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ORIGINAL ARTICLE

The Mechanical Relation between Chronic Ankle Instability and Pelvic Alignment: A Matched Case-Control Study

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ABSTRACT

Background. Mechanical relation between the foot and pelvic alignment had been studied in healthy subjects and individuals with other musculoskeletal disorders; however, in chronic ankle instability (CAI), it has not yet been determined. **Objectives:** To investigate the difference in pelvic torsion (PT) among individuals with CAI and uninjured subjects and correlate PT with perceived ankle instability sensation and giving way episodes. **Methods.** This matched case-control study was performed on fifteen participants with unilateral CAI and 30 matched controls. All participants with CAI scored ≤ 24 on the Cumberland Ankle Instability Tool. The control participants were sex- and dominance limb-matched to the CAI group. A pelvic inclinometer and 10-cm visual analog scale were used for measuring PT and perception of ankle instability, respectively. The Mann–Whitney U-test and Pearson correlation coefficient were used for statistical analysis. **Results.** A statically significant difference in PT was observed between CAI participants and controls ($P < 0.05$) with a large clinically meaningful difference (effect size = 1.12). However, no significant ($P > 0.05$) relationships were observed between PT and perceived ankle instability or giving way episodes. **Conclusion.** Patients with unilateral CAI appear to have PT as a proximal strategy to maintain the proximal stable base and compensate for distal ankle instability. The clinically detectable difference in PT helps clinicians be aware of the chronic maladaptations in CAI. Additional studies are needed to investigate other lumbopelvic impairments affecting pelvic kinematics and ankle stability.

KEYWORDS: ***Ankle, Joint Instability, Pelvis, Foot, Biomechanical Phenomena, Visual Analog Scale.***

INTRODUCTION

Lateral ankle sprain (LAS) is one of the most prevalent lower limb musculoskeletal injuries during sports among athletes or daily living activities within the general population. LAS extends beyond being a benign ligamentous injury as the index LAS turns on a gateway to more negative sequelae: chronic symptoms, residual impairments, and high recurrence rate (1) leading to CAI condition. CAI represents the most common impairment with an incidence rate of approximately 40% that is characterized mainly by giving way to episodes and perception of ankle instability persistent for at least 1 year following LAS (2).

The International Ankle Consort (3) considers both LAS and CAI as significant global healthcare issues due to physical and functional long-term impairments affect health-related quality of life and expand to more proximal body regions that result from the spinal and supraspinal compensations, including sensorimotor and biomechanical changes, to control ankle joint motions. However, these compensations are inadequate to prevent re-sprain and contribute to

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CAI, leading to chronic neuromuscular maladaptation in different body locations (4).

One of those pathomechanics compensations is excessive foot inversion that had been determined after acute LAS and during walking or running in patients with CAI who exhibit more ankle inversion (6º–7º) than uninjured subjects or copers (4). Moreover, the coordination deficiency between the rearfoot and shank along with increased rearfoot inversion and tibial external rotation (5, 6) predispose individuals with CAI to further LAS.

On a biomechanical basis, lower extremity joints act as a serial linkage in which dysfunction of one joint could lead to, result from, or be corrected by compensation from other joints. The interrelationship between foot position and pelvis alignment had been investigated in healthy subjects (7) Subsequently, alterations in rearfoot and shank kinematics in CAI could trigger lower extremity chain reactions and influence pelvic alignment. However, other authors have revealed that the effect of calcaneal inversion motion was too small to be detected in the pelvis in healthy subjects, suggesting that pelvis malalignment could occur with time (8). Thus, pelvic alignment could be mechanically affected in individuals with CAI.

