The Journal of Foot & Ankle Surgery 58 (2019) 1187–1191

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Relationship Between Isokinetic Muscle Strength and Functional Tests in Chronic Ankle Instability

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ARTICLE INFO

Level of Evidence: 3

Keywords:
ankle joint
chronic disease
exercise test
lateral ligament
muscle strength

ABSTRACT

Isokinetic muscle strength measurements and functional tests are usually performed to evaluate ankle condition in chronic ankle instability (CAI), yet there is no clear demonstration of the relationship between isokinetic muscle strength and functional tests. The objective of this study was to evaluate the relationship between isokinetic muscle strength and functional tests in CAI. Between April 2014 and August 2016, 103 patients with unilateral CAI were studied. Single-leg balance, single-heel raise, and single-leg squat tests were performed for static balancing assessment. Single-leg hop, double-leg jump, and sidestep tests were performed for dynamic balancing assessment. The isokinetic muscle strength of both ankles was measured using a dynamometer. The involved ankle showed lower muscle strength in inversion than the uninvolved ankle, while eversion, dorsiflexion, and plantarflexion muscle strength had no significant differences between ankles. There were significant correlations between the isokinetic muscle strength of inversion and the single-leg balance test, single-heel raise test, and sidestep test (Pearson's *r*; 0.246, 0.514, and 0.229 at 30°/second; 0.288, 0.473, and 0.239 at 180°/second, respectively). The single leg balance, single heel raise, and sidestep tests are useful to assess not only ankle functional performance but also isokinetic muscle strength. Among these tests, the single heel raise test was the most reliable test to reflect muscle strength deficiency in CAI.

The ankle joint is commonly exposed to sp\orts injury because of its function in various activities. Despite reasonable treatments, approximately 10% to 60% of individuals with an initial ankle sprain eventually develop long-standing ankle functional limitations and repetitive sprains, which has been described as chronic ankle instability (CAI) (1–4).

In recent years, recovery of muscle strength and ankle proprioception are the main aims of treatment for CAI (5–7); therefore, isokinetic ankle exercises are commonly used as a primary treatment to increase muscle strength and performance (8–11). Consequently, there are many specific exercise programs to improve muscle strength and ankle functional performance (12–14). To identify the ideal exercise programs for improving ankle instability, a patient's precise ankle condition must be known, including both muscle strength and functional performance ability. A computer-based isokinetic dynamometer is used to measure muscle strength, and various functional tests are used to assess performance ability (5,6,15–18). The relationship between isokinetic muscle strength and functional tests in CAI has not previously been studied however. By understanding this relationship, we can more comprehensively understand a patient's ankle condition. In addition, among various functional performance tests, we can identify the appropriate test to more precisely represent current ankle conditions.

The aim of this study is to determine the relationship between isokinetic muscle strength and functional tests in CAI. A dynamometer assessed isokinetic muscle strength in both involved and uninvolved ankles. These isokinetic muscle strengths were compared with the results of the single-leg balance, single-heel raise, and single-leg squat tests performed to assess static balancing. The single-leg hop, double-leg jump, and sidestep tests were performed to assess dynamic balancing.

Patients and Methods

Subjects

This study included 103 patients who were treated for CAI between April 2014 and August 2016 at our institution; all data were collected prospectively. The local ethics committee approved this study. Patients were considered to have unilateral CAI if they

Financial Disclosure: None reported.
Conflict of Interest: None reported.
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https://doi.org/10.1053/j.jfas.2019.04.005

(1) had an instability that they attributed to the initial injury, (2) had a history of at least 1 ankle sprain on the involved ankle requiring medical care, and (3) reported more than 3 episodes of the ankle giving way on the involved side in the past 12 months. Exclusion criteria included patients reporting any of the following: (1) a history of ankle fracture, (2) bilateral ankle instability, (3) ankle injury within 3 months of participation, (4) a history of anterior cruciate ligament injury, or (5) a history of balance disorders.

