference between the FAI group (29.00 ± 0.67) and the control group (21.00 ± 2.58) regarding the CAIT (Japanese version) score (P<0.01).

Kinematic date

During the heel rise phase, the FAI group tended to present less inversion at the point of peak ankle plantar flexion compared with inversion in the control group (P=0.071). The ES for inversion/eversion were large (Cohen's d=0.86).

During the pause phase, the FAI group tended to be in a more adducted position compared with adduction in the control group (P=0.060). The ES for abduction/adduction were large (Cohen's d=0.90). The FAI group also tended to present a less inverted position compared to that of the control group (P=0.069), and the ES were large (Cohen's d=0.87).

EMG data

The results showed that the EMG activity did not differ between the FAI group and the control group during the heel rise phase for any of the muscles. However, during the pause phase, the muscular activities of the PB were significantly greater in the control group than in the FAI group (P<0.05). The ES were large (Cohen's d=1.04). During the pause phase, the muscular activities of the TP tended to be greater in the control group than in the FAI group (P=0.076), and the effect sizes were large (Cohen's d=0.84). There were no significant differences in the other muscle activities between the two groups.

Results are given in Tables 1-4.

Kinematic angle	FAI Group (n=10)	Control Group (n=10)	P-value	95% CI	ES
Ankle dorsi/ plantar flexion angle(°)	-38.84 ± 3.78	-41.44 ± 5.49	0.233	-7.03–1.82	0.55
Ankle inv/ eversion angle (°)	6.58 ± 3.84	10.98 ± 6.14	0.071	-9.21 – 0.42	0.86
Foot abd/ adduction angle(°)	-9.96 ± 4.28	-6.93 ± 3.74	0.109	-0.74 – 6.81	0.76
Note. Values are mean ± S.Ds					

Table 1: Foot kinematic angles at the point of peak ankle plantarflexion in the heel rise phase in FAI group compared to control group.

Muscle	FAI Group (n=10)	Control Group (n=10)	P-value	95% CI	ES
Tibialis Anterior (%MVC)	7.66 ± 4.54	11.16 ± 7.14	0.207	-2.12-9.12	0.59
Gastrocnemius Lateralis (%MVC)	45.34 ± 15.91	52.35 ± 11.81	0.278	-6.15-20.17	0.5
Peroneus Longus (%MVC)	41±8.23	45.35 ± 11.69	0.348	-5.15-13.85	0.43
Peroneus Brevis (%MVC)	35.62 ± 5.03	44.17 ± 14.1	0.796	-1.85-18.94	0.07
Tibialis Posterior (%MVC)	34.11 ± 10.94	34.71 ± 10.02	0.9	-9.26-10.46	0.06
Note. Values are mean ± S.Ds					

Table 2: Muscle activity during the heel rise phase in FAI group compared to control group.

Kinematic angle	FAI Group (n=10)	Control Group (n=10)	P-value	95% CI	ES
Ankle dorsi/ plantar flexion angle(°)	39.16 ± 3.08	-41.18 ± 5.81	0.342	-2.34-6.4	0.44
Ankle inv/ eversion angle (°)	6.12 ± 4.43	10.9 ± 6.43	0.069	-0.4-9.98	0.87
Foot abd/ adduction angle(°)	10.55 ± 4.5	-6.56 ± 4.42	0.06	-8.19-0.19	0.9
Note. Values are mean ± S.Ds.					

Table 3: Averaged foot kinematic angles during the pause phase in FAI group compared to control group.

Muscle	FAI Group (n=10)	Control Group (n=10)	P-value	95% CI	ES
Tibialis Anterior (%MVC)	5.49 ± 3.35	6.8 ± 2.86	0.36	-1.62-4.23	0.42
Gastrocnemius Lateralis (%MVC)	31.65 ± 9.02	42.01 ± 16.74	0.102	-2.27-23	0.77
Peroneus Longus (%MVC)	38.05±8.91	39.04 ± 9.71	0.814	-7.76-9.75	0.11
Peroneus Brevis (%MVC)	30.63 ± 7.68	44.51 ± 17.34	0.033	1.29-26.48	1.04
Tibialis Posterior (%MVC)	21.27 ± 9.56	29.23 ± 9.33	0.076	-0.92-16.83	0.84
Note. Values are mean ± S.Ds.					

Table 4: Muscle activity during the pause phase in FAI group compared to control group.

Discussion

During the pause phase, the FAI group tended to be in a more adducted position of the ankle joint than that of the control group in this study. Previous studies have shown that individuals with FAI demonstrate altered kinematics in their functional activity. Doherty et al. [26] reported that subjects in the acute phase of a lateral ankle sprain injury had a more adducted position of the ankle joint during the pre-initial ground contact of gait cycle. Subjects with FAI may also have an adducted position of the ankle joint when the ankle is in plantar flexion. Previous studies have reported that the lateral ankle ligamentous injuries result from a motion combining plantar flexion, adduction, and inversion of the ankle joint [27,28]. Therefore, presenting a more adducted position of the ankle during plantar flexion may lead to recurrent ankle sprain.