According to the literature, there is a gap of knowledge around the static pelvic alignment in CAI, and only a few studies have assessed pelvic kinematics despite the mechanical importance of the pelvis (9, 10). The pelvic region represents the basis of the axial system, which influences spinal stability. Stability means preserving structural integrity and limiting displacement. Deficiency in pelvic stabilization correlates with a dynamic balance deficit which leads to a recurrent ankle sprain. Moreover, alterations in pelvis position affect the function of core muscles that have implications for ankle sprain and lower extremity injuries through controlling lower extremity rotation and ankle position (11). Pelvic asymmetry (PA) occurs in different forms; lateral pelvic tilt in the frontal plane, pelvic axial rotation in the transverse plane, and PT in the sagittal plane, which is the most common one. PT is defined as the absolute difference in sagittal inclination between the right and left innominate (12). Assessing PT rather than the pelvic inclination of the affected limb is more clinically meaningful as the ipsilateral and contralateral sides are affected in CAI.

PA results in a deficiency to dissipate the spinal cephalad or caudal forces that could trigger shearing stress in the sacroiliac joint, which results in sacroiliac joint pain. This is considered a contributing factor to symphyseal instability and nonspecific low back pain (odds ratio: 1.17) (12). Therefore, in CAI management strategy that includes the pelvic alignment assessment, can help to early detect lower back dysfunction. In addition, it would be a preventive measure against pelvic crossed syndrome, the expected functional leg length discrepancy (13), and trunk and spinal rotation asymmetries (14). The respiratory function of peak expiratory flow and forced expiratory volume were exhibited to be affected by pelvic tilt as well (15). Establishing PT in CAI would help identify a critical factor that has a link to ankle posture and function and contributes to persistent symptoms and functional disability. This link adds insight into the literature on the possible deficit that exists and thus demonstrates another pathomechanics picture across the full kinematic chain that assists in the development of preventive measures.

Therefore, this study was designed to investigate PT and its direction in patients with CAI compared with those in uninjured control subjects and correlate PT with the perception of ankle instability and giving way episodes. We hypothesized that there would be a difference in PT between the CAI group and the uninjured control group, and PT is related to the perception of ankle instability and giving way to episodes within the CAI group.

MATERIALS AND METHODS

Design. This matched group case-control study was conducted at the outpatient clinic of the Faculty of Physical Therapy, Cairo University. The study protocol was approved by the Research Ethical Committee of the Faculty of Physical Therapy (P.T.REC/012/002302) and registered in ClinicalTrials.gov as well (NCT04555083). All subjects read and signed the approved consent form before participating in the study.

Participants. Forty-five participants (including 34 females and eight males) were enrolled in this study. The gender imbalance was according to the results of the study by Tanen et al. (2014) (16) who showed that CAI is more prevalent in females than in males. In the CAI group (n = 15; 12 females and three males), the mean age, weight, and height were 25.8 ± 0.81 years, 69.33 ± 18.73 kg, and 169.80 ± 12.17 cm, respectively. The duration since the first LAS was 5.4 ± 3.73 years with a range of 1.5−12 years, the mean number of giving way episodes per year was 39.80 ± 31.46 with a range of 2−96, and the mean percentage of perceived ankle instability was 39.5 ± 20.3. Meanwhile, in the control group (n = 30; 24 females and six males), the mean age, weight, and height were 26.5 ± 0.48 years, 64.2 ± 12.97 kg, and 164.83 ± 8.75 cm, respectively. The control group matched with the CAI group in terms of gender and dominant limb.

Based on the previous guidelines outlined by the International Ankle Consortium (17); the inclusion criteria of this study were as follows: individuals aged between 18 and 30 years; those with a history of LAS for at least 1 year before the study onset that required at least 1-day weight-bearing restriction; those with a self-reported tendency of ≥2 giving way episodes during 6 months before enrollment in the study; those with a perception that the injured ankle was chronically weaker, more painful, and/or less functional than the contralateral ankle before the first LAS; and those who scored less than 24 in the Cumberland Ankle Instability Tool (CAIT).

Meanwhile, the exclusion criteria were as follows: individuals who had bilateral LAS; those with a history of spine, pelvis, and lower extremity injury, fracture, or surgery; those with LBP that required medical or surgical intervention; those who participated in supervised or unsupervised ankle rehabilitation within a year before enrollment in the study; those with LAS within 3 months before participation, and those with trunk asymmetry angle of more than 7º (18) and leg length discrepancy of more than 0.5 cm (19).

Screening protocol. Each participant went through an examination for leg length discrepancy and spinal scoliosis. A standard clinical tape with a paper clip was used to the nearest 0.5 mm that was previously reported to have high interrater reliability and good accuracy compared with computed tomographic scanograms (20) (Figure1). Moreover, a scoliometer application combined with the Adams forward bending test was used to detect axial trunk asymmetry (21). This scoliometer application is one of the best applications within the Android and Apple systems used for measuring trunk inclination compared with a manual scoilometer (22). This study used the smartphone “Huawei nova 3i” with the following dimensions: 157.6 mm length, 75.2 mm width, and 7.6 mm thickness. The procedure was repeated twice as described previously (23) (Figure 2).

After that, specific data from patients with CAI were taken related to their first-time ankle sprain and the number of giving way episodes per month. Other study outcomes, including pelvic torsion and perceived ankle instability, were measured using a pelvic inclinometer and a 10-cm visual analog scale (VAS), respectively.

Figure 1. Clinical Tape with a Paper Clip

Figure 2. Axial Trunk Asymmetry Examination Using Scoiliometer Application and Adams Forward Bending Test

Pelvic Inclinometer. PALM-meter (Performance Attainment Associates, St. Paul, MN), consists of a bubble inclinometer with one-degree gradation and two calipers for palpation of bony landmarks; anterior superior (ASIS) and posterior superior (PSIS) iliac spines (Figure 3). Used to measure the angle between the line connecting ASIS to PSIS and the horizontal plane with high intratester reliability (23).

10-cm VAS. Some studies have used this scale in measuring self-reported perception of ankle stability sensation because it can measure patient acceptance and compliance and reduce collection and interpretation bias. The patients were asked to rate their perceived sensation of instability on the 10-cm VAS, with 0 indicating no instability and 10 indicating the worst instability. After that, the score was measured, then divided by 10, and multiplied by 100 (24).

Figure 3. Pelvic Inclinometer

Figure 4. Pelvic Torsion Measurement

Pelvic Torsion Measurement. Before measuring the PT, the floor inclination was checked using a digital inclinometer to confirm the zero level. Then, the participants were asked to undress the upper part of the pelvis and place their bare feet shoulder width apart, extending the knees, folding their arms across the chest, and equally distributing their body weight. To minimize postural sway, the anterior thigh should be in touch with the stabilizing table, and visual contact was maintained on a fixed mark positioned at eye level. Bony landmarks were determined by scooping under ASIS and PSIS and then moving to the most projecting prominent point, and a 10-mm adhesive dot was placed over each one. Finally, calipers were pressed until hard resistance was felt while palpating the determined landmarks concurrently at the moment of reading, which was repeated thrice for each innominate (23) (Figure 4).

Pelvic torsion was the output of the side inclination of the right pelvis minus that of the left side with a positive value indicating that the right innominate is more anteriorly inclined than the left, and vice versa. PT denotes the angular orientation of one innominate relative to the other but does not indicate whether one innominate or the other is anteriorly or posteriorly rotated to the body (23).

The assessor was the same throughout all data collection. To assure the inter-rater reliability, the PT of 20 participants had been measured at two separate times, 1 week apart and with the same setting (25).

Statistical Analysis. The sample size was initially calculated based on a pilot study of 14 participants (seven subjects with CAI and seven controls). Using the power and sample size calculator program, PT was set as the primary outcome at a significance level of 0.05, a mean difference of 3.4, a ratio of 2:1, a control group standard deviation of 1.1, and a power of 0.8. Moreover, the sample size of 6 participants with two in the study group and four in the control group was required to reject the null hypothesis that the population means of the study and control groups are equal. All statistical analyses were conducted using the Statistical Package for the Social Sciences (version 24; IBM Corp., Armonk, NY, USA). The significance level of all statistical tests was $\alpha = 0.05$. The normality and homogeneity of the data were checked using the Shapiro–Wilk test and Levene's test, respectively, as prerequisites for parametric analysis. Demographic data were presented using descriptive statistics. This study included one independent variable as the tested group (study and control), and three dependent variables (i.e., PT, perceived sensation of ankle instability, and giving way episodes) were considered as quantitative variables.

Intraclass correlation coefficients (ICC) were used for calculating the intra-rater reliability of measuring PT. The Mann–Whitney U-test was used to determine the statistical difference in PT between both groups because of the non-normal distribution of the control group and the non-homogeneity of both groups. Cohen's d effect size was calculated to measure the magnitude of difference between the groups and interpreted as large (≥0.80), moderate (0.50–0.79), small (0.20–0.49), or trivial (≤0.19).

Before exploring the correlations, assumptions of normality and linearity were checked. Pearson's correlation coefficient was used to calculate the correlations between PT and the perceived sensation of ankle instability and giving way episodes. The strength of the relationship was expressed as follows: 0.00–0.25 = little or no relationship; 0.26–0.50 = fair relationship; 0.51–0.75 = moderate to a good relationship, and 0.76–1.00 = good to an excellent relationship.

RESULTS

Fifty-nine participants were recruited for the study. Fourteen were excluded, as they did not meet the inclusion criteria. Forty-five participants were eligible for the study and divided into two groups: the CAI study group (n = 15) and the matched control group (n = 30). Table 1 shows no significant differences (P > 0.05) in the mean values of age, weight, and height between both groups. The chi-square test revealed no significant difference in sex distribution between both groups (P > 0.05). Table 2 presents the CAIT scores that revealed a significant difference between the CAI and matched control groups (P < 0.05).

Pelvic torsion Difference. The intra-observer reliability of the pelvic inclinometer was calculated before PT measurements, concluding high intra-rater reliability (ICC = 0.94 and 0.97 for the right and left sides, respectively).

The Mann–Whitney U-test revealed a significant difference in PT between both groups (z = −3.158; P = 0.002). The CAI group had significantly higher PT values than the control group with a large effect size according to Cohen's guidelines (1.35) (Table 3).

Correlations. Pearson correlation coefficients indicated no significant relations either between PT and the perceived sensation of ankle instability (P = 0.124) or between PT and ankle giving way episodes in the CAI group (P = 0.085) (Table 4).

Table 1. Demographic Characteristics of the Participants in Both Groups

Items	Control Group	Study Group	Comparison	
	Mean ± SD	Mean ± SD	t-value	P-value
Age (years)	26.5 ± 0.48	25.8 ± 0.81	0.78	0.47
Body mass (kg)	64.2 ± 12.97	69.33 ± 18.73	- 1.07	0.28
Height (cm)	164.83 ± 8.75	169.80 ± 12.17	- 1.40	0.17

SD, standard deviation**.**

Table 2. Comparison between the CAI and Control Groups Regarding the CAIT Score

Measure	CAI (n = 15)	Control (n = 30)	P-Value
CAIT	14.47 ± 2.9	28.6 ± 0.4	< 0.001*

*****statistically significant difference**; CAI,** chronic ankle instability**; CAIT,** Cumberland Ankle Instability Tool**.**

Table 3. Median, Range, z Values, and P Values of Pelvic Torsion of Both Groups

Pelvic Torsion	Control Group	CAI Group
Median	0.00	2.00
Range	7.67	9.33
Cohen's d	1.12	
Z-value	-3.367	
P-value	0.001*	

*****Significant level is set at alpha level < 0.05**, CAI,** chronic ankle instability**.**

Table 4. Correlation between Pelvic Torsion and Perceived Sensations of Ankle Instability and Giving Way to Episodes

Measure	Pelvic Torsion
Perception of ankle instability	
Pearson correlation	−0.415
Significance	0.124
Giving way	
Pearson correlation	−0.460
Significance	0.085

DISCUSSION

The results of this study show a significant difference in PT with the CAI group exhibiting greater torsion than the uninjured matched group. The large effect size suggests a clinically meaningful difference in the magnitude of PT. Other interesting results were the insignificant fair negative correlations either between PT and the perception of ankle instability sensation or between PT and giving way episodes in CAI.

There is a lack of standard normative data on pelvic inclination or asymmetry. Moreover, the literature has shown variations in PT among the asymptomatic population and different pelvic morphology between individuals and within the same subjects that may explain the non-normal distribution of PT and dispersion within the groups (25). The flowing sections discuss each outcome interpretation, possible explanations, and how it would affect the CAI continuum.

Pelvic Torsion. According to the literature on CAI, up to the best of our knowledge, no studies have measured and compared the static pelvic alignment in any anatomical plane. Otherwise, pelvic external rotation was altered during the star excursion balance test, whereas no difference in superior nor anterior tilt was observed (10). Another study tracked the pelvic displacement during simulated ankle inversion injury that illustrated elevation of both innominate with more displacement on the perturbed side (9).

Individuals with CAI demonstrating compensatory adaptive motor-control strategies, including kinematic alterations proximally at the trunk, pelvis, and hip joint, could be preexisting and contribute to LAS and CAI risk factors. This study adds PT to CAI proximal kinematic alternations. The causes of PA in the sagittal plane could be explained through the results of a study that introduced the aspects of the following formula (26):

Pelvic asymmetry = asymmetrical load + mechanical shock

In this regard, the statistically significant difference in PT between subjects with unilateral CAI and controls is due to alternations in ground reaction forces representing mechanical shock in the formula (27). Moreover, asymmetrical mechanical loads include kinematic chain and muscular factors.

Kinematic Chain. Lower limb joint motions are mechanically linked to each other. Thus, the more inverted position of the injured ankle and rearfoot motions with external rotation of the tibia during weight-bearing activities could alter the pelvic alignment and induce pelvic tilt in the sagittal plane. Moreover, altered shank motion acts as a strong moderator affecting the pelvic position (5, 6).

Muscle Imbalance. It was suggested that muscle imbalance created by the rectus femoris and hamstrings contributes to PT. Both muscles showed activation imbalance in CAI that consists of bilateral hamstring muscle arthrogenic inhibition along with unilateral quadriceps facilitation (28).

Core Muscles Weakness. Gluteal muscular dysfunctions and weakness of the diaphragm contribute to pelvis malalignment. Weakness of the hip abductor, especially the gluteus medius, and the extensor portion of the gluteus maximus is correlated with the anterior inclination of innominate ipsilateral and may occur contralaterally with less magnitude (29, 30). Therefore, patients with a chronic ankle sprain and CAI are susceptible to inclining the pelvis anteriorly and developing PT because of gluteal muscle weakness, delayed latency, and abnormal firing patterns either ipsilaterally or contralaterally (31, 32). Moreover, a hemidiaphragm contractility deficit with a moderate effect size could lead to anterior pelvic tilt through increased activation of the erector spine as compensation for inhibited diaphragm (33).

Correlations. This study showed fair negative insignificant relations either between PT and perceived ankle instability or between PT and giving way episodes. Those relations were thought to be in a positive direction in which increasing instability indicators correlate with increasing PT, whereas negative correlations mean the more PT, the less giving way episodes, and perceived ankle instability sensation. This refers to PT as a compensatory mechanism to decrease instability symptoms. The relatively small sample size may have contributed to the lack of statistical significance for these correlations; however, these fair negative relationships should be interpreted.

Pelvic torsion may be interpreted as compensation for decreased degrees of freedom of the ankle. Individuals with CAI limit their excessive foot motion by creating supinated rearfoot in an attempt to maintain the stability of the ankle during functional tasks; thus, the degrees of freedom would be released at other proximal regions (34). PT could be considered a protective mechanism to safeguard against any interruption of the unstable ankle by providing proximal stability. Another possible explanation linking the correlation of more proximal PT to less distal ankle instability is a deficit of the gluteus maximus in CAI (31, 32). This muscle has a critical effect on lower limb alignment as a powerful external rotator of the thigh; therefore, a decrease in the amplitude of this muscle could influence the tibia rotation peak internal velocity (35). PT caused by gluteus maximus dysfunction would induce less thigh external rotation and a longer time to reach peak internal tibia rotation, consequently resulting in a more available time for a supinated stable foot.

Some clinical applications could be drawn from our findings; early examination of pelvic malalignment and regaining the function of the muscles that are attached to the pelvis. CAI rehabilitation should include pelvis reposition exercises and core muscle activation to induce the symmetry of the pelvis and consequently obtain the muscles' functional length (36).

Regarding the limitation of this study, the sample size was small due to the extent of the exclusion criteria, which were designed to obtain the best internal validity of the results. Moreover, it was originally calculated to identify differences in static PT between the groups and did not account for the secondary outcomes: correlations between PT and perceived instability and between PT and giving way episode variables. A larger sample size may be needed to detect the statistical differences in those variables. The case-control design could not identify the exact cause-and-effect relationship in terms of whether CAI leads to PT or vice versa. The findings were limited to young active individuals with CAI aged between 20 and 30 years with certain educational status to read and understand the Cumberland Ankle Instability tool.

Further studies are needed to explore more proximal CAI adaptation strategies, including lumbopelvic hip complex kinematics and other aspects of pelvic malalignment and kinematics during dynamic tasks. Sacroiliac joint dysfunction in individuals with CAI should also be investigated.

CONCLUSION

This study found a new proximal impairment associated with CAI that guides clinicians in designing management programs for CAI. A significant difference in static PT was observed between the CAI and uninjured controls, which acts as a compensation strategy to achieve ankle joint complex stability and a proximal stable base to obtain more control of the ankle joint during dynamic activities. During CAI rehabilitation, assessment of full kinematic chain deficits and inclusion of pelvic reposition exercises and core muscle activation should be addressed.

APPLICABLE REMARKS

- PT is considered one of the proximal mechanical deficits associated with CAI to compensate for the unstable ankle.
- Clinicians should be aware of CAI maladaptive strategies that contribute to PT as proximal muscle imbalance, gluteal muscular dysfunction, and decreased ankle degrees of freedom.
- In CAI management, clinicians should consider two pathways; a preventive program against PT development and a pelvic realignment approach based on regaining the attached muscles' functional length and strength.
- Further research is needed to determine the cause-effect relation between pelvic malalignment and CAI.

AUTHORS' CONTRIBUTIONS

Study concept and design: Afaf Mohamed Tahoon, Dalia Mohamed Mosaad, Salwa Fadl Abdelmageed. *Acquisition of data:* Afaf Mohamed Tahoon. *Analysis and interpretation of data:* Afaf Mohamed Tahoon, Dalia Mohamed Mosaad. *Drafting the manuscript:* Afaf Mohamed Tahoon. *Critical revision of the manuscript for important intellectual content:* Dalia Mohamed Mosaad, Afaf Mohamed Tahoon, Salwa fadl Abdelmageed. *Statistical analysis:* Afaf Mohamed Tahoon, Dalia Mohamed Mosaad. *Administrative, technical, and material support:* Afaf Mohamed Tahoon, Dalia Mohamed Mosaad, Salwa Fadl Abdelmageed. *Study supervision:* Dalia Mohamed Mosaad, Salwa Fadl Abdelmageed.

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CONFLICTS OF INTEREST

There is no conflict of interest.

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