Single-Leg Balance Test

Patients are asked to stand on 1 foot without shoes with the contralateral knee bent, not touching the weightbearing leg, and with their hands on their hips. The eyes are open and fixed on a spot marked on the wall. Once stable, patients close their eyes and maintain balance as long as they are able. The investigator notes if a patient's legs touch each other, if the feet moved on the floor, if the foot touches down, or if the arms move from their starting position (19,20).

Single-Heel Raise Test

The test is a modification of the method described by Lunsford and Perry (21) to evaluate static ankle balance. Patients stand facing away from the investigator. They are asked to stand on their involved leg only and to then plantar flex the ankle such that they rise up onto the ball of their feet. The test is terminated when the heel touches the ground.

Single-Leg Squat Test

This test is similar to the single-leg squat test described by Ugalde et al (22), but to evaluate static balance, the maintenance time of the position is measured. Patients are asked to place their hands on their hips, stand on 1 limb, and flex the opposing limb to 90°. They are then instructed to perform a single leg squat to 70° of knee flexion and maintain this knee position. The investigator notes loss of balance and when the foot touches down.

Single-Leg Hop Test

Patients are asked to perform a single-leg forward hop for a maximum distance, similar to the description in previous studies (23−25). They are instructed to hop as far as possible with their hands at their sides. The distance from the location of the distal aspect of their toes from start to landing is measured.

Double-Leg Jump Test

Patients start by standing behind a line with their feet shoulder width apart. Starting in a crouched position, they leap forward off both feet. They attempt to jump as far as possible, landing on both feet without falling backward. The measurement is taken from the takeoff line to the nearest point of contact on landing (back of the heels) (26,27).

Sidestep Test

One complete cycle of the sidestep test is when patients stand at a center line, jump 100 cm to the side (e.g., right) and touch a line with the closest foot, jump back to the center, jump 100 cm to the other side, and then jump back to the center. They try to complete as many cycles as possible in 30 seconds (28).

All functional tests were performed before ankle strengthening rehabilitation in our institution, and 2 trials were performed for each test. The average maintenance time of the single-leg balance, single-heel raise, and single-leg squat tests were recorded in seconds. The average distance of the single-leg hop and double-leg jump tests were recorded in meters. The number of completed cycles was recorded for the sidestep test. Absolute measurements were used for statistical analysis in the double-leg jump and sidestep tests because these could not be separately measured for involved and uninvolved ankles. Otherwise, the relative deficit of the involved foot was used for statistical analysis calculated as follows (29):

$$(\text{uninvolved side} - \text{involved side}) / \text{uninvolved side} \times 100\%$$

Isokinetic Muscle Strength Measurements

The isokinetic muscle strength of both ankles in inversion, eversion, dorsiflexion, and plantarflexion were assessed at the time of ankle functional test. A blinded athletic therapist performed all strength measurements using a computer-based isokinetic Cybex dynamometer (CSMI HUMAC Norm, Stoughton, MA). Five isokinetic cycles of inversion, eversion, dorsiflexion, and plantarflexion were performed at a speed of 30°/second and 15 isokinetic cycles were performed at 180°/second angular velocity. The peak torque of the involved and uninvolved ankles was measured. The relative deficit in peak torque was calculated according to the previously mentioned method in the functional test.

Statistical Methods

Outcomes were analyzed for a normal distribution using the Kolmogorov-Smirnov test. Paired *t* test was used to determine if there was any significant difference between involved and uninvolved ankles. Pearson correlation coefficient was used to determine the relationship between isokinetic muscle strength and functional tests. A chi-squared test was used for patient sex, and Pearson correlation coefficient was used for age, leg dominance, height, weight, and body mass index. Statistical analysis was performed using SPSS v20.0 (SPSS Inc., Chicago, IL). Statistical significance was defined at the 5% ($p \leq .05$) level.

