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# Changes in dynamic quadriceps angle in patients with chronic ankle instability: Cross sectional observational study

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***Abstract*---**Background: Changes in dynamic Quadriceps Angle (Q angle) had been studied in healthy subjects and individuals with other musculoskeletal disorders; however, in chronic ankle instability (CAI), it has not yet been determined. The purpose of this study was to investigate the difference in dynamic Q angle of patients with unilateral chronic ankle instability and those without chronic ankle instability. Methods: One-hundred and four participants with and without chronic ankle instability from both genders aged between 18-30 years, with a BMI range of 17.9-27.3, were enrolled into 2 equal groups; a study group and a control group, with mean values of age of the study and control groups (20.8±2.4) and (20.9±3) years respectively and of BMI (24.1±4.3) and (23.8±2.9) kg/m2 respectively. Dynamic Q angle measurement is carried out using dynamic knee valgus (DKV) through the frontal plane projection angle (FPPA) during single limb squat. Results: A statistically significant difference in FPPA angle was observed between the affected limb of the CAI group and controls (P=0.001). Conclusion: The present study suggested that unilateral CAI display an increased knee valgus, suggesting an additional proximal kinematic alteration and chronic maladaptation in the CAI population.

***Keywords*---**Ankle, Joint Instability, Dynamic Q angle, DKV, FPPA, Biomechanical Phenomena.


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**Introduction**

Chronic Ankle Instability (CAI) emerges as a common consequence of Lateral Ankle Sprain (LAS), manifesting as functional decline and reported instability. This condition significantly predisposes individuals to recurrent ankle sprains and eventually osteoarthritis, leading to substantial medical expenses and presenting a noteworthy public health concern [1] Following an initial ankle sprain, 40% of patients experience persistent symptoms, including recurrent sprains, subjective instability, and disabling issues such as pain and swelling even a year post-injury [2] The International Ankle Consort [3] identifies both LAS and CAI as significant global healthcare issues, emphasizing the long-term physical and functional impairments affecting health-related quality of life and extending to proximal body regions due to compensations in the sensorimotor and biomechanical systems.

CAI not only damages the sensorimotor system but also alters the dynamic restraint mechanisms in the lower extremity, resulting in impaired joint loading and reduced joint protection against impairments [2] These constraints on the sensorimotor systems create a continuum of impairments [4] [5] As a consequence of the initial injury, the impairment in the sensorimotor system has the potential to induce neuromuscular changes. These changes can manifest in faulty movement patterns [6] such as alterations in Dynamic knee valgus (DKV) and subsequent dynamic Q angle during various functional tasks.

The Q-angle, which represents the resultant force vector of the quadriceps muscle and patellar tendons on the patella in the frontal plane, has been a subject of research in lower limb pathomechanics. An advancement in this domain introduced the concept of "dynamic Q-angle," [7] specifically defined as the Q angle during knee joint flexion [8]. To accurately predict force vectors during weight-bearing activities, it is recommended to measure the dynamic Q-angle rather than relying on static measurements [9]. Previous study highlights that understanding patellofemoral pain (PFP) mechanisms is more effective in dynamic situations due to increased muscular and mechanical demands [10]. Consequently, there is growing interest in exploring the clinical significance of lower extremity biomechanics in dynamic activities [7].

Dynamic equivalent for the dynamic Q angle is the DKV [11]. Knee valgus is defined by the lateral deviation of the distal tibia relative to the center of the knee in the frontal plane [12]. Despite three-dimensional (3D) motion capture being the recognized "gold standard" for kinematic recording [13], utilizing two-dimensional (2D) video analysis of the frontal plane projection angle (FPPA) offers clinicians a cost-effective and readily available tool for assessing dynamic knee valgus during functional tasks [14]. Previous reports indicate that the 2D FPPA measured during single leg squats (SLS) correlates with the 3D kinematics of the knee [15].

According to the literature, there is a gap of knowledge around the changes in dynamic Q angle of patients with chronic ankle instability and only a few studies have assessed the relationship between ankle and the static Q angle. The study aimed to investigate the difference in dynamic Q angle of patients with unilateral chronic ankle instability and those without chronic ankle instability. Dynamic Q angle measurement is carried out using dynamic knee valgus through the frontal plane projection angle during single limb squat.

## Materials and Methods

### Design

Cross sectional observational study. The study protocol was approved by the Research Ethical Committee of the Faculty of Physical Therapy (P.T.REC/012/004802) and registered in ClinicalTrials.gov as well (NCT06188416). Before participating in this study, a written consent form was signed down by each subject.

