Evaluation of Trunk Muscle Strength and Endurance: A Comparison of Women With and Without Chronic Ankle Instability

Hossam E. Fawaz, PhD, Noha M. Youssef, MSc, Ghada M. Elhafez, PhD, Ahmed S. Yamany, PhD, and Azza M. Abdelmohsen, PhD

Abstract

Objective: The purpose of this study was to compare the strength and endurance of the trunk muscles in women with chronic ankle instability (CAI) compared with those who do not have CAI.

Methods: Sixty-two women were assigned into 2 equal groups of 31; group A included women with CAI and group B included healthy women. Peak torques per body weight of the trunk extensors and flexors were measured using a Biodex System 3 Isokinetic Dynamometer. McGill core endurance tests (prone bridge, right side bridge, left side bridge, trunk flexion, and horizontal back extension) were administered to assess trunk muscle endurance. Statistical analysis using 1-way between-subjects multivariate analysis of variance was performed.

Results: No significant differences in peak torques per body weight strength ratios of trunk extensors and flexors between the 2 tested groups ($P > .05$) were found. Similarly, no significant difference was found in the trunk muscle endurance between the 2 tested groups ($P > .05$).

Conclusion: No statistically significant differences were observed in the strength and endurance of the trunk muscle between women with CAI and healthy women. (J Chiropr Med 2024;00;1-12)

Key Indexing Terms: *Muscle Strength; Physical Endurance; Ankle; Joint Instability*

Introduction

Lateral ankle sprains are among the commonly occurring musculoskeletal injuries of the lower extremities.[1] Chronic ankle instability (CAI) affects approximately 40% of individuals who have experienced a lateral ankle sprain.[2] The frequency of CAI injury in women is more than in males.[3] Despite its high incidence, CAI remains a phenomenon that researchers and clinicians still have a limited understanding of. The primary factors contributing to CAI include ligament laxity, muscle strength deficits, impaired proprioception, and compromised postural control.[4]

There are 2 types of CAI; mechanical ankle instability and functional ankle instability (FAI). Various deficiencies that cause each type of instability have been identified in patients with CAI. Lack of proprioception, neuromuscular control changes, muscle weakness,[4] and impaired postural control[5] are the main problems in FAI. However, mechanical ankle instability occurs as a sequence of anatomical abnormalities after the first ankle sprain. They include pathologic laxity, poor arthrokinematics, synovial changes, and joint arthritis.[4]

It has been established that the stability of the lumbopelvic hip complex is referred to as core stability (CS), which plays a crucial role in injury prevention. Deficiencies in CS have been documented in various conditions, including anterior cruciate ligament injuries, patellofemoral joint pain, iliotibial band disorders, and lower back dysfunction.[6,7] The coordination of trunk positioning and movement in relation to the pelvis, with the aim of efficiently generating, transmitting, and controlling force and motion to the peripheral joints, is commonly referred to as CS. The action of the core muscles involves the automatic integration of local single-joint muscles and multijoint muscles to establish stabilization prior to movement, ultimately ensuring proximal stability for distal mobility. This sequential pattern of force generation from proximal to distal, along with the production of corresponding torques, is essential for facilitating proper distal mobility.[8]

The effectiveness of CS training in reducing injury rates and optimizing performance has been recently demonstrated and acknowledged. A previous study indicated that incorporating CS training into a rehabilitation program resulted in a decrease in the incidence of lower extremity injuries.[9] Stability of the core muscles influences lower limb functioning.[10]

Biomechanics Department, Faculty of Physical Therapy, Cairo University, Giza, Egypt.

Corresponding author: Noha M. Youssef, MSc, 26M3+XJM, El-Tahrir St, In Front of Ben El-Sarayat Traffic, Ad Doqi, Al Giza, Giza Governorate 11432, Egypt.
(e-mail: *nohamahmoud55555@gmail.com*).

Paper submitted June 13, 2023; in revised form September 1, 2024; accepted September 5, 2024.
1556-3707

https://doi.org/10.1016/j.jcm.2024.09.001

There is limited literature available that elucidates the relationship between CS and injury prevention. Core muscle endurance is the most predictable method of CS measurement, neuromuscular control, and function evaluation. Core endurance tests were used to identify athletes who have a higher incidence of injuries and evaluate the effectiveness of rehabilitation programs.[11]

To the best of the authors' knowledge, only a few studies have examined the relationship between the CS indicators and lower extremity injury,[12,13] and no previous studies have investigated the relationship between CS and CAI. Therefore, the purpose of this study was to compare the strength and endurance of the trunk muscles in women with CAI compared with those who do not have CAI.

Methods

Participants

This study involved 62 women recruited from the outpatient clinic of the faculty of physical therapy. They were selected as a purposeful sample according to the inclusion criteria. They were diagnosed with CAI and fulfilled the requirements. They were classified into 2 equal groups of 31: group A included women with CAI and the healthy control (group B) included healthy women. Before the assessment, all female participants read and signed an informed consent form. The participant's name, age, address, body mass, height, and phone number were recorded. The research study was approved by the Faculty of Physical Therapy research ethics committee, Cairo University (P.T.REC/012/003263).

Inclusion Criteria. Participants were included in the study if they had at least 1 significant ankle sprain (associated with inflammatory symptoms and at least 1 interrupted day of desired physical activity). The first ankle sprain must have occurred at least 12 months prior to the study enrollment. The most recent injury must have developed at least 3 months prior to the study recruitment (unassisted walking without limping for at least 3 months after injury). Previous symptoms of the affected ankle joint including giving way, recurrent sprain and/or sensations of instability were also inclusion criteria. The affected ankle was more painful, unstable, and functionally impaired than the unaffected one[14,15] (the Oswestry Disability Index [ODI] score for each group was from 0 to 20% [minimal disability]).[16] The Identification of Functional Ankle Instability questionnaire (IdFAI) score for the healthy control group (B) was less than 10 and for group A was 11 or more.[17]

Exclusion Criteria. Participants were excluded if they had any of the following criteria: previous history of lower limb fractures or operations, a recent injury to the lower extremity joints 3 months ago, which affected the joint integration and activity (ie, sprains, fractures),[15] a positive anterior drawer or talar tilt tests,[14] any shoulder[7] and/or elbow joints injuries[18] as they hamper doing the core endurance tests.