Results

A total of 103 patients were enrolled in this study. The mean patient age was 32.4 (range 18 to 55) years; 47(45.6%) patients were male and 56 (54.4%) were female. Of all cases, 46 (44.7%) cases were on the right side and 57 (55.3%) cases were on the left side. A total of 88 patients had right side dominance and 15 patients had left side dominance. Height, weight, and body mass index were 167.5 ± 9.1 cm, 67.2 ± 14.2 kg, and 23.8 ± 3.9 kg/m^2, respectively (mean ± standard deviation). According to the chi-squared test and Pearson correlation coefficient, there was no correlation between basic patient demographics and assessment outcomes ($p > .05$).

Functional test results are summarized in Table 1. The involved ankle showed significantly lower functional status than the uninvolved ankle for both static and dynamic balancing. Table 2 gives the results of Cybex dynamometer isokinetic muscle strength measurements. Peak torque of the involved ankle at both angular velocities (30°/second and 180°/second) in inversion activity was significantly lower than that of the uninvolved ankle. There was a trend toward lower peak torque of the involved ankle compared with the uninvolved ankle in eversion, but there were no significant differences in eversion, dorsiflexion, and plantarflexion. With 103 patients, the study has 0.96 power to detect an effect size of 0.37 between

Table 1
Results of functional assessment tests (N = 103 patients)*

	Static Balance			Dynamic balance		
	Single-Leg Balance, seconds	Single-Heel Raise, seconds	Single-Leg Squat, seconds	Single-Leg Hop, m	Double-Leg Jump, m	Sidestep, repetitions/30 seconds)
Involved	23.6 ± 8.8	3.1 ± 5.8	19.0 ± 10.9	1.7 ± 0.4	1.45 ± 0.5	10.31 ± 3.27
Uninvolved	28.0 ± 5.1	4.6 ± 4.4	23.1 ± 8.9	1.8 ± 0.4		
Deficit, %	17.4 ± 12.8	30.7 ± 24.3	21.2 ± 13.5	10.8 ± 8.1	NA	NA
p value†	<.001	<.001	<.001	.005	NA	NA

Abbreviation: NA, not applicable.
* Values are given as mean ± standard deviation.
† Involved vs. uninvolved ankle

Table 2
Cybex dynamometer results of peak torque (Nm)* (N = 103 patients)

	Inversion		Eversion		Dorsiflexion		Plantarflexion	
	30°/second	180°/second	30°/second	180°/second	30°/second	180°/second	30°/second	180°/second
Involved	21.5 ± 10.2	21.4 ± 10.4	15.8 ± 6.6	15.2 ± 5.9	30.3 ± 11.6	22.8 ± 8.5	68.1 ± 38.3	37.5 ± 19.8
Uninvolved	25.5 ± 11.2	25.7 ± 11.3	17.2 ± 6.7	18.0 ± 6.8	28.7 ± 10.1	21.2 ± 7.4	68.3 ± 33.5	36.0 ± 17.6
Deficit, %	24.6 ± 18.0	20.4 ± 14.2	13.1 ± 23.8	6.2 ± 19.0	−1.8 ± 21.7	−2.4 ± 26.3	6.8 ± 24.7	2.3 ± 26.3
p value†	.017	.008	.194	.528	.368	.215	.974	.627

* Data are presented as mean ± standard deviation.
† Involved vs. uninvolved ankle

involved and uninvolved ankle in inversion peak torque with a type I error probability of 0.05.

Correlation Analysis

For the double-leg jump and sidestep tests, absolute measurement values were used for correlation analysis; otherwise, the percentage of relative deficit was used. Results of the single-leg balance, single-heel raise, and sidestep tests showed significant correlation with the isokinetic muscle strength of inversion at both 30° and 180°/second angular velocities. Among these tests, the single heel raise test showed the highest Pearson correlation coefficient (0.514 at 30°/second, 0.473 at 180°/second, respectively). However, none of the isokinetic muscle strength data correlated significantly with the single leg squat test, single leg hop test, or double leg jump (Table 3).

Discussion

The primary findings of our study were: (1) muscle strength in inversion was significantly different for involved and uninvolved ankles; and (2) single-leg balance, single-heel raise, and sidestep tests showed a significant correlation with inversion strength deficits. Among 6 functional tests, the single-leg balance test was well known and has already been shown to be associated with ankle instability, especially on proprioceptive deficits (6,16,17,19). The single-heel raise and sidestep tests were also demonstrated as reliable methods for assessing ankle joint performance and ankle instability (21,28,30−33). These tests demonstrate not only ankle proprioception but also ankle muscle strength. Furthermore, the single-heel raise test was the most reliable test to reflect inversion strength deficiency in CAI. This set of tests can be used to evaluate the effect of isokinetic ankle exercises in muscle strengthening, especially inversion power.

Various studies on muscle strength deficits in CAI have been conducted, and 3 distinct theories have been suggested for the relationship between muscle weakness and CAI. Bonnin (34) proposed the first theory in 1950, which suggests that the evertors must be strong enough to counter the inversion mechanism associated with a repeated ankle sprain. In addition, Bosien et al (35) and Staples (36) reported that peroneal muscle weakness is present in a substantial percentage of subjects with functional ankle instability. On the basis of these studies, strengthening of the evertor muscles was widely advocated as a key component of lateral ankle sprain rehabilitation. However, both clinical studies cited previously were thought to lack objectivity because muscle weakness was subjectively determined using a manual muscle test.

After the first study that measured peak torque with a Cybex isokinetic dynamometer in CAI (37), various studies were performed to assess the muscle strength of ankle motion in CAI. As a second theory, many authors concluded that lack of muscle strength was not a factor contributing to CAI because they failed to support the finding of muscle weakness in CAI (38−41). No differences were seen in either inversion or eversion strength between the healthy and functionally unstable ankles. According to these results, proprioceptive activities should be a primary consideration in the management of CAI.

A third, more recent theory is that weakness of the ankle invertor is a contributing factor because there is a difference in inversion peak torque between the CAI ankle and the opposite uninvolved ankle (42,43), consistent with the results of our study. During closed-chain eversion in the weightbearing foot is characterized by flattening of the medial longitudinal arch, the lateral displacement of the leg in relation to the relatively stationary foot occurs, and the eccentric contraction of ankle invertors controls the extent of displacement. Excessive lateral displacement of the leg induces lateral shifting of the center of gravity beyond the lateral border of the foot, which is referred to as lateral postural sway. Lateral postural sway causes the lateral border of the foot to act as a fulcrum that induces sudden inversion of the foot beneath the weightbearing leg; therefore, the eccentric action of the ankle invertor muscles that control lateral postural sway may play an important role in maintenance of dynamic ankle stability and weak invertor muscles may contribute to CAI. Considering the evidence of deep peroneal nerve injury after lateral ankle sprain (44), weak inversion might result from selective inhibition or deep peroneal nerve dysfunction as a result of overstretching the peroneal nerve after the initial ankle sprain. This inversion weakness induces further ankle sprain, and this vicious cycle may eventually lead to CAI.

In addition to the previously mentioned studies, several authors have investigated strength deficiency in CAI. Hertel (7) identified inversion and dorsiflexion strength deficits, and similar results were also found in other studies. In addition, Fox et al (45) found eccentric plantar flexor torque deficits in functionally unstable ankles and no deficits in inversion, eversion, or dorsiflexion torque. Feger et al (46) found significantly less

Table 3
Pearson correlation coefficients between inversion peak torque and functional tests (N = 103 patients)

	Static Balance			Dynamic Balance		
	Single-Leg Balance	Single-Heel Raise	Single-Leg Squat	Single-Leg Hop	Double-Leg Jump	Sidestep
30°/second	0.246	0.514	0.087	−0.042	−0.006	0.229
p value	.005	<.001	.321	.633	.945	.009
180°/second	0.288	0.473	0.113	−0.101	0.010	0.239
p value	.001	<.001	.200	.254	.912	.006

eversion and dorsiflexion strength compared with a healthy control group. They also evaluated quantitative foot and ankle muscle volumes in patients with CAI using magnetic resonance imaging, which showed that the CAI group had smaller total shank, superficial posterior compartment, soleus, adductor hallucis oblique, and flexor hallucis brevis muscle volumes compared with healthy controls. However, these findings do not explain the previously mentioned variable strength deficits. Our results also differed from the results of these studies.

To assess static balancing, the single-leg balance and single-heel raise tests showed significant correlation with inversion strength deficit of the ankle in CAI. Unlike the single-leg squat test in which ankle joints tend toward dorsiflexion, the ankle joint is neutral or in plantarflexion in these tests. With a neutral or plantarflexed ankle joint, the subtalar joint tends to an inverted position, which gives increased stability to the midfoot. Ankle balance might be more precisely evaluated in this position with a stable midfoot. The single-heel raise test showed a higher Pearson's *r* score. That might be due to more increased stability in the midfoot compared with the single leg balance test. In the dynamic balancing assessment, sidestep showed a more significant correlation than other tests. This might indicate that repeated use of inversion and eversion is better to evaluate dynamic balancing. Further study including electromyographic examination during ankle motion is needed to fully understand these mechanisms in CAI.

The relationship between muscle strength and functional performance tests has been well examined in the knee joint. Petschnig et al (47) evaluated isokinetic knee extensor muscle strength and the results of 4 functional tests of knee joint performance after anterior cruciate ligament reconstruction. They concluded that specific functional tests can detect functional performance limitations and muscle strength deficits; therefore, these tests can be used as a reference guide for rehabilitation outcome. Wilk et al (48) found a significant positive correlation between isokinetic knee extension peak toque and the 3 hop tests. Ostenberg et al (49) concluded using linear regression models corrected for body weight, height, and age that there were low correlations between isokinetic strength measurements and functional tests. They suggest that functional performance testing and isokinetic testing should not be used interchangeably. Yildiz et al (50) also concluded that improvement in functional capacity tests did not correlate with isokinetic muscle parameters. The author's conclusions showed debate about the relationship between isokinetic muscle strength and functional tests in the knee joint. Studies similar to ours performed with other joints would be help to clarify the overall relationship.

Despite numerous studies over many years, muscle strength deficits in CAI are not fully understood. Our study is the largest study that prospectively examined muscle strength deficits in CAI using a consistent examiner, as far as we are aware. Our results may therefore be helpful to better understanding of CAI. Moreover, and to the best of our knowledge, this is the first study that has demonstrated the relationship between isokinetic muscle strength and functional tests in patients with CAI. Isokinetic muscle strength deficits and functional ankle performance in CAI can be assessed with the single-leg balance, single-heel raise, and sidestep tests.

A limitation of this study is that it does not include postrehabilitation results for correlation analysis. The single-leg balance, single-heel raise, and sidestep tests are well correlated with isokinetic muscle strength in CAI before strengthening rehabilitation. The diagnostic value of these 3 functional tests was identified and can be applied to evaluate ankle condition before rehabilitation. For the more accurate assessment, however, we have to identify the change of isokinetic muscle strength and functional test results after rehabilitation. To demonstrate that the ankle inversion weakness seen in our study is a definite etiology of CAI, results should be investigated after specific rehabilitation of the inversion muscle. To this aim, we will conduct a prospective study for selective inversion muscle rehabilitation in CAI.

In conclusion, this study evaluated the relationship between isokinetic muscle strength and functional tests in CAI. By comparing 2 parameters, a significant correlation was found between inversion strength deficit and the single-leg balance, single-heel raise, and sidestep tests. Consequently, these tests are useful to assess both functional ankle performance and isokinetic muscle strength. In addition, the single-heel raise test was the most reliable test to reflect inversion strength deficiency in CAI.

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