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# The Effects of Open versus Closed Kinetic Chain Exercises on Ankle Joint Function in Athletes with Chronic Ankle Instability

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**Abstract**

**Objective:** Lateral ankle sprains are common sport injuries that often result in structural and functional alterations leading to chronic ankle instability (CAI). Insufficiencies in proprioception, neuromuscular control, and strength are suggested as contributing factors to CAI. Open Kinetic Chain (OKC) and Closed Kinetic Chain (CKC) exercises often constitute the core of ankle specific training before progression to advanced training. Though commonly used in the management of CAI, there is no consensus regarding their efficacy on physical therapy outcomes. The purpose of this study was to compare the effect of OKC and CKC exercises on dynamic postural control, self-reported function, and subjective sense of instability in subjects with CAI.

**Methods:** Subjects with unilateral CAI were randomly assigned into three groups: OKC (n=5), CKC (n=6), and control (n=6). Outcome measures included star excursion balance test (SEBT) reach distance, center of pressure (COP) sway velocity, sway area, and path length; and Foot and Ankle Ability Measure-Sport Subscale. Intervention groups completed 6 weeks of exercises. Also, subjects completed a global rating of change (GROC) form at week 6 post-intervention.

**Results:** Following intervention, both OKC and CKC groups had significant improvements in the outcome measures, indicating an improvement in dynamic postural control and subjective function; however, CKC had greater improvements than OKC. The control group did not show improvements. GROC revealed a significant difference in median score for CKC group when compared to OKC and control groups (p=0.04 and p=0.03, respectively).

**Conclusion:** The 6-week of OKC and CKC exercise programs improved parameters of postural control and subjective function in CAI subjects. CKC exercises, however, were more effective than OKC exercises. Hence, exercise programs should become more functional and task oriented. Further research is needed in a larger cohort of subjects to determine effects of both training programs on ankle joint injury risk factors.

**Keywords**

Chronic ankle instability; Ankle sprains; Open kinetic chain; Closed kinetic chain; Postural control; Star excursion balance test

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## Introduction

Lateral ankle sprain is a common phenomenon for individuals engaging in vigorous sports activities [1,2]. They account for approximately 25% to 30% of all sport-related injuries [1], with a recurrence rate of as high as 70% in most of the cases [3]. Following a lateral ankle sprain, approximately 40% of the cases will develop persisting symptoms resulting in a longstanding dysfunction known as Chronic Ankle Instability (CAI) [4,5]. Two of the most frequently encountered residual symptoms of CAI include: 1) a recurring sensation of ankle instability and 2) reported episodes of giving way, which result in repetitive injuries, increased self-reported disability, activity limitations, and participation restrictions [5]. Despite the high recurrence rate, nearly 55% of those who experience ankle sprains do not seek medical attention [6]. If left untreated, however, repetitive sprains may cause damage to the articular surface of the ankle joint, thus increasing the likelihood of developing degenerative changes such as ankle osteoarthritis [7,8].

Subjects with CAI typically present with diminishing neuromuscular control and are unable to carry out their routine activities with the affected limb [4,9,10]. In addition, the impaired joint position sense and accompanying muscle weakness results in altered function [11,12]. Moreover, the presence of pain can also affect the performance of tasks and the demonstration of the specific skills. Affected individuals also demonstrate deficiency in postural control owing to the affected musculature of the affected joint [4,9,10]. Alteration in postural control when carrying out activities is seen as the greatest contributor to lateral ankle sprains [12-15]. Furthermore, with the presence of these alterations, one may develop prolonged functional ankle instability even after healing has taken place [16].