Instrumentation

Each participant of the 2 tested groups was examined using:

Biodex Isokinetic Dynamometer System. The Biodex System 3 Isokinetic Dynamometer (Biodex Medical System) is a multijoint testing and rehabilitation system. It was used to measure the peak torques per body weight ratios (PT/BW) of the trunk flexors and extensors. During the joint's movement, the isokinetic dynamometer maintains a consistent velocity and offers an accommodating resistance. It provides a safe and objective method to measure the internal muscle torque during the maintained constant velocity.[19]

The system consists of a head assembly that can be tilted and rotated and its height can be adjusted according to the testing condition, a seat that similarly can be adjusted, and a control unit (Fig 1). The results are provided in the form of printable testing data tables and graph charts.

The isokinetic dynamometer system provides a mechanical reliable measurement of torque, position, and velocity.[20] According to the force-velocity relationship, the isokinetic trunk muscle strength was evaluated in a concentric contraction mode with an angular velocity of 60°/s which is the most ideal and representative of muscle strength as reported by other researchers.[20]

McGill Trunk Endurance Tests. The endurance of trunk muscles was evaluated using the McGill trunk endurance tests and they are highly reliable tests.[10] The tests were prone bridge, right side bridge, left side bridge, trunk flexion, and horizontal back extension tests. Each participant was informed to hold the test position as long as possible. The examiner recorded the duration in seconds.[21] Multiple repetition McGill trunk endurance tests were performed. Each test was repeated 3 times and the results were averaged for analysis.

Oswestry Disability Index. The ODI[16] is a validated and widely utilized measure to assess the impact of low back pain on disability. It includes 10 concise questions that evaluate the impact of pain on the activities of daily living. It includes questions about pain intensity, personal care, walking, standing, sleeping, and social life. The ODI scores range from 0 (no disability) to 100% (maximum disability).[16]

The score for each section consists of 5 statements; if the participant labeled the first statement, the score is 0, and if the last statement is labeled, the score is 5. The composite scores were computed by dividing the summed score by the total possible score (50), then multiplied by 100 and expressed as a percentage. For every unanswered question, the denominator was lowered by 5 and the total possible score was 45.[16] The ODI score for each participant was performed as a part of the inclusion criteria.

- Example: 16 (total scored)/50 (total possible score) × 100 = 32%

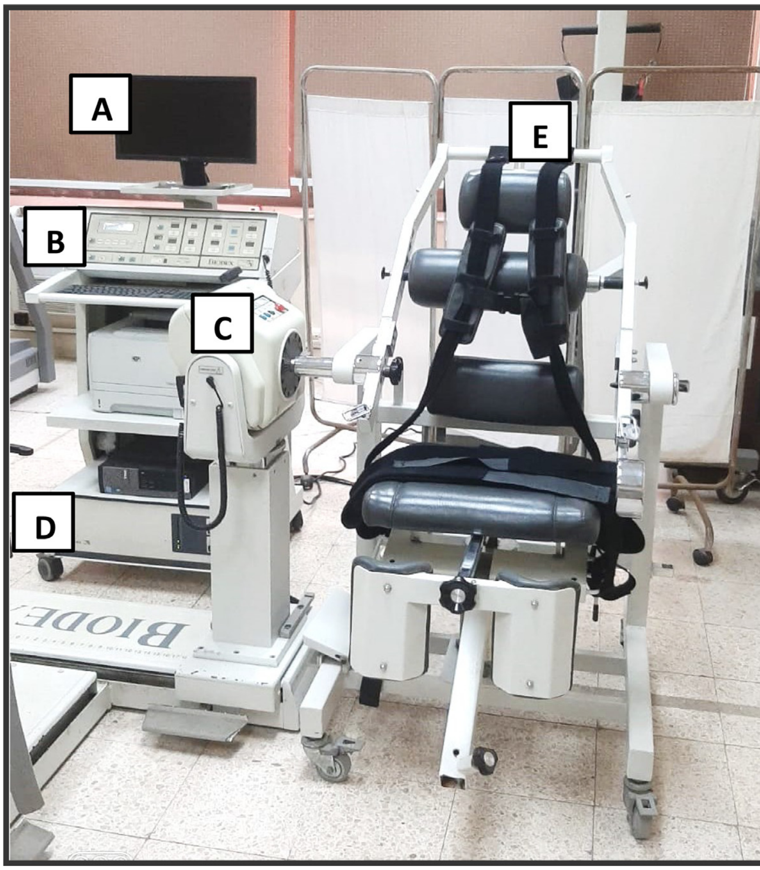

Fig 1. *The Biodex Isokinetic system with its components. Monitor (A), control panel (B), dynamometer (C), controller (D), and positioning chair (E).*

- If 1 section is missed or not applicable, the score is calculated: 16 (total scored)/45 (total possible score) × 100 = 35.5%

The IdFAI Questionnaire. The IdFAI provides a reliable and valid method for classifying the status of FAI individuals.[17,22] It is a sequence of modification and integration of the primary items of the Cumberland Ankle Instability Tool and all questionnaires.[16] When compared with the other self-report measures used to assess the FAI, the IdFAI is the only 1 questionnaire that has a 95% confidence level in predicting the FAI status.[23]

This questionnaire consists of 10 items that can be classified into 3 groups as follows: (1) information regarding the initial ankle sprain, (2) complaints related to ankle instability, and (3) the level of instability experienced during the activities of daily living. The IdFAI scores range from 0 to 37. Scores below 10 indicate the absence of FAI, whereas scores of 11 or higher suggest the presence of FAI. The questionnaire is used independently without comparing it with the contralateral ankle.[16,21] The Arabic version of IdFAI was used.[24] Each participant completed an initial IdFAI questionnaire as a part of the inclusion criteria.