In this study, during the pause phase, the FAI group's motion was less inverted, while the control group's motion was inverted. This result disagreed with the finding reported by Delahunt et al. [16], who found a more inverted position in subjects with FAI in the interval before the initial contact. These differences in observations may be the result of differences in the task used in both studies. Although a single-leg drop jump was used in the previous study, the heel rise was used as the task in this study. A heel rise is a closed chain exercise for ankles. During a heel rise, body weight is loaded on an ankle-foot complex and an inversion torque is produced to receive the body weight. Houck et al. [22] reported that healthy subjects exhibit an inverted position of the ankle during the heel rise. Results from our study suggested that the FAI group's range of motion was less efficient than that of the control group's range of motion in the plantar flexed position of the ankle joint. The altered movement in the subjects with FAI varies according to the task. Therefore, it is necessary to find out the characteristics associated with each task.

In the analysis of the muscle activity, the FAI subjects showed a lower PB activity in the pause phase. There have been a few studies on the PB activity of subjects with FAI. The previous studies have reported that the reaction time in the PB muscle of the FAI ankle is slower than the ankle without FAI [29,30]. Impaired neuromuscular patterns have been shown by assessing the reflexive response times of the peroneal muscles to inversion [31-33]. Ankle eversion strength deficits have also been reported among individuals with FAI [11]. The PB is one of the muscles responsible for eversion. Thus, the PB of the FAI group may also have impaired neuromuscular patterns in this study. Functional deficit of the PB in FAI may lead not only to a delay in the muscle reaction time, but also to a decrease of the muscle activity volume in the sustained contraction phase.

The subjects in the FAI group were observed to have a more adducted position of the ankle joint during the pause phase. During the same phase, the subjects in the FAI group also had decreased PB activity compared with that of the subjects in the control group. These results suggested that reduced PB activity may lead to a more adducted position of the ankle joint. It has been reported that FAI decreases the force sense, which describes an individual's ability to detect muscular force generation. Wright and Arnold [34] reported that the ankle affected by FAI had deficits of eversion force sense reproduction. At higher loads, there was an underestimation of desired force [35]. Some authors have also reported that if a subject has a deficit of force sense it is likely to experience a greater underestimation of desired force. Because the study by Flanagan et al. [36] demonstrated that heel rise motion also created a high force load, the PB activity of subjects in this present study may be decreased due to a deficit of force sense during the heel rise. When the muscles contract, musculotendinous units generate stiffness, which serves as the dynamic restraint to joint movement [7]. The PB is integral to the control of supination of the rear foot [37]. The inability of the FAI subjects to exhibit proper control of the PB activity may have been due to a more abducted position of the ankle. These altered movement patterns can be a risk factor for ankle sprains. Thus, it is necessary to improve the muscle function of the PB for the prevention of recurrent ankle sprains.

Although the FAI group showed lower PB activity, there was no significant difference between the groups with regard to PL activity during the pause phase. Many studies have reported that subjects with FAI have longer reaction time of the PL than controls, which indicates that the subjects with FAI have a PL functional deficit. At the ankle joint, the superior articular surface of the talus is narrower posteriorly, which creates a looser fit within the mortise during ankle plantar flexion. Because the ankle's bony stability is decreased during plantar flexion, the lower thigh muscles assume a key role in controlling the adduction of the ankle during this motion. The primary function of the PL is to provide eversion moment similar to the PB. However, its origin, insertion and length were different from the PB. These differences may lead to the difference in muscle function. Otis et al. [38] reported differences in muscle function between the PB and the PL during a simulated early heel rise phase of the gait cycle. They have shown that the calcaneus is in a more abducted position when the PB has been loaded than in the case of the PL-loaded condition. This suggests that the PB plays an important role in controlling the ankle abduction, more so than the PL.

During the pause phase, the FAI group tended to demonstrate a less inverted position of the ankle and tended to have lesser TP activity than did the control group. During the heel rise, an inversion torque was produced. The TP is one of the most important muscles to contribute to this torque. Houck et al. [22] found that subjects with stage II posterior tibial tendon dysfunction have lesser inversion at the point of peak ankle plantar flexion during a heel rise. Our result showed that subjects with FAI exhibited less TP activity, suggesting that they may have a functional deficit of TP. Thus, it was indicated that the functional deficit of the TP led to the altered movement of the ankle joint. The ankle eversion exercise is mainly performed during rehabilitation of an ankle sprain. However, our results suggested that the functional deficit of TP may be one of the factors contributing to the altered movement of the ankle joint. Since the altered movement caused the recurrent ankle sprain, we feel that it is necessary to improve the function of the TP for athletes with FAI.

Limitations

A limitation of our study was that we did not take any measures to consider mechanical ankle instability. Mechanical ankle instability is characterized by pathologic laxity, arthrokinematic impairments, and synovial and degenerative changes [7]. Green et al. [39] suggested that movement of the ankle joint is altered by mechanical ankle instability. Therefore, we believe that future studies investigating subjects with ankle instability should consider both FAI and mechanical ankle instability.

Since only 10 athletes met the CAIT-J inclusion criteria, we did not perform prior power analysis. However, when we performed a post hoc analysis, all results met medium power (1-β>0.6). Thus, the results of this study suggest the characteristics of movement of the subject with FAI. This could have been further validated with a larger sample size.

Conclusion

This study investigated the kinematics of the ankle joint in subjects with FAI during heel rise. We have shown that subjects with FAI exhibited deficits in both kinematics and neuromuscular control. These deficits could be a risk factor for recurrent ankle sprain.

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