Previous literature suggest that subjects with CAI symptoms often exhibit deficits in evertor strength that affects their capacity to maintain balance of the body [17]. In addition, subjects with CAI were shown to have a lower activation of the Peroneus Longus (PL) and Tibialis Anterior (TA) associated with pre-landing when performing a jump [18,19], and during pre and post touchdown phases of stepping down in gait [20]. Thus, the risk of injury is high during such activities in the presence of poor ankle stabilization. Specifically, ambulatory and exercise capacity of subjects with CAI is severely affected. Previous research studies have also suggested hip muscle activation and strength is altered in subjects with CAI [21-23]. Friel et al. [21] reported significantly less gluteus medius muscle strength (Gmed) on the affected side than the unaffected side in subjects with CAI. Subjects with CAI demonstrated decreased gluteus maximus (Gmax) activity as compared to healthy individuals during a single leg rotational squat exercise [23]. During a transition from bilateral to unilateral stance, those with CAI have also displayed a delay in onset of muscle activation and less anticipatory activation in muscles acting around the ankle, knee, and hip joints [22]. These alterations in the proximal muscle strength and activation, along with changes in movement patterns, were reported to negatively affect measures of postural control, leading to functional impairments and increased recurrence rates in those with CAI [24-27].

The two forms of exercises that often constitute the core of ankle specific training before progression to more advanced training

are open and closed kinetic chain exercises. These exercises are frequently administrated to enhance resistance training that is conducted to improve ankle stability, achieve balance, and improve functionality [11].

In general, Open Kinetic Chain (OKC) exercises are single joint movements in which the proximal part of the limb is often fixed while the distal aspect of the limb is allowed to move freely [28]. The exercises are performed in a non-weight bearing manner, vital in the isolation of individual muscle groups, and tend to generate rotational and distraction forces [28]. On the other hand, Closed Kinetic Chain (CKC) exercises are multi-joint movements where the distal part remains fixed [28]. The exercises are performed in a weight bearing position and considered to be more functional [28]. The most important aspect of CKC exercises is the capacity to achieve resistance training at both the distal and proximal ends concurrently [29]. Furthermore, CKC exercises have been suggested to produce eccentric contraction and co-contraction of muscles, which reduces the shearing forces while adding compressive forces to the joints, thus improving joint stability [30,31]. Moreover, CKC exercises promote proprioception by emphasizing the proprioceptive feedback to initiate and control the muscle activation patterns [32]. Kwon et al. [33], showed that CKC exercises were found to be more effective than OKC exercises at improving dynamic postural control in healthy adults. Electromyographic (EMG) studies have also recommended the use of weight bearing exercises over the open chain exercises to treat lower extremity injuries [34,35]. Bellew et al [34] reported an increased peroneus longus EMG activity with heel raises exercises as compared to conventional ankle eversion exercises using resistive therabands.

OKC and CKC exercises have considerably been in practice as muscle strengthening exercises. However, there is no distinction as to which exercise would be more beneficial in improving the dynamic aspects of postural control performance, self-reported function, and subjective sense of instability in subjects with CAI. There is a poverty of literature on this issue. Therefore, this pilot study aimed at comparing the effectiveness of open versus closed kinetic chain exercises on chronic ankle instability. We hypothesized that both OKC and CKC exercises would improve the outcome measures, and that CKC training would produce better improvement.

## Methods

### Participants

A sample of seventeen physically active subjects (13 males, 4 females) with mean age 28.8 ± 4.7 years, height 171.1 ± 6.7 cm, mass 72.5 ± 13.4 kg, and body mass index 24.6 ± 3.5 kg/m$^2$) volunteered to participate in this study. All subjects read and signed an informed consent approved by the Institutional Review Board of Loma Linda University prior to participation. All subjects met the following inclusion criteria [36]: 1) were between 18 and 35 years of age; 2) had a history of at least 1 significant lateral ankle sprains to the same side that resulted in pain and loss of function of more than one day; 3) had a history of at least 2 episodes of "giving way" in the past 6 months; and 4) participate in physical activity for at least 90 min each week. Subjects were excluded if they reported: 1) bilateral ankle instability; 2) a history of neuromusculoskeletal or vestibular disorders; 3) previous lower limb surgeries; 4) trauma to the lower limbs for at least 3 months prior to the study; 5) physiotherapy within the last 3 months or current participation in supervised physical rehabilitation; or 6) inability to comply with the home exercise program.