Testing Procedures

Pretesting Procedures (Preparatory Phase). Initially, each participant was asked to sign an informed consent form of participation in the current study. All inclusion and exclusion criteria were checked out. The anterior ankle drawer and talar tilt tests were performed to confirm the inclusion and exclusion criteria (Fig 2).

Anterior Drawer Test. This test (Fig 2A) evaluates the anterior talar translation in relation to the ankle mortise and assesses the integrity of the anterior talofibular ligament. The participant assumed a sitting position with their knee flexed at 90°, and their leg relaxed with the ankle joint in 10° to 20° of plantar flexion (Fig 2A). While palpating the articulation between the lateral surface of the talus and the anterior aspect of the distal fibula, the examiner placed 1 hand on the distal tibia. The other hand grasped the posterior aspect of the calcaneus. Then, the examiner pulled the calcaneus and the talus in an anterior direction while supporting the distal tibia. The test result was negative if there were no side-to-side changes. The result was considered positive if there was greater motion observed on the affected side compared with the unaffected side, indicating instability or abnormal movement.[25]

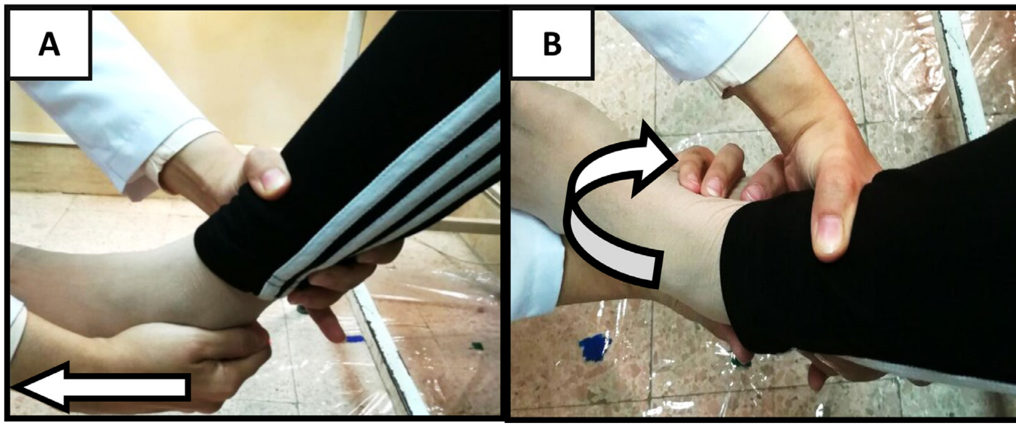

Fig 2. *Anterior drawer test (A) and talar tilt test (B).*

Talar Tilt Test. This test (Fig 2B) evaluates the amount of talar inversion within the ankle mortise and assesses the integrity of the calcaneofibular ligament. The participant assumed a sitting position with 90° knee flexion and the legs relaxed. The examiner grasped the distal tibia and fibula with one hand and the calcaneus with the other hand while maintaining the neutral position of the ankle. Then, the examiner inverted the calcaneus, and the talus, relative to the ankle mortise (Fig 2B). The test result was considered negative if there were no side-to-side changes. The test result was considered positive if there was greater motion observed on the affected side compared with the unaffected side, indicating instability or abnormal movement.[25]

Additionally, each participant completed an ODI and IdFAI questionnaire as a part of the inclusion criteria. Upon arriving at the Isokinetic Laboratory, the participants were provided with an explanation of the nature of the study, its objectives, the equipment used, and the procedures involved. This was done to ensure that the participants were familiar with the study and what would be expected of them during the measurements. Additionally, to maintain a random order of assessment, the sealed envelope method was employed. In this method, the participants randomly selected a paper from the envelope, which indicated whether they would undergo isokinetic testing or McGill core endurance testing.

Testing Procedures. ***Isokinetic Trunk Flexion and Extension Testing Procedures.*** The trunk seated compressed protocol has been adjusted which isolates the movement of the trunk without any pelvic or hip muscle action. To initiate the protocol, the participant was instructed to sit on the isokinetic chair. Straps were utilized to provide support to the pelvis and thighs. The 2 curved anterior leg pads were positioned to support both knees (Fig 3). Additionally, a lumbar support pad was used to provide support to the lower back.[26]

During the measurement of flexion torque, 2 vertical straps were positioned in front of the chest. These straps were then connected by another horizontal strap to apply anterior force. During extension torque measurement, a cushioned roller bar was positioned on the back of the trunk immediately distal to the scapular spine to apply a posterior force. The actuator arm's axis was placed at the point of intersection between the mid-axillary line and the disc space between the fifth lumber to the first sacral vertebrae. Each Participant was positioned in a neutral position which served as the starting position for measuring trunk range of motion (ROM) (Fig 3). Trunk extension ROM was adjusted from 0° neutral position to 20° extension, while trunk flexion ROM was adjusted from 0° neutral position to 50° flexion. The total tested range was 70° (from 20° extension to 50° flexion)[27] (Fig 4). Initially, each participant completed 3 submaximal trials to familiarize herself with the nature of the test followed by a 1-minute rest. After that, the actual testing was done with 3 consecutive maximal concentric trunk extensors' and flexors' contractions at an angular velocity of 60°/s. The examiner instructed each participant to flex and extend the trunk as fast as she could with verbal encouragement to exert her maximal efforts.

McGill Trunk Endurance Testing Procedures. ***Prone Plank Endurance Test (Prone-Bridge Test).*** The frontal and dorsal core muscles were assessed using the prone-bridge test (Fig 5). The participant was instructed to support her body using her elbows and toes while maintaining a neutral position of the pelvis and a straight body posture (Fig 5). The investigator used a stopwatch to measure the duration for which the participant was able to maintain the neutral position of the pelvis. Time was stopped if the participant lost the straight body position or assumed anterior pelvic tilting.[28]

Right Side Plank Endurance Test (Right Side Bridge Test). The lateral core muscle endurance, especially the quadratus lumborum, was assessed using the side-bridge test (Fig 6). The participant was instructed to lie on her right side with the upper foot positioned in front of the

Fig 3. *The starting position (neutral position).*

lower foot while keeping the hip in a neutral position. The participant was asked to keep the hips off the table, supporting herself on her right elbow and feet. The left arm was crossed over the chest with the hand resting on the

Fig 5. *Prone plank endurance test.*

right shoulder (Fig 6). The investigator used a stopwatch to measure the duration for which the participant was able to keep his lower pelvis off the table. Time was stopped if the participant lost the straight body posture and fell onto the table.

Left Side Plank Endurance Test (Left Side-Bridge Test). The same procedures of the right side plank were repeated but for the left side (Fig 7).

Trunk Flexors Endurance Test. The flexors endurance test (Fig 8) evaluates the frontal core muscles. The test started by asking the participant to support her body against a wedge at 60° trunk flexion, 90° hips and knees flexion,

Fig 4. *The participant moves the trunk backward in 20° extension (A) and forward in 50° flexion during the test with a total arc of 70° (B).*

Fig 6. *Right side plank endurance test.*

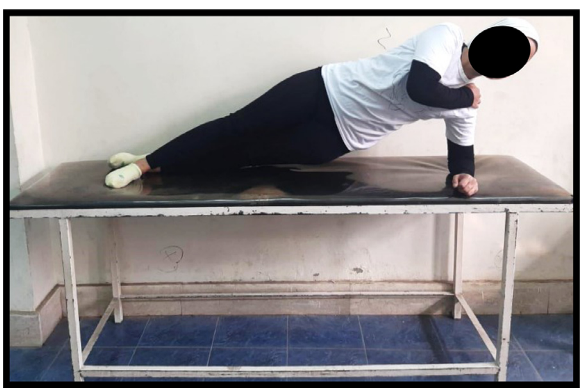

Fig 7. *Left side plank endurance test.*

and neutral head position. Both the arms of the participant were crossed over her chest. The angles of the trunk, hips, and knees were measured using a goniometer. The wedge was positioned as a reference point to ensure that the participant did not touch it with her back during the test. Then, the examiner moved the wedge away and the participant was instructed to hold her position without back support (Fig 8). The total duration the participant was able to keep this position was recorded by a stopwatch. The test was ended when the participant's trunk fell below 60° (touched the wedge).

Horizontal Back Extension Endurance Test (Modified Biering-Sorensen Test). The endurance of the dorsal core muscles was assessed using the horizontal back extension test[29] (Fig 9). The participant was asked to assume a prone lying position while keeping the trunk straight out of the table with the anterior superior iliac spines positioned at the edge of the table, and the lower legs supported by the examiner on the table (Fig 9). The investigator used a stopwatch to measure the period of time the participant was able to keep the trunk in a horizontal position. The test time was stopped when the participant was no longer able to maintain the horizontal back posture and flexed her trunk.

Posttesting Procedures. ***Data Analysis.*** Initially and prior to the final statistical analysis, data were screened for normality and homogeneity of variance assumptions. This exploration was done as a prerequisite for parametric analysis. This was done by assessing the normality tests: Kolmogorov-Smirnov and Shapiro-Wilk tests. In addition, frequency distribution curves were explored for skewness and kurtosis. The results showed that the data were normally distributed for each of the measured variables. The tests of normality indicated that there were no significant differences between the distribution of the tested sample raw data and those of normally distributed population data using the same means as those of the tested variables ($P > .05$). Additionally, both values of skewness divided by the SE of skewness and kurtosis divided by the SE of kurtosis were within the normal ranges, between −2 and +2, after managing outliers. Moreover, boxplots showed no outliers. Furthermore, testing for the homogeneity of variance revealed that there were no significant differences between the variances of both tested groups for the tested dependent variables ($P > .05$). Thus, it was concluded that the data

Fig 8. *The trunk flexors endurance test.*

Fig 9. *Horizontal back extension endurance test.*

were normally distributed and accordingly the normality assumption was not violated. Since the normality and homogeneity of variance assumptions were met, parametric statistical analysis of the collected data was done.

Statistical Analysis

Before starting the study, sample size calculation was done using the G*Power 3.1.9.7 software (developed by department of psychology at Heinrich Heine University Dusseldorf, Germany), which is a valid and objective method to calculate the sample size as a priori type of power analysis. A large effect size f 2 (V) of 0.4 was administered to the software as suggested by Cohen[30] and many recent previous studies.[5,31,32] The α error of probability was set at 0.05 and the power of the study (1-β err prob) was set at 0.8. The software calculated the sample size and revealed that the minimal total required sample size for both groups was 44. The authors examined a larger sample size of 62 women for eligibility to participate in the study to avoid participant drop during the testing procedures and to ensure a good power of significance.

Independent *t* tests were conducted to determine if there were any significant differences in the mean values of age, body mass, height, or body mass index (BMI) between group A and control group B.

In the current study, 1 independent variable was tested. It was the tested group (between-subject factor) with 2 levels; group A included 31 women with CAI and healthy control group B included 31 healthy women. There were 7 dependent variables, which were trunk extensors' PT/BW ratios (Newton.Meters/Kilogram%) (%), trunk flexors' PT/BW ratios (Nm/kg%), prone plank endurance time (seconds), right side plank endurance time (seconds), left side plank endurance time (in seconds), trunk flexors endurance time (seconds) and horizontal back extensors endurance time (seconds). Therefore, 1-way multivariate analysis of variance was conducted to compare the previously stated dependent variables between the 2 tested groups. The α level was adjusted at 0.05 for all the statistical tests ($P < .05$). The statistical analysis was conducted using version 17 (IBM Version) of the Statistical Package for Social Sciences.

Results

Participant Characteristics

The mean values ± SD of age, body mass, height, and BMI were 24.35 ± 2.40 years, 66.00 ± 11.07 kg, 163.29 ± 5.53 cm, 24.62 ± 3.75 kg/m^2, respectively for group A. The data of the healthy control (group B) were 23.54 ± 1.43 years, 67.35 ± 21.80 kg, 160.25 ± 21.25 cm, and 23.59 ± 3.93 kg/m^2, respectively. Concerning the homogeneity between the 2 tested groups in the demographic data, no statistically significant difference in the average values of age, body mass, height, and BMI was detected ($P > .05$) (Table 1).

Box's test for the equality of covariance matrices (as a prerequisite for the parametric multivariate homogeneity analysis) was performed. This test assesses the multivariate homogeneity of covariance and the null hypothesis for the similarity of variances and covariance between the tested groups. There was a nonsignificant difference between both groups for the covariance of the tested dependent variables (F = 1.439; P = .063).

Statistical analysis using 1-way between-subjects multivariate analysis of variance indicated that there were insignificant effects of the tested group factor (independent variable) on the 7 tested dependent variables: trunk

Table 1. *Descriptive Statistics and Independent t tests for the Mean Age, Body Mass, Height, and Body Mass Index in Group A and Control Group B*

Baseline characteristics	Group A (N = 31) X̄ ± SD	Control Group B (N = 31) X̄ ± SD	*t* Value	*P* Value
Age (y)	24.35 ± 2.40	23.54 ± 1.43	1.605	.114
Body mass (kg)	66.00 ± 11.07	67.35 ± 21.80	0.308	.759
Height (cm)	163.29 ± 5.53	160.25 ± 21.25	0.769	.445
BMI (kg/m^2)	24.62 ± 3.75	23.59 ± 3.93	1.058	.294

BMI, body mass index.
Significant at α level of <0.05.

extensors' PT/BW ratios (Nm/kg%), trunk flexors' PT/BW ratios (Nm/kg%), prone plank endurance time (seconds), right side plank endurance time (seconds), left side plank endurance time (seconds), trunk flexors endurance time (seconds) and horizontal back extensors endurance time (seconds) (F = 0.917; *P* = .501).

Similarly, univariate tests detected no significant differences in the mean values of PT/BW ratios (Nm/kg%) of trunk extensors and flexors as well as the endurance times (seconds) of prone plank, right side plank, left side plank, trunk flexors, and horizontal back extensors tests between both group A and the group B (healthy control) (*P* > .05) (Table 2).

Discussion

Core stability plays a critical role in movement and dynamic balance. There is a strong correlation between CS impairments and lower limb injuries. The control of core muscle's endurance and strength increases the link between the upper and lower kinetic body chains. The core muscles are the center of all kinematic chains. Core muscles' function has been demonstrated to affect the structures from the lower back to the ankle joint.[33] To implement this concept in injury prevention, it is necessary to assess the strength and endurance of trunk muscles in patients with CAI just as it was done in the current study. The findings showed no significant difference in trunk extensors and flexors PT/BW strength ratios and trunk muscle endurance times between group A and group B (healthy control) (*P* > .05).

Trunk Muscle Strength Measured by Biodex Isokinetic Dynamometer

In the current study, the average values of the trunk extensors′ and flexors′ PT/BW strength ratios and trunk muscle endurance times were higher in group A compared with the group B (healthy control) but did not reach statistical significance. The unexpected findings of higher endurance times and PT/BW in group A compared with group B may be explained by the fact that individuals with a long history of CAI might complain of neuromuscular impairment than a healthy person or even a person with a

Table 2. *Descriptive Statistics and 1-Way Multivariate Analysis of Variance of Tested Dependent in Group A and Control Group B*

Measured Variables	Tested Groups		Univariate Tests	
	Group A (N = 31) X̄ ± SD	Control Group B (N = 31) X̄ ± SD		
Trunk extensors PT/BW (Nm/kg%)	197.3 ± 71.39	174.4 ± 58.72	F = 1.899	*P* = .173
Trunk flexors PT/BW (Nm/kg%)	118.62 ± 31.85	103.19 ± 32	F = 3.621	*P* = .062
Prone plank endurance time (s)	30.37± 12.86	29.98 ± 12.37	F = 0.015	*P* = .902
Right side plank endurance time (s)	29.75 ± 10.45	25.94 ± 11.76	F = 1.813	*P* = .183
Left side plank endurance time (s)	30.31 ± 12.09	25.11 ± 11.66	F = 2.973	*P* = .090
Trunk flexors endurance time (s)	67.83 ± 34.46	65.19 ± 32.39	F = 0.097	*P* = .757
Horizontal back extension endurance time (s)	60.52 ± 20.79	58.39 ± 17.13	F = 0.195	*P* = .661

PT/SW, peak torques per body weight.
Significant at α level of <0.05.

recent injury. The healthy individuals used the ankle strategy, whereas patients with CAI switched from an ankle to a hip-dominant strategy to keep postural stability. This altered myoelectric activity of the proximal muscles of the trunk and hip, leading to an increase in their strength.[34,35] Therefore, isokinetic PT/BW strength ratios of trunk extensors and flexors in patients with CAI showed a substantial increase compared with those of the healthy controls in the current study.

Early and higher activity of the trunk muscles in patients with CAI is a protective method to support the spine[36] or due to ankle dorsiflexion restriction.[37] This finding[36] comes also in line with the current study as the patients with CAI have greater trunk muscle strength compared with healthy controls.

The findings of the study by Rios et al[34] supported our results and reported that patients with CAI had a lower magnitude of electromyographic activity (EMG) at the muscles around the ankle but higher activity at those around the hip joint. Moreover, they stated that patients with CAI have different muscular activity to compensate for their ankle instability. Specifically, they tend to rely more on the muscles of the hip and spine, which are considered core muscles. In the same context, Lin et al[31] reported that individuals with unilateral CAI have different motor control strategies around the proximal joints bilaterally. They reported early and higher activity of the trunk muscles (bilateral rectus abdominis) in the CAI group compared with the healthy control group.

On the other hand, Karbalaeimahdi et al[38] assessed the muscular activity of the trunk muscles in unilateral ankle sprain using surface EMG during unstable balance conditions by the Biodex Balance System. They reported lower rectus abdominis activity in athletes with CAI compared with the healthy control group. This opposing finding may be due to the difference in the way of performing the test in addition to the method of testing as they used EMG, which assesses individual muscle activity, unlike the isokinetic testing which measures PT of a muscle group.

There is a lack of studies that have specifically examined the correlation between isokinetic trunk muscle strength and CAI. The only study carried out by Abbaszadeh and Delavari[39] used manual muscle testing. It showed that male athletes with CAI had a significant decrease in 60° trunk flexor strength compared with the healthy control group. The opposing results between the studies could potentially be attributed to the different methods of muscle testing employed. Their study utilized manual muscle testing, which involves subjective assessments of muscle strength and may be less accurate and sensitive compared with isokinetic testing.

Trunk Muscle Endurance Measured by McGill Trunk Endurance Tests

The current study revealed no significant differences in the average values of endurance times (seconds) of trunk endurance tests (prone plank, right side plank left side plank, trunk flexors and horizontal back extensors) between group A and group B (healthy control) ($P > .05$). In the current study, multiple repetition McGill core endurance tests were conducted.

The findings of the current research are in agreement with the research of Pathan and Jethwani.[40] They reported that there was no significant difference in the trunk flexors and extensors endurance tests between the players with and without ankle sprain injuries. On the other hand, they reported a significant decrease in lateral musculature endurance in players with ankle sprain injuries. Similarly, Calicchio et al[41] reported a weak correlation between the core muscle endurance and measures of CAI (Balance Error Scoring System), the Foot and Ankle Disability Index, the Foot and Ankle Disability Index sport survey, and Ankle Joint Functional Assessment Tool in athletes.

On the other hand, Razeghi et al[42] disagreed with the findings of the current study. They concluded that athletes with CAI had a significantly lower time of endurance tests in relation to healthy athletes. Concerning the reduced muscular endurance, the back extensors are the most related muscles to the core endurance impairment followed by trunk flexors, right side flexors, and left side flexors. These opposing findings might be explained by the nature of their sample. Their sample included athletes with CAI and they also did not exclude the athletes with low back pain. In addition, athletes are vulnerable to different stresses that affect measures of strength and endurance due to the nature of their sports.

Abdallah et al[43] assessed the core endurance in athletes with noncontact lower extremity injury (sprain or strain) using McGill core endurance testes. The average values of time of prone-bridge and side-bridge tests were significantly shorter in athletes with noncontact lower extremity injuries when compared with healthy athletes. Their findings may not be applicable to all athletes in general. They also conducted their study on athletes with noncontact lower extremity injury (sprain or strain) and did not determine the site of injury, unlike the current study which was conducted specifically on the ankle joint. They recruited the athletes to participate in the study during the season and they did not determine the stage of their injury (acute, subacute, or chronic), whereas the current study was carried out specifically on patients with CAI. This may interpret their different findings from the current study.

The ability of the lumbopelvic stability tests to identify ankle sprain injuries has not been investigated. The static CS tests may not represent the lumbopelvic stability impairments in CAI patients.[44] Marshall et al[44] used another core endurance test in cases of an ankle sprain. They evaluated the trunk stability during the unloading task. They reported a higher latent period of the rectus abdominis and erector spinae muscles and increased trunk displacements in individuals with CAI compared with the healthy control group. Also, the higher latency period means more time is needed to stabilize the spine after the sudden disturbances. The unloading task gives special dynamic challenges not included in the static core endurance tests. Sudden disturbances decreased the sensorimotor system preparation, compared with predictable tasks.[45]

In the current study, it is not obvious why no other clear link was identified between trunk endurance and CAI, but the McGill core endurance tests may not truly represent the lumbopelvic stability in patients with CAI and are unable to discriminate the individuals with and without CAI. The sudden disturbances were required to evaluate the trunk stability impairments in CAI patients. The chosen static tests would not do this.

Limitations

First, the inability of the examiner to ensure the maximum exertion of the participants' efforts during testing when they were asked to exert their greatest efforts. Second, the isokinetic strength testing and McGill core endurance tests are used to evaluate a group of muscles and cannot evaluate a separate or specific muscle. Third, although the core endurance was assessed with widely applicable tests (McGill core endurance tests), as explained earlier, the tests could not sufficiently challenge the sensorimotor system of the participants to detect the between-group differences. These tests assess the static core endurance only. Last, this study was of younger women only; therefore, the findings are limited to younger women. Further, longitudinal studies are needed on both sexes to gain a clearer understanding of this research point.

Conclusion

No statistically significant differences were observed in the strength and endurance of the trunk muscle between women with CAI and healthy women.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): N.M.Y., A.M.A.
Design (planned the methods to generate the results): N.M.Y., A.M.A.
Supervision (oversight, organization, and implementation): H.E.F., G.M.E., A.M.A., A.S.Y.
Data collection/processing (experiments, organization, or reporting data): N.M.Y., A.M.A.
Analysis/interpretation (analysis, evaluation, and presentation of results): N.M.Y., A.M.A., H.E.F.
Literature search (performed the literature search): N.M.Y., A.M.A.
Writing (responsible for writing a substantive part of the manuscript): N.M.Y., A.S.Y., A.M.A., H.E.F.
Critical review (revised manuscript for intellectual content): N.M.Y., A.M.A., G.M.E.

Practical Applications

- This study compared the strength and endurance of the trunk muscles in women with CAI compared with those who did not have CAI.
- No significant differences in PT/BW strength ratios of trunk extensors and flexors between the 2 tested groups ($P > .05$) were found.
- Similarly, no significant difference was found in the trunk muscle endurance between the 2 tested groups ($P > .05$).

References

1. Spennacchio P, Meyer C, Karlsson J, Seil R, Mouton C, Senorski EH. Evaluation modalities for the anatomical repair of chronic ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(1):163-176. https://doi.org/10.1007/s00167-019-05755-1.
2. Miklovic TM, Donovan L, Protzuk OA, Kang MS, Feger MA. Acute lateral ankle sprain to chronic ankle instability: a pathway of dysfunction. *Phys Sportsmed*. 2018;46(1):116-122. https://doi.org/10.1080/00913847.2018.1409604.
3. Doherty C, Delahunt E, Caulfield B, Hertel J, Ryan J, Bleakley C. The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. *Sports Med*. 2014;44(1):123-140. https://doi.org/10.1007/s40279-013-0102-5.
4. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.
5. Youssef NM, Abdelmohsen AM, Ashour AA, Elhafez NM, Elhafez SM. Effect of different balance training programs on postural control in chronic ankle instability: a randomized controlled trial. *Acta Bioeng Biomech*. 2018;20(2):159-169.
6. Hewett TE, Myer GD, Ford KR. Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. *J Knee Surg*. 2005;18(1):82-88. https://doi.org/10.1055/s-0030-1248163.
7. Jacobs CA, Uhl TL, Mattacola CG, Shapiro R, Rayens WS. Hip abductor function and lower extremity landing kinematics: sex differences. *J Athl Train*. 2007;42(1):76-83.
8. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006;36(3):189-198. https://doi.org/10.2165/00007256-200636030-00001.
9. Waldén M, Atroshi I, Magnusson H, Wagner P, Hägglund M. Prevention of acute knee injuries in adolescent female

football players: cluster randomised controlled trial. *BMJ*. 2012;344(344):e3042. https://doi.org/10.1136/bmj.e3042.
10. McGill SM. Core training: evidence translating to better performance and injury prevention. *Strength Cond J*. 2010;32(3):33-46. https://doi.org/10.1519/SSC.0b013e3181df4521.
11. Waldhelm A, Li L. Endurance tests are the most reliable core stability related measurements. *J Sport Health Sci*. 2012;1(2):121-128. https://doi.org/10.1016/j.jshs.2012.07.007.
12. Wilkerson GB, Colston MA. A refined prediction model for core and lower extremity sprains and strains among collegiate football players. *J Athl Train*. 2015;50(6):643-650. https://doi.org/10.4085/1062-6050-50.2.04.
13. De Bruin M, Coetzee D, Schall R. The relationship between core stability and athletic performance in female university athletes. *S Afr J Sports Med*. 2021;33(1). https://doi.org/10.17159/2078-516X/2021/v33i1a10825. v33i1a10825.
14. Hubbard TJ, Kaminski TW. Kinesthesia is not affected by functional ankle instability status. *J Athl Train*. 2002;37(4):481-486.
15. Gribble PA, Delahunt E, Bleakley CM, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *J Athl Train*. 2014;49(1):121-127. https://doi.org/10.4085/1062-6050-49.1.14.
16. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine*. 2000;25(22):2940-2952. https://doi.org/10.1097/00007632-200011150-00017. [discussion 2952].
17. Simon J, Donahue M, Docherty CL. Development of the identification of functional ankle instability (IdFAI). *Foot Ankle Int*. 2012;33(9):755-763. https://doi.org/10.3113/FAI.2012.0755.
18. Ben Kibler W, Sciascia A. Kinetic chain contributions to elbow function and dysfunction in sports. *Clin Sports Med*. 2004;23(4):545-552. https://doi.org/10.1016/j.csm.2004.04.010.
19. Drouin JM, Valovich-mcLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol*. 2004;91(1):22-29. https://doi.org/10.1007/s00421-003-0933-0.
20. Thorp LE, Wimmer MA, Foucher KC, Sumner DR, Shakoor N, Block JA. The biomechanical effects of focused muscle training on medial knee loads in OA of the knee: a pilot, proof of concept study. *J Musculoskelet Neuronal Interact*. 2010;10(2):166-173.
21. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80(8):941-944. https://doi.org/10.1016/s0003-9993(99)90087-4.
22. Donahue M, Simon J, Docherty CL. Critical review of self-reported functional ankle instability measures. *Foot Ankle Int*. 2011;32(12):1140-1146. https://doi.org/10.3113/FAI.2011.1140.
23. Simon J, Donahue M, Docherty CL. Critical review of self-reported functional ankle instability measures: a follow up. *Phys Ther Sport*. 2014;15(2):97-100. https://doi.org/10.1016/j.ptsp.2013.03.005.
24. Khalil AA, Docherty CL, Elhafez SM, Mattar AG. Validity and reliability of the Arabic version of the Identification of Functional Ankle Instability questionnaire (IdFAI-Ar) in college-aged population. *Phys Ther Sport*. 2021;49:250-254. https://doi.org/10.1016/j.ptsp.2021.03.008.
25. Martin RL, Davenport TE, Paulseth S, Wukich DK, Godges JJ, Orthopaedic Section American Physical Therapy Association. Ankle stability and movement coordination impairments: ankle ligament sprains. *J Orthop Sports Phys Ther*. 2013;43(9):A1-A40. https://doi.org/10.2519/jospt.2013.0305.
26. Hamada Y, Okubo Y, Hattori H, Nazuka T, Kikuchi Y, Akasaka K. Relationship between isokinetic trunk muscle strength and return to sports competition after conservative therapy in fresh cases of lumbar spondylolysis: a retrospective observational study. *Healthcare (Basel)*. 2023;11(4):625. https://doi.org/10.3390/healthcare11040625.
27. Aly SM, Abd El-Mohsen AM, El Hafez SM. Effect of six weeks of core stability exercises on trunk and hip muscles' strength in college students. *Int J Ther Rehabil*. 2017;6(2):9-15. https://doi.org/10.5455/ijtrr.000000237.
28. Bliss LS, Teeple P. Core stability: the centerpiece of any training program. *Curr Sports Med Rep*. 2005;4(3):179-183. https://doi.org/10.1007/s11932-005-0064-y.
29. de Araujo Ribeiro Alvares JB, Rodrigues R, de Azevedo Franke R, et al. Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Phys Ther Sport*. 2015;16(1):59-65. https://doi.org/10.1016/j.ptsp.2014.04.004.
30. Cohen J. *Statistical Power Analysis for the Behavioral Science*. Lawrence Erlbaum Associates; 1988.
31. Lin CI, Khajooei M, Engel T, et al. The effect of chronic ankle instability on muscle activations in lower extremities. *PLoS One*. 2021;16(2): e0247581. https://doi.org/10.1371/journal.pone.0247581.
32. Tahoon AM, Abdelmageed SF, Mosaad DM. The mechanical relation between chronic ankle instability and pelvic alignment: a matched case-control study. *Ann Appl Sport Sci*. 2022;10(4):e1076. https://doi.org/10.52547/aassjournal.1076.
33. Bullock-Saxton JE, Janda V, Bullock MI. The influence of ankle sprain injury on muscle activation during hip extension. *Int J Sports Med*. 1994;15(6):330-334. https://doi.org/10.1055/s-2007-1021069.
34. Rios JL, Gorges AL, dos Santos MJ. Individuals with chronic ankle instability compensate for their ankle deficits using proximal musculature to maintain reduced postural sway while kicking a ball. *Hum Mov Sci*. 2015;43:33-44. https://doi.org/10.1016/j.humov.2015.07.001.
35. Son SJ, Kim H, Seeley MK, Hopkins JT. Altered walking neuromechanics in patients with chronic ankle instability. *J Athl Train*. 2019;54(6):684-697. https://doi.org/10.4085/1062-6050-478-17.
36. Ghamkhar L, Kahlaee AH. Trunk muscles activation pattern during walking in subjects with and without chronic low back pain: a systematic review. *PM R*. 2015;7(5):519-526. https://doi.org/10.1016/j.pmrj.2015.01.013.
37. Guan XY, Kuai SZ, Song L, et al. Effects of ankle joint motion on pelvis-hip biomechanics and muscle activity patterns of healthy individuals in knee immobilization gait. *J Healthc Eng*. 2019(1): 3812407. https://doi.org/10.1155/2019/3812407.
38. Karbalaeimahdi M, Alizadeh MH, Minoonejad H, Behm DG, Alizadeh S. Higher leg and trunk muscle activation during balance control in copers versus people with chronic ankle instability and healthy female athletes. *Sports (Basel)*. 2022;10(8):111. https://doi.org/10.3390/sports10080111.
39. Abbaszadeh A, Delavari MA. Comparing balance, function, strength and endurance of selected core muscles in male volleyball players with and without a chronic ankle sprain in Bandar Abbas: a descriptive study. *J Rafsanjan Univ Med Sci*. 2019;18(3):251-266.

40. Pathan R, Jethwani D. Comparative study of core muscle endurance, balance and ankle instability in basketball players with and without ankle sprain injuries. *Int J Phys Educ Sports Health*. 2022;9(1):151-154.
41. Calicchio A, Ludwig G, DeBeliso MA. Is there a relationship between core muscular strength and chronic ankle instability? *J Phys Educ Res*. 2016;3(2):48-58.
42. Razeghi A, Rahnama N, Shokri E, Ghanbary A. Evaluation of endurance of core muscles in female athletes with chronic ankle instability. *J Paramedical Sci Rehabil*. 2017;6(1):47-57.
43. Abdallah AA, Mohamed NA, Hegazy MA. A comparative study of core musculature endurance and strength between soccer players with and without lower extremity sprain and strain injury. *Int J Sports Phys Ther*. 2019;14(4):525-536. https://doi.org/10.26603/ijspt20190525.
44. Marshall PWM, McKee AD, Murphy BA. Impaired trunk and ankle stability in subjects with functional ankle instability. *Med Sci Sports Exerc*. 2009;41(8):1549-1557. https://doi.org/10.1249/MSS.0b013e31819d82e2.
45. Dicus JR, Seegmiller JG. Unanticipated ankle inversions are significantly different from anticipated ankle inversions during drop landings: overcoming anticipation bias. *J Appl Biomech*. 2012;28(2):148-155. https://doi.org/10.1123/jab.28.2.148.