### Participants

One-hundred and four participants from both genders with and without chronic ankle instability aged between 18-30 years, with a BMI range of 17.9-27.3, were assigned into 2 equal groups, Study group (n = 52 ) and control group (n = 52). Previous study [16] confirmed a higher prevalence of CAI in females compared to males, as illustrated by the gender distribution in each study group (n = 52; 42 females and 11 males). The mean values of age of the study and control groups (20.8±2.4) and (20.9±3) years respectively and of BMI (24.1±4.3) and (23.8±2.9) kg/m2 respectively. Participants were assessed at the research laboratory section, Faculty of Physical Therapy, Cairo University, Giza, Egypt, in the period from September 2023 to December 2023. This study adhered to the guidelines set by the International Ankle Consortium [3]. Inclusion criteria for the study group was as follows:

- Subjects aged between 18 and 30 years.
- Subjects with a history of LAS for at least one year before the study onset, that required at least 1-day weight-bearing restriction.
- Subjects with a self-reported tendency of ≥2 giving way episodes during 6 months before enrollment in the study.
- Subjects with a perception that the injured ankle was chronically weaker, more painful, and/or less functional than the contralateral ankle before the first LAS.
- Subjects who scored less than 24 in CAIT [21].

While the control group was included as follows: 52 participants without chronic ankle instability, normal participants with no musculoskeletal disorders or history of knee disease and no obvious limb length discrepancy [8].

The exclusion criteria for both group:

- Subjects with a history of lower extremity injury, fracture, or surgery
- Subjects who participated in supervised or unsupervised ankle rehabilitation within a year before enrollment in the study
- Subjects with LAS within 3 months before participation
- Subjects diagnosed with flat foot [17]
- Subjects with a history of knee pain during the last 6 months [18]
- Subjects diagnosed with knee osteoarthritis [19]

**Materials**

- The Cumberland Ankle Instability Tool (CAIT), a validated questionnaire consisting of 9 items designed to assess the presence of functional ankle instability [20], Its recommended cutoff score, CAIT-C<24, serves as a criterion to ascertain the presence or absence of CAI [21].
- Kinovea software: Kinovea is a cost-free software application designed for the analysis, comparison, measurement, and evaluation of various angles [22] to measure FPPA during SLS [23].
- Adjustable tripod: An adjustable phone tripod was used to hold the phone in the desired position, offering both stability and flexibility to the footage.
- Redmi Note 12: Its main camera uses a 50MP, 1/2.76", 0.64µm sensor coupled with a wide f/1.8 aperture, and the other two cameras are 8MP f/2.2, 1/4.0", 1.12µm ultrawide one with advertised 120-degree field of view and a 2MP f/2.4 camera for macro photography.
- Colored markers were placed on the lower extremity of each subject to approximate the radiographic landmarks as shown in fig (1)

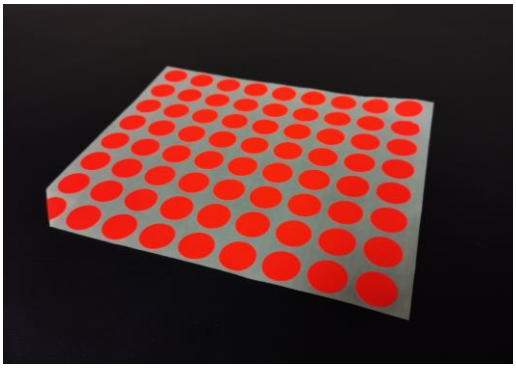

Fig (1) colored marks

- Standard tape measure to determine midpoints of the ankle and knee joints as shown in fig (2).


Fig (2) standard tape measure

- Standard goniometer used to measure Squatting to a depth of 60° as shown in fig (3).

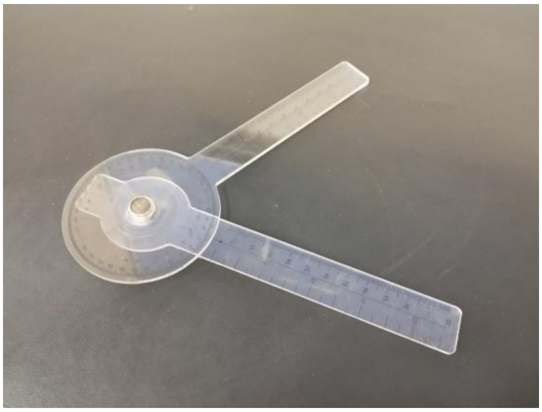

Fig (3) standard goniometer

**Procedures**

*Frontal plane projection angle*

Before conducting the tests, markers were positioned on the lower extremity of each participant to approximate the radiographic landmarks [24] [25]. These markers were placed at each ASIS, the midpoint of the femoral condyles for the knee joint center, and the midpoint of the ankle malleoli for the ankle joint center [26]. Using a standard tape measure, the midpoints were determined, and all markers were consistently placed by the same experimenter. These markers were essential for determining FPPA of the knee from digital images using Kinovea software [23]. FPPA was determined by measuring the angle formed in the frontal view between lines connecting the knee to hip markers and the ankle to knee markers [27] as shown in fig (4).


Fig (4) FPPA measured using Kinovea software

FPPA was assessed in both legs of patients with chronic ankle instability and the controls as recent study [28] suggests that unilateral chronic ankle instability can impact the kinematics of the contralateral uninjured ankle in individuals with unilateral CAI.

*Single limb squat*
Subjects were directed to stand barefoot on the test limb, with the opposite limb flexed at the knee to approximately 90°. Arms folded in front for balance, subjects performed controlled single limb squats to 60° of knee flexion before returning to the initial position [29]. During each squat, lasting five seconds at a standardized speed, the experimenter acted as a counter. The first count signaled the start, the third marked the lowest point, and the fifth indicated the end. A two-minute recovery period between squats minimized fatigue effects. Trials were accepted only if the subject squatted to the desired 60° knee flexion at a consistent speed, maintaining balance.

Excluded were trials that did not meet the specified criteria, prompting the collection of another trial. Before testing, subjects practiced single limb squats four to six times to warm up and become familiar with the test. Feedback on squat depth (measured with a standard goniometer) and speed was provided until subjects consistently and accurately executed the test movement as shown in fig (5).

Fig (5) squatting to a depth of 60° using standard goniometer

**Statistical methods**

Data were expressed as mean± SD. Unpaired t-test was used to compare between subjects characteristics of the two groups. One way MANOVA was used to compare measured variables between the two groups. Statistical package for the social sciences computer program (version 20 for Windows; SPSS Inc., Chicago, Illinois, USA) was used for data analysis. P less than or equal to 0.05 was considered significant.

**Results**

A total of 104 participants with and without chronic ankle instability from both genders participated; they were assigned into 2 equal groups, Group A, Study group: 52 participants with unilateral chronic ankle instability and Group B, control group, 52 participants without chronic ankle instability.

As shown in table (1) and figures (6-9); the mean values of age of study and control groups were (20.8±2.4) and (20.9±3) years respectively, and of weight were (65.9±13) and (65.8±8.5) kg respectively, the mean values of height of study and control groups were (165.2±8.7) and (166.3±7.5) cm respectively, and of BMI were (24.1±4.3) and (23.8±2.9) kg/m$^2$ respectively. There were no significant differences between both groups of mean age, weight, height and BMI ($p > 0.05$).

Table (1): Subjects characteristics of both groups

| Measured variable | Study Mean±SD | Control Mean±SD | t-value | p-value |
|---|---|---|---|---|
| Age (years) | 20.8±2.4 | 20.9±3 | -0.24 | 0.810 |
| Weight (kg) | 65.9±13 | 65.8±8.5 | 0.06 | 0.956 |
| Height (cm) | 165.2±8.7 | 166.3±7.5 | -0.71 | 0.478 |
| BMI (kg/m$^2$) | 24.1±4.3 | 23.8±2.9 | 0.44 | 0.656 |
| Sex N (%)<br>Male<br>Females | 11 (21%)<br>41 (79%) | 11 (21%)<br>41 (79%) | $x^2$ =0 | 1 |

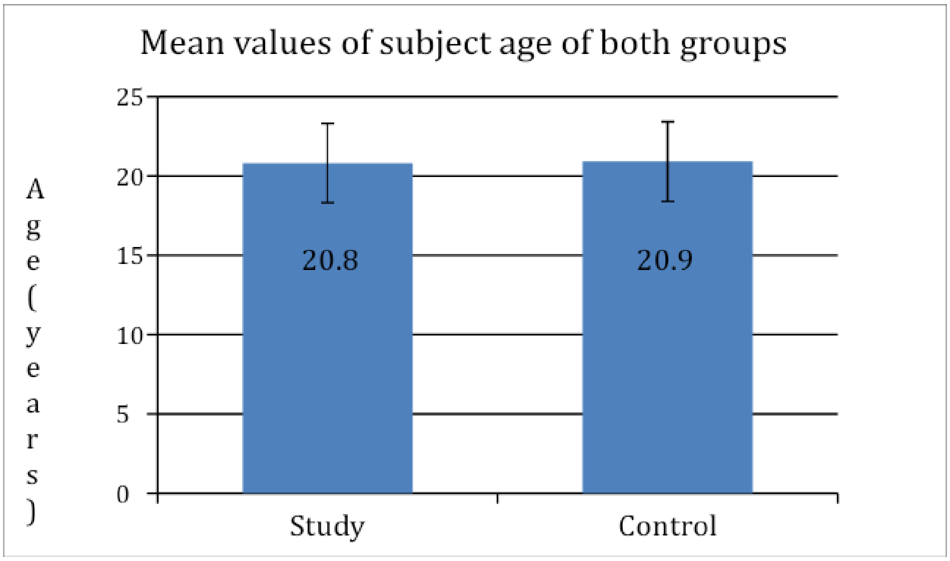


Fig 6: mean values of subjects age of both groups

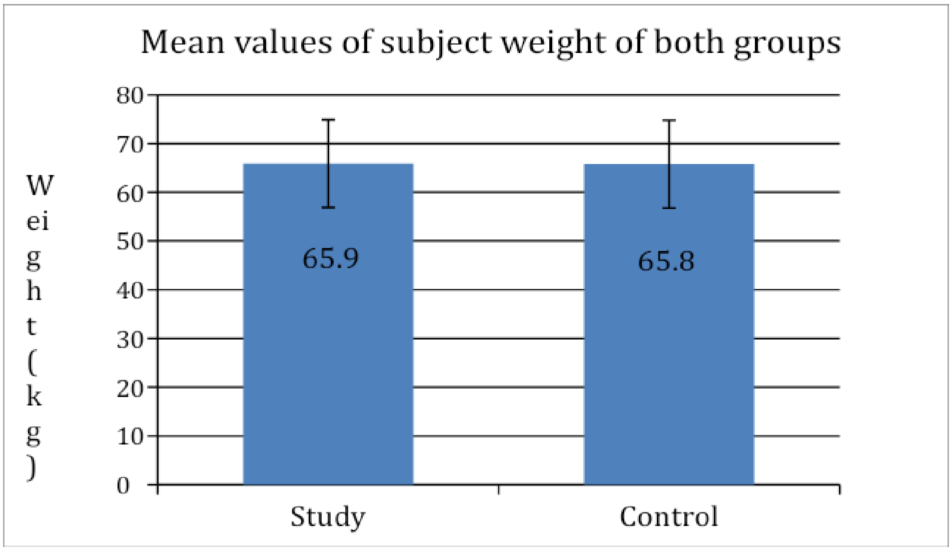


Fig 7: mean values of subjects weight of both groups

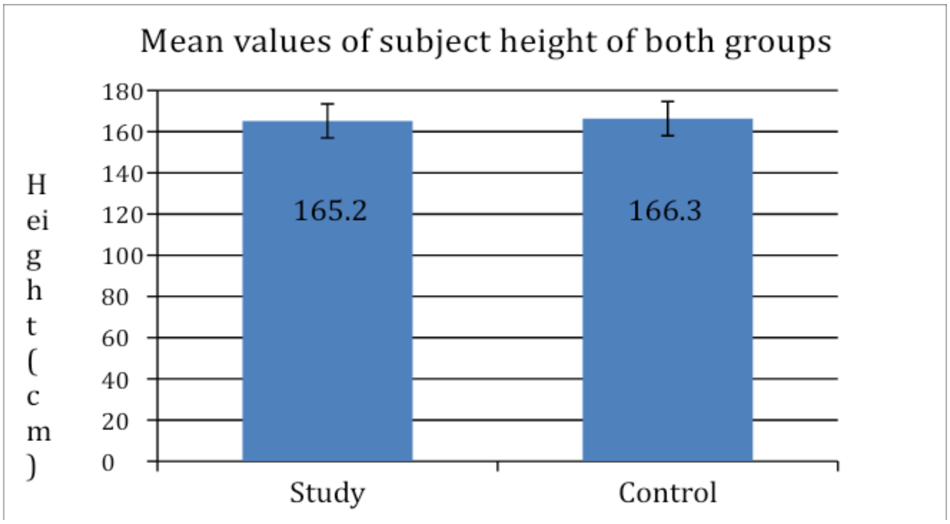


Fig 8: mean values of subjects height of both groups

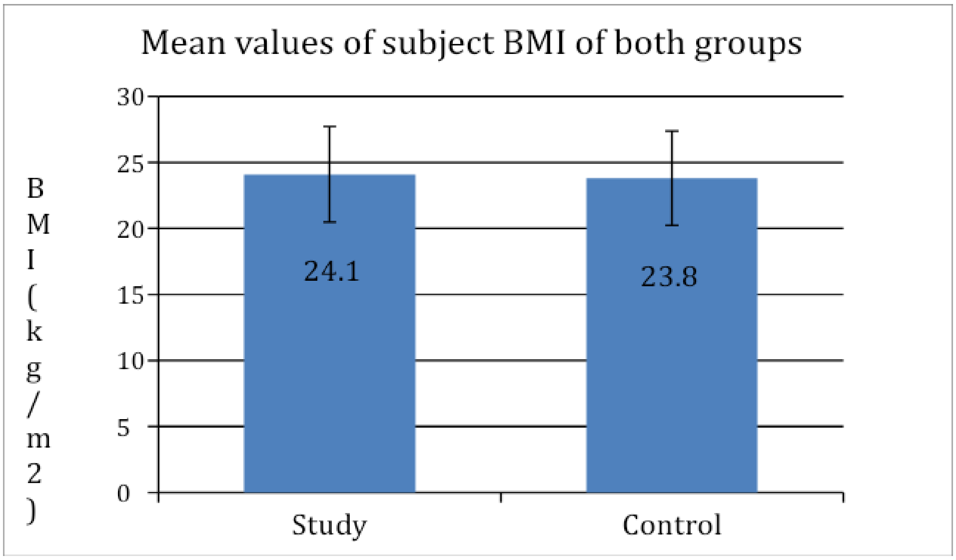


Fig 9: mean values of subjects BMI of both groups

**Sex distribution**

The number (%) of males of study and control groups were 11 (21%) and 11 (21%) and the number (%) of females 41 (79%) and 41 (79%) and respectively. There was no significant difference in sex distribution between the groups (p =1).

**Ankle stability by Cumberland Ankle Instability Tool**

As shown in table (2); the mean values of CAIT of study and control groups were (17.7±4.2) and (30±0) respectively, there were significant differences between both groups of mean value of CAIT (p=0.001).

Table (2): Comparison of mean values of CAIT between the two groups

| CAIT | Study Mean±SD | Control Mean±SD | t-value | p-value |
|---|---|---|---|---|
| | 17.7±4.2 | 30±0 | -20.8 | 0.001 |

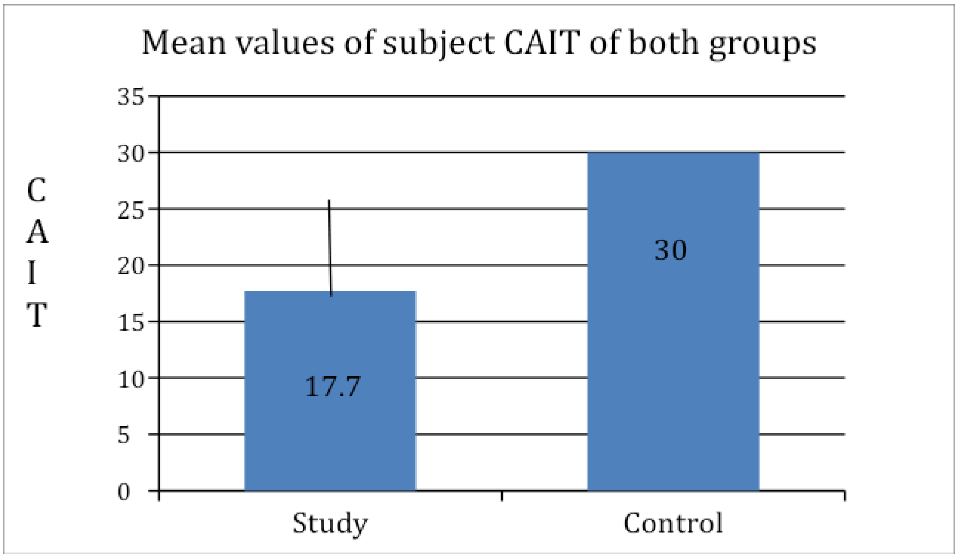


Fig 10: mean values of subjects CAIT of both groups

**Normality test**

Data were screened for normality assumption, homogeneity of variance, and presence of extreme scores. Shapiro-Wilk test for normality showed that all measured variables are normally distributed, so one way MANOVA for between groups' comparison was used.

**I- Effect of ankle instability on FPPA angle**

As shown in table (3) and demonstrated in figures (11), the mean values ± SD of the FPPA angle of the right side for subjects in study and control groups were (21.8 ± 6.6) and (9.6 ± 3.3) degrees respectively. The mean values ± SD of the FPPA angle of the left side for subjects in study and control groups were (18.1 ± 7) and (8.5 ± 2.5) degrees respectively. There was a statistical significant difference in the mean values FPPA angle of both right and left sides between both groups (P=0.001).

Table (3): Comparison of mean values of measured variables between groups

| **FPPA angle** (degrees) | **Study Mean ±SD** | **Control Mean ±SD** | **Mean difference** | **f-value** | **P-value** |
|---|---|---|---|---|---|
| **Right side** | 21.8 ± 6.6 | 9.6 ± 3.3 | 12.2 | 140 | 0.001 |
| **Left side** | 18.1 ± 7 | 8.5 ± 2.5 | 9.6 | 84 | 0.001 |

SD: standard deviation p-value: probability value

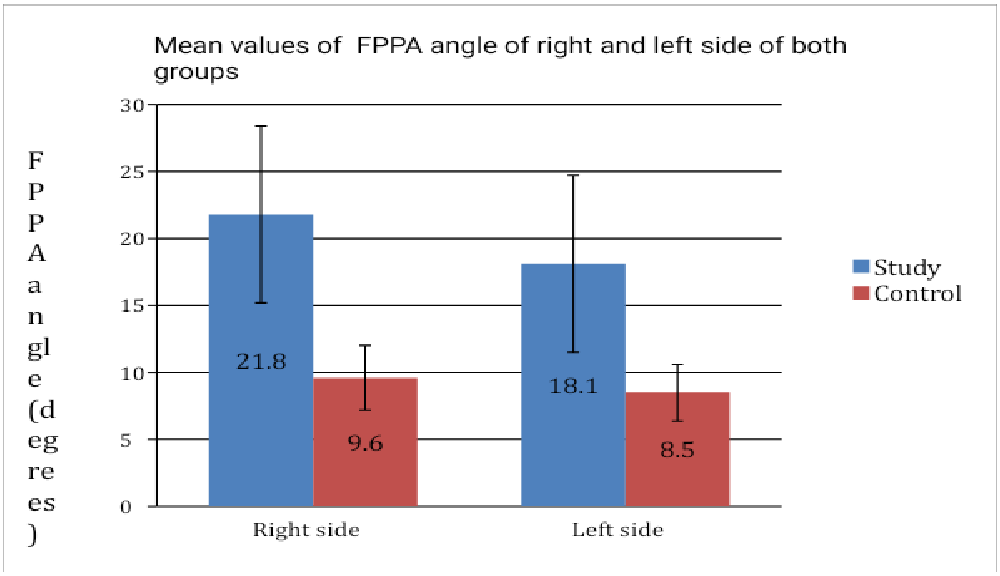


Fig 11: mean values of FPPA angle of right and left side of both groups

**Discussion**

This research was conducted to investigate the difference in dynamic Q angle of patients with unilateral chronic ankle instability and those without chronic ankle instability. Dynamic Q angle measurement is carried out using dynamic knee valgus through the frontal plane projection angle during single limb squat.

The results of this present study show a statistically significant difference in FPPA with the CAI group. Concerning the affected limb, the CAI group is exhibiting greater FPPA than the uninjured control group. Another interesting result was the significant correlation between the unaffected limb of the CAI group and the control group.

Measuring a dynamic Q-angle requires a 3D motion capture system, a process that can be limited due to high cost, unattainable resources, and the time needed for its analysis. A viable alternative method is measuring the dynamic knee valgus (the dynamic equivalent of Q-angle) through measuring FPPA. It's interesting how Wilson and Davis (2008) found a correlation between 2D FPPA in single leg squats and 3D knee kinematics [30]. Afandor et al.'s (2022) emphasis on the reliability and economy of 2D video analysis, especially in handling large population groups [31], adds another dimension to the discussion. The potential for reduced time, cost, and personnel involvement could significantly impact research and practical applications in biomechanics. Specifically in the SLS, A systematic review with meta-analysis was carried out by Alves Lopes et al. (2018) that confirmed the reliability of the SLS both intra- and inter-rater, with values ranging from 0.97 to 1.00 for intra-rater and 0.97 for inter-rater reliability [32]. Kingston et al. (21) found a moderate validity (0.70) in favor of the FPPA during the SLS [33].

In choosing the SLS test for this study, not only its validity and reliability were considered, but also its widespread use in clinical practice. Additionally, this test was chosen because it is less physically demanding compared to commonly used jump tests. Moreover, the SLS test closely mirrors daily activities like stair ascending and descending, as highlighted by Hansen et al. (2021) [34]. Making it more relevant for this study population, where symptoms primarily impact the quality of daily life, function, and performance.

According to the literature on CAI, up to the best of our knowledge, no studies have measured and compared the changes in Dynamic Q angle nor DKV of patients with chronic ankle instability, otherwise Moghadam et al (2017) studied the relationship between static Q angle, weight, body mass index and history of sprained ankle with the incidence of ankle sprain occurrence. They measured Q angle using the Romberg method, and confirmed that there is significant correlation between Q angle and incidence of ankle sprain [35]. Daneshmandi et al (2011) investigated the relationship between Q angle and selected lower extremity alignment characteristics. After examining the navicular drop, genu - recurvatum, femoral anteversion, T-F angle, tibiofemoral angle, dorsiflexion, hip internal and external rotation, general joint laxity and the Q angle, they confirmed that alignment of lower extremity is associated with the magnitude of static Q angle [36]. Another study [37], carried out by Abdelhaleem et al (2021) tracked the association between low back pain and limited dorsiflexion in unilateral functional ankle instability group and illustrated positive correlation between low back pain and both positive drawer test and limited dorsiflexion range of motion. Furthermore, Tahoon et al (2021) investigated the difference in pelvic torsion (PT) among individuals with CAI and observed a statistically significant difference in PT between CAI participants and the matched controls [38]. In contrast, Pefanis et al (2009) examined the effect of Q angle on probability of sustaining an ankle sprain. Q angle measurements were made on radiographs then the athletes in the sample were monitored for 2 years. They found that there is a lack of significant difference between Q angle values for both legs of each athlete [39].

Individuals with chronic ankle instability (CAI) exhibit adaptive motor-control strategies, involving kinematic changes at the trunk, pelvis, hip, and knee joints. These compensatory patterns may preexist and contribute to lateral ankle sprains and CAI risk factors as indicated by Tahoon et al (2021) [38]. This study introduces excessive knee valgus as an additional proximal kinematic alteration associated with CAI. The causes of dynamic knee valgus in the frontal plane are clarified by the findings of the following referenced studies.

Existing research indicates a significant association between 2D FPPA, knee lateral rotation, and hip adduction—essential components of DKV. Since the lower extremity joint motions are mechanically linked to each other, consequently, as emphasised by Drewes et al. (2009), the more inverted position of the injured ankle and rearfoot motions, coupled with external rotation of the tibia during weight-bearing activities, could alter knee alignment, potentially resulting in increased knee valgus [40].

Moreover, the challenge of maintaining control in the frontal plane during dynamic tasks is attributed to weakened proximal hip muscles, specifically the hip abductors and external rotators. The reduced activation of the gluteus medius and external rotators is implicated in encouraging hip adduction and internal rotation, potentially resulting in excessive knee valgus. Lin et al. (2021), Son et al. (2019), and DeJong et al. (2019) collectively support the notion of decreased gluteus medius activation in individuals with chronic ankle instability (CAI) [41] [42] [43]. In addition Son et al. reported diminished external rotators (gluteus maximus) activity. In contrast, Lin et al. observed increased gluteus maximus activity, indicating potential sensorimotor deficits, while DeJong et al. noted bilateral decreases in gluteus medius activity during walking gait. McCann et al. (2017) and Stickler et al (2015) highlighted deficiencies in external rotation strength in individuals with CAI [44] [45]. However, not all studies align on this matter, with Koldenhoven et al. (2016) reporting increased gluteus medius activation [46], and Koshino et al. (2016) finding no significant differences in muscle activities between subjects with and without CAI [47]. The discrepancies in findings across studies could be attributed to variations in the methods employed during each research.

Another possible explanation for the heightened FPPA among individuals with chronic ankle instability could be a muscular imbalance in the medial-lateral activity of the quadriceps muscle. Palmieri-Smith et al. (2008) observed that increased pre-activity of the vastus lateralis muscle and decreased pre-activity of the vastus medialis are predictors of elevated knee valgus [48]. Similarly, Li et al. (2018) found greater activations for the vastus lateralis in individuals with CAI [49], although Son et al. (2018) reported a conflicting result [42], indicating reduced electromyography (EMG) activation of the vastus lateralis during most of the stance phase. Additionally, when considering muscle imbalance involving the rectus femoris and hamstrings, Sedory et al. (2007) concluded that CAI is characterized by an activation imbalance, involving bilateral hamstring muscle arthrogenic inhibition and unilateral quadriceps facilitation [50]. Similarly, Wild et al. (2013) revealed a significant increase in dynamic knee valgus with low hamstring strength [51]. In contrast, Wilson et al. (2006) demonstrated that greater knee flexor strength is associated with larger knee valgus angles [52]. According to Wilczy´nski et al. (2020), an imbalance in medial-to-lateral quadriceps-hamstring co-contraction may contribute to increased knee valgus among recreational athletes [53]. These findings are consistent with and support the results of this study.

Hertel (2000) and Hoch et al. (2012) have identified that some individuals diagnosed with CAI experience a deficit in ankle dorsiflexion range of motion (ROM) [54][55]. Furthermore, Hertel et al. (2019) have observed that soft tissue restrictions and limited anterior-to-posterior talar glide contribute to the frequent occurrence of limited dorsiflexion ROM in patients with CAI [56]. In their systematic review with meta-analysis, Lima et al. (2017) assessed 17 studies and found consistent results [57]. They demonstrated that individuals exhibiting DKV show a connection with reduced ankle dorsiflexion (ADF) compared to controls. The study indicated a consistent association across various ADF measurement methods, such as restrictions measured in weight-bearing positions, non-weight-bearing with the knee flexed, or non-weight-bearing with the knee extended. Thus the elevated value of DKV in Chronic Ankle Instability (CAI) patients may be attributed to the observed deficit in ankle dorsiflexion range of motion.

Moreover, Ziabari et al. (2022) strongly indicate that unilateral chronic ankle instability can influence the kinematics of the contralateral uninjured ankle in patients with unilateral CAI [28]. They observed a reduction in ankle dorsiflexion in the unaffected limbs of patients with unilateral CAI, displaying similar alterations as the unstable side. This observation adds context to our finding of increased FPPA in the unaffected limb within CAI patients. Consistent with earlier explanations, other factors contributing to this biomechanical alteration may include deficits in the gluteus medius muscle. As emphasized by Lin et al. (2021) and DeJong et al. (2019), reduced activation of the gluteus medius is present on both sides in the CAI group [41][43]. Additionally, Sedory et al. (2007) reported that individuals with unilateral CAI exhibit bilateral inhibition of the hamstring muscles, a factor that may contribute to our observed findings when compared with a healthy control group [58]. These various factors collectively contribute to a more comprehensive understanding of the complex biomechanics associated with CAI. Additional research is highly recommended and necessary in this regard.

Schmidt et al. (2019) highlighted that elevated dynamic knee valgus, characterized by increased hip adduction, hip internal rotation, and knee external rotation, contributes to an increased dynamic Q angle [59]. This heightened motion not only has the potential to raise stresses on both the knee and hip joints but also poses a risk for long-term issues such as patellofemoral pain or chronic discomfort in the hip joint.

Additionally, an elevated Q-angle, as recognized by Skouras et al. (2022) [7], serves as a risk factor for a spectrum of disorders and injuries. These include PFP, patellar subluxation and dislocation, chondromalacia patellae, knee osteoarthritis, overuse injuries, anterior cruciate ligament injury, patellar instability, disturbances in dynamic balance, and even ankle sprains. Both studies underscore the importance of understanding and addressing these factors to mitigate the potential for various musculoskeletal issues.

## Conclusion

The present study suggested that individuals with unilateral CAI display an increased knee valgus in both the affected and unaffected limb, suggesting an additional proximal kinematic alteration and chronic maladaptation in the CAI population. When addressing individuals with chronic ankle instability, healthcare professionals should incorporate evaluations and interventions targeting alterations in proximal regions. This is crucial, as there is substantial evidence indicating that changes in proximal neuromuscular function impact movement patterns within this population. It is also advisable to incorporate both the unstable and stable ankles into any rehabilitation protocol.

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