Perceived ankle instability was assessed using self-reported questionnaires that included the Cumberland Ankle Instability Tool (CAIT) (minimum score 0, maximum score 30) and the Ankle Instability Instrument (AII). The CAIT has been shown to be valid and reliable in assessing the perceived symptoms of ankle instability [37]. The combination of the two instruments (the AII and CAIT) was reported to be most accurate in classifying CAI [38]. Subjects were classified as having CAI if they scored 24 or less on CAIT, which was confirmed with the AII (answered 'yes' to at least five questions, including question 1). Those who scored between 24 and 28 were excluded from the study to eliminate any potential effect on the results. Subjects were then randomly assigned to either OKC exercise group, CKC exercise group, or control group.

### Instrumentation

Postural control was quantified by the Star Excursion Balance Test (SEBT) reach distance and the magnitude of the Center of Pressure (COP) movement and excursion. A computerized force platform (SCIFIT Systems Inc., Tulsa, Oklahoma, USA) was used to acquire COP measures (sway area, sway velocity, and path length) during the performance of the SEBT. The area represented the magnitude of distribution of COP excursions during a trail, whereas velocity represented the average speed of COP movement during a trail. COP length was the traveling distance of COP trajectory from the starting position to the maximal position of the COP during each trial. The center of the SEBT grid was aligned with the center of the force plate. The SEBT has been shown to be a valid and reliable clinical test for assessing dynamic postural control and functional deficits associated with CAI [39].

### Procedures

After subjects read and signed the informed consent and completed the self-reported questionnaires designed to identify subjects with CAI, subjects completed baseline measurements that included Foot and Ankle Ability Measure (FAAM)-Sport Subscale, SEBT reach distance, and the COP measures, which were collected during the performance of the SEBT. Subjects in the control group were instructed to continue with their normal routine activities for 6 weeks then return for follow-up testing. Subjects in the other groups began the 6-week rehabilitation program the same week. Post-intervention testing included the same outcome measures that were administrated at baseline. In addition, subjects completed a Global Rating of Change (GROC) form at week 6 post-intervention.

### SEBT protocol

To perform SEBT, subjects were instructed to stand barefoot on the test leg with their midfoot positioned over the center of a tape grid and slowly reach with their contralateral leg as far as possible in three different directions [40] (anterior, posteromedial and posterolateral directions), touch the line on the floor lightly with the tip of the foot of the reaching limb while keeping the heel of the stance foot on the ground and their hands resting on their waist, then return to the starting position while maintaining single-leg stance balance for about 10 s before resting. Three practice trials in each reach direction were allowed to familiarize subjects with the test followed by three measurements trials. An additional practice trail was given when necessary. Subjects were verbally encouraged to reach as far as possible. Thirty seconds of rest (sit on a chair) were given between each reach trial and 60 s between each direction to minimize fatigue. The test was demonstrated to each participant by one of the research

team members prior to the practice trials. A metronome was used at a rate of 60 beats/min to ensure consistent timing of each reach trial. The trial was discarded and repeated if subjects lifted the heel of the stance limb off the floor, did not keep their hands on their waist, touched down with their reach foot (weight bearing with the reaching limb), lost balance, or could not return to the starting position. The order of the reach directions was randomized to account for any potential bias. COP data were recorded simultaneously during the procedure.

## FAAM-sport subscale

To measure the self-reported function, all subjects completed the FAAM-Sport Subscale. The FAAM consists of 8-item sports subscale. Each item is scored from 4 to 0, with 4 being (no difficulty) and 0 being (unable to do). The subscale has a total score of 32, which expressed as a percentage, with 100% representing a higher level of function [41]. The scale has shown strong evidence for validity, test-retest reliability (ICCFAAM-Sport=0.87), and responsiveness among subjects with CAI [41].

## GROC scale

The GROC scale is a subjective measure of clinical changes [42]. The scale is commonly used in clinical research and is considered a useful method for assessing the participant's perception of the efficacy of a particular intervention [43]. It consists of a 15-point scale ranging from -7 (a very great deal worse) to 0 (about the same) to 7 (a very great deal better), allowing participants to rate changes experienced in a clinical parameter following the intervention [42]. The scale has been shown to have acceptable levels of validity and reliability [42]. Subjects were asked to rate their overall perception of ankle instability "giving way" at the conclusion of the 6-week intervention period. They were asked to check only one point out of the 15 points present in the scale.

## Intervention

Subjects in the OKC and CKC groups underwent 6-weeks of an exercise program, 3 times per week. During the first week and following the baseline measurements, exercises were demonstrated to each participant to ensure understanding of each technique. Subjects then reported to the laboratory once a week to perform the exercises under the supervision of a physical therapist to ensure proper performance. Subjects were asked to complete the other two times of exercises at home (as a home-based exercise program). To ensure and facilitate compliance, subjects were given an exercise log sheet with a detailed description and demonstrative figures of each exercise to be completed during the week. Subjects were also contacted weekly through phone calls and text messages as a reminder to minimize lack of compliance. Subjects in the OKC group were instructed to perform OKC exercises using elastic theraband for the ankle and hip muscles, while subjects in CKC group were instructed to perform CKC exercises as prescribed. The program was gradually progressed throughout the 6-week period. Because we were interested in dynamic postural control during sagittal and frontal plane stability, we chose to strengthen hip and ankle muscles that contribute to sagittal plane stability (Gmax & TA) and those that contribute to frontal plane stability (Gmed & PL). Exercise description is summarized in Table 1.

## Data Processing

Reach distance was manually measured in centimeter from the center of the grid to each marked point on the grid line. Measurements from the three trials were averaged and normalized to subject's leg length, which was measured manually from the anterior superior iliac

**Table 1:** Groups, Exercise Prescriptions and Progression Modes.

| Group | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 |
|---|---|---|---|---|---|---|
| CKC | Double leg heel raises: (3 sets x 12 reps) | Double leg heel raises: (3 sets x 12 reps) | Single leg heel raises: (2 sets x 10 reps - each side) | Single leg heel raises: (2 sets x 10 reps - each side) | Single leg heel raises with weight (15 kg): (3 sets x 12 reps - each side) | Single leg heel raises with weight (20 kg): (3 sets x 12 reps - each side) |
| | SEBT Functional Reaching (1 set x 5 reps - each side) | SEBT Functional Reaching (1 set x 5 reps - each side) | SEBT Functional Reaching (2 sets x 5 reps - each side) | SEBT Functional Reaching (2 sets x 5 reps - each side) | SEBT Functional Reaching (3 sets x5 reps - each side) | SEBT Functional Reaching (3 sets x 5 reps - each side) |
| | Double leg squats: (3 sets x 10 reps) | Double leg squats: (3 sets x 10 reps) | Double leg squats: (3 sets x 12 reps) | Double leg squats: (3 sets x 12 reps - each side) | Single leg squats: (3 sets x 10 reps - each side) | Single leg squats: (3 sets x 10 reps - each side) |
| OKC | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) | Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side) |
| | Side-lying hip abduction: (2 sets x 20 reps - each side) | Side-lying hip abduction: (3 sets x 20 reps - each side, Thera-progression) | Clam-shell gluteus medius: (2 sets x10 reps - each side, Thera-progression) | Clam-shell gluteus medius: (2 sets x 10 reps - each side, Thera-progression) | Clam-shell gluteus medius: (2 sets x 20 reps - each side, Thera-progression) | Clam-shell gluteus medius: (2 sets x 20 reps - each side, Thera-progression) |
| | Fire Hydrant (2 sets x 10 reps - each side) | Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side) | Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side) | Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side) | Fire Hydrant (Thera-progression, 2 sets x 10 reps - side) | Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side) |
| Control | No Exercise | | | | | |

Abbreviation: SEBT: Star Excursion Balance Test; PF: Plantarflexion; DF: Dorsiflexion

spine to the distal tip of the medial malleolus [44]. The average reach distance for each direction was expressed as a percentage of leg length and used for analysis. Composite reach distance of the four directions was also analyzed. Composite reach distance was the sum of the 4 reach directions divided by 4 times limb length and then multiplied by 100. COP data during the SEBT were recorded at 100Hz. Data collected from the 3 reaching trials in each direction were averaged and analyzed in respect of the averaged reaching distance within each direction.

### Statistical analyses

A total of 17 subjects were recruited, 6 in CKC group, 5 in OKC group, and 6 in the control group. Data was summarized using mean and Standard Deviation (SD) for quantitative variables and counts (%) for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk's test and box plots. The distribution of subjects' characteristics by study group was evaluated using chi-square for qualitative variables. We used One-Way Analysis of Variance (ANOVA) to compare means of baseline quantitative variables among the study groups. Outcome variables at baseline were compared among groups using One Way ANOVA. Mean postural control variables and FAAM sports subscale scores were compared by group type over time using 2 × 3 mixed factorial ANOVA. Post hoc comparisons using Bonferroni test were conducted to identify specific differences when significant group main effects were detected. Kruskal-Wallis ANOVA was used to compare GROC scores among the study groups. If results were significant, Mann-Whitney test was conducted to determine which groups were significantly different. The level of significance was set at $p \leq 0.05$. All statistical tests were performed using IBM SPSS Statistics Software version 24 for Windows (Chicago, IL, USA).

## Results

Subjects' characteristics are summarized in Table 2. The distribution of all quantitative variables was approximately normal. There was no significant difference in characteristics of subjects by study group ($p>0.05$).

### SEBT reach distance

Results are presented in Table 3. There was a significant change in mean SEBT composite reach distance over time ($F1,14=15.7$, $p=0.001$). A significant group by time interaction was also noted ($F2,14=3.8$, $p=0.04$). The change was significantly different among groups ($F2,14=3.8$, $p=0.04$, $\eta^2=0.4$). Specifically, Bonferroni's post hoc comparison revealed that the difference was significant between CKC and control groups ($p=0.01$), and between OKC and control groups ($p=0.02$); however, this difference was not significant between CKC and OKC groups ($p=0.43$).

### COP sway velocity

Results are displayed in Table 3. There was a significant change in mean COP sway velocity over time ($F1,14=3.2$, $p=0.04$). Significant group by time interaction was also noted ($F2,14=3.7$, $p=0.03$). The change was significantly different among groups ($F2,13=3.7$, $p=0.03$, $\eta^2=0.4$). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups ($p=0.01$); however, this difference was not significant between CKC and OKC groups, and between OKC and control groups ($p=0.13$, $p=0.06$, respectively). Though the difference between OKC and control groups was not statistically significant, the OKC group did show a slight improvement in sway velocity of about 11% from baseline, whereas controls' sway velocity got worse.

### COP sway area

Results are summarized in Table 3. There was no significant change in mean COP sway area over time ($F1,14=2.3$, $p=0.14$). Significant group by time interaction, however, was noted ($F2,14=4.0$, $p=0.03$). A significant difference among groups was also found ($F2,13=4.0$, $p= 0.03$, $\eta^2=0.1$). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups ($p=0.01$), and between OKC and control groups ($p=0.03$); however, this difference was not significant between CKC and OKC groups ($p=0.38$).

### COP path length

Results are presented in Table 3. There was no significant change in mean COP path length over time ($F1,14=0.3$, $p=0.65$). However, significant group by time interaction was noted ($F2,14=4.5$, $p=0.03$). A significant difference among groups was also found ($F2,13=4.5$, $p= 0.03$, $\eta^2=0.4$). Bonferroni's post hoc comparison revealed that the difference was significant between CKC and control groups ($p=0.01$); however, this difference was not significant between CKC and OKC groups, and between OKC and control groups ($p=0.08$, $p=0.09$, respectively). Though the difference between OKC and

**Table 2:** Mean (SD) of Baseline Characteristics by Study Group (N=17).

| | CKC Group (n=6) | OKC Group (n=5) | Control Group (n=6) |
|---|---|---|---|
| Male (n) | 4 | 5 | 4 |
| Age, y | 30.0 (5.4) | 28.8 (2.6) | 27.5 (5.6) |
| Height, cm | 170.3 (6.8) | 171.2 (7.4) | 171.8 (7.2) |
| Mass, kg | 65.9 (12.5) | 72.2 (7.9) | 79.3 (16.1) |
| BMI (kg/m$^2$) | 22.7 (3.9) | 24.6 (1.6) | 26.6 (3.7) |
| Leg length, cm | 88.2 (3.8) | 89.5 (5.9) | 92.2 (4.2) |
| MD visit for LAS (n) | 3 | 1 | 2 |
| Grade of LAS (II/III, n) | 3/3 | 4/1 | 5/1 |
| LAS frequency (≥ 3, n) | 6 | 5 | 6 |
| Pain during sport (n) | 5 | 2 | 5 |
| Previous rehab (n) | 1 | 1 | 0 |
| Sport participation, hours per week | 5.7 (1.2) | 7.6 (2.9) | 7.3 (3.4) |
| CAIT score | 18.5 (4.4) | 22.0 (2.4) | 20.3 (5.5) |

**Abbreviations:** SD: Standard Deviation; CKC: Closed Kinetic Chain; OKC: Open Kinetic Chain; BMI: Body Mass Index; MD: Medical Doctor; LAS: Lateral Ankle Sprain; CAIT: Cumberland Ankle Instability Tool

**Table 3:** Mean (SD) of Postural Control by Study Group Over Time.

| | CKC Group (n=6) | | | OKC Group (n=5) | | | Control Group (n=6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline | Post 6 weeks | Effect Size ($\eta^2$) | Baseline | Post 6 weeks | Effect Size ($\eta^2$) | Baseline | Post 6 weeks | Effect Size ($\eta^2$) | p-value* over time | Effect Size ($\eta^2$) | p-value* among groups |
| SEBT Composite Reach, %[a] | 87.1 (9.2) | 93.3 (5.1) | 1.0 | 91.4 (6.4) | 94.1 (4.0) | 2.3 | 84.6 (5.8) | 84.7 (5.4) | 0.0 | 0.001 | 0.5 | 0.02 |
| Composite Sway Velocity (mm/sec)[b] | 68.3 (12.3) | 48.8 (12.7) | 2.0 | 66.2 (17.4) | 58.8 (16.7) | 0.5 | 70.6 (11.0) | 76.4 (17.4) | 0.4 | 0.04 | 0.2 | 0.04 |
| Composite 95% Confidence Ellipse Area ($mm^2$)[c] | 3117.6 (1109.0) | 2295.8 (1724.9) | 0.6 | 3667.3 (1092.3) | 3007.0 (903.8) | 0.7 | 2966.5 (1060.4) | 3474.1 (1317.3) | 0.5 | 0.14 | 0.1 | 0.03 |
| Composite Path Length (mm)[d] | 956.2 (210.5) | 730.6 (191.2) | 1.1 | 906.5 (177.6) | 889.1 (244.4) | 0.1 | 999.3 (166.0) | 1164.9 (328.6) | 0.7 | 0.65 | 0.0 | 0.03 |
| FAAM-Sports Subscale[e] | 73.3 (9.8) | 93.3 (8.7) | 2.2 | 81.8 (12.9) | 86.4 (15.7) | 0.3 | 80.0 (5.5) | 80.8 (2.0) | 0.2 | 0.004 | 0.5 | 0.01 |

**Abbreviations:** SD: Standard Deviation; CKC: Closed Kinetic Chain; OKC: Open Kinetic Chain; SEBT: Star Excursion Balance Test; FAAM: Foot and Ankle Ability Measure. For all variables except reaching distance and FAAM, reduction in scores means improvement in postural stability

[a] Significant difference between CKC and controls (p= 0.01), and between OKC and controls (p= 0.02); No significant difference between CKC and OKC (p=0.43)

[b] Significant difference between CKC and controls (p= 0.01); No significant difference between OKC and controls (p= 0.06) and between CKC and OKC (p= 0.13)

[c] Significant difference between CKC and controls (p= 0.01), and between OKC and controls (p= 0.03); No significant difference between CKC and OKC (p= 0.38)

[d] Significant difference between CKC and controls (p= 0.01); No significant difference between OKC and controls (p= 0.09) and between CKC and OKC (p= 0.08)

[e] Significant difference between CKC and controls (p=0.005), and between CKC and OKC (p=0.02); No significant difference between OKC and controls (p=0.5)

*Mixed factorial analysis of variance (ANOVA)

control groups was not statistically significant, the OKC group did show a slight improvement in the path length from baseline, whereas controls' path length got worse.

### FAAM-sport subscale

Results are summarized in Table 3. There was a significant change in mean FAAM-Sport Subscale score over time ($F_{1,14}=12.2$, p=0.004). A significant group by time interaction was also noted ($F_{2,14}=6.1$, p=0.01). The change was significantly different among groups ($F_{2,13}=6.1$, p= 0.01, $\eta^2=0.5$). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups (p= 0.005), and between CKC and OKC groups (p= 0.02); however, no significant difference was detected between OKC and control groups (p=0.5).

### GROC scale

There was a significant difference in GROC score among the three study groups (Z=6.8, p=0.03). Mann-Whitney results showed that the difference was significant between CKC and control groups (median (min, max): 5 (3, 7) *vs.* 0 (-5, 5), p=0.04), and between CKC and OKC (median (min, max): 5 (3, 7) *vs.* 2 (0, 4), p=0.03); however, no significant difference was found between OKC and control groups (median (min, max): 2 (0, 4) *vs.* 0 (-5, 5), p=0.43).

## Discussion

Open and closed kinetic chain exercises are important components of the rehabilitation programs of ankle instability. However, to our knowledge, this is the first study to examine the efficacy of OKC and CKC exercises as a method of improving dynamic postural control, self-reported function, and perceived sense of instability in subjects with CAI. Results revealed that both experimental groups had significant improvements in the outcome measures; however, CKC group had greater improvements than OKC group. In contrast, the control group did not show any improvements from baseline.

### Postural control

Impaired postural control has been consistently identified in the literature as a risk factor for ankle sprains and a feature of CAI [12-15]. Following the 6-week training protocol, both OKC and CKC groups improved on all postural control variables, with higher improvement noted for the CKC group, thus emphasizing the importance of these exercises for reducing CAI symptoms.

Several studies have reported that CKC exercises elicit performance gains similar to or better than OKC exercises in healthy individuals and those with knee problems [45-48]. CKC exercises have been found to be more effective than OKC exercises at improving vertical jump performance in healthy adults [45]. Yack et al. [49] compared the effectiveness of OKC and CKC exercises in ACL rehabilitation and reported that OKC group had more laxity than CKC group. However, limited evidence exists regarding the effect of these exercises on subjects with CAI. Most of previous studies used a combination of strengthening and coordination exercises as intervention, while in this study, we sought to compare the effect of CKC and OKC exercises as a method of improving dynamic postural control.

Nonetheless, the effect of OKC and CKC exercises on dynamic postural control was previously examined in healthy subjects [33,50]. Kwon et al. [33] reported that CKC exercises showed a significant improvement in dynamic postural control when compared to OKC exercises, which produced some improvement but was not significant. In contrast, Dannelly et al. [50] reported that both exercises showed significant changes in dynamic postural control with CKC group had slightly better improvement.

Though performed on CAI subjects, our findings are in agreement with the results reported by Dannelly et al. [50]. Both exercises produced significant improvement in postural control. One possible explanation of the significant improvements seen in both groups could be attributed to the fact that the OKC group

in our study received strengthening training to the hip muscles in addition to ankle muscles. With this, the effect acquired from OKC exercises would someway resemble that of CKC with the exception of the functional nature of CKC exercises, which might have led to the higher improvement in postural control and functional performance in the CKC group. These findings further support the contention that hip strengthening is a viable intervention for this population [23,51]. It should be noted, however, that both Kwon et al. [33] and Dannelly et al. [50] studies did not include control groups. We believe that adding the control group strengthened our findings and the observed changes in both experimental groups were clinically relevant.

### Self-reported function

The FAAM-sports subscale was used to allow participants to rate their level of function during sports related activities pre- and post-intervention. The change in self-reported function was mainly significant for the CKC group. The CKC group showed an improvement of about 20% from baseline, whereas OKC group increased by only 5%. In contrast, the control group did not show any change from baseline. The greatest improvement seen in CKC group could be attributed to the functional nature of these exercises.

### GROC scale

The GROC scale was used to assess the participant's perception of ankle instability following the 6-weeks of intervention. The CKC group had a significant change in the subjective perception of ankle instability and a greater level of satisfaction as compared to the other groups. The functional nature of the CKC exercises may have induced some proprioceptive changes that might have led to improved sense of ankle stability.

Our hypothesis that CKC exercises would improve the performance on postural control measures and self-reported function better than OKC exercises was supported with the results of this study. The higher improvement seen in the CKC group signifies the superiority of the functional training of these exercises over regular non-weight bearing training. CKC exercises are performed in a weight bearing position. In weight bearing movements, several group of muscles work across multiple joints [28]. In addition, CKC training generates more eccentric contraction and muscular co-contraction, which produces more tension in the muscles while adding compressive forces to the joints and thereby resulting in greater joint stability [30,31,46]. This could be the primary factor in the higher improvement noted in function and dynamic postural control in the CKC group as compared to the OKC group. Adding the SEBT (functional reaching) in the CKC exercise protocol may also explain the better improvement noticed in the CKC group. Traditionally, the SEBT has been used as a functional test of dynamic postural control; however, Donovan and Hertel [52] have recommended using it as a functional rehabilitation exercise. The SEBT is a CKC activity; therefore, we sought to include it in the CKC training protocol. Reaching on the SEBT imposes a postural control challenge that ankle, knee, and hip joints of the support limb must effectively resist to maintain stability. In addition, in a weight bearing position, the central nervous system constantly make adjustment to keep the center of mass within the base of support [53]. Thus, CKC exercise training applied in our study may have induced changes in neural control that might have led to improved postural control.

Though we were able to show that OKC and CKC exercises can improve postural control in subjects with CAI, we do not know the extent to which this improvement in postural control might lead to a reduction in the recurrence of ankle sprains in this population. Hence, a follow up study may be needed to examine the longitudinal effect of these exercises on the incidence and recurrence of ankle sprains. It is also worth mentioning that the mean age of the population included in our study was between 27 and 30 years of age, which was higher than the age reported (20-21 years) in the majority of the previous CAI research. Future studies should investigate whether similar comparisons would yield similar results in younger population.

## Study Limitations

Limitations of this study include the relatively small sample size and the lack of follow up. Follow up was not one of our purposes in this study, however, the long-term benefits of OKC and CKC exercises training in chronic ankle instability are not known, which necessitates the need for further research. Furthermore, electromyographic activity was not recorded in our study. This might be important, as previous research has indicated that subjects with CAI have altered muscle activation patterns [18-20,22,23].

### Clinical Implications

On the basis of this study results, both OKC and CKC training programs had positive effects on the outcome measures with greater improvement noted for the CKC exercises. The higher improvements seen in the CKC group support previous findings suggesting the superiority of the functional training. Though safe and effective in the early rehabilitation, OKC exercises do not challenge the performance of the muscles as CKC exercises may do. In addition, hip strengthening is a viable intervention for this population and clinicians should consider including it in the training programs. Furthermore, clinicians should incorporate the SEBT as a functional rehabilitation exercise. It is for the clinician, however, to decide when to use open or closed kinetic chain training in their rehabilitation program for this population. The longitudinal effect of exercises is usually unknown, however, evidence from previous exercise trials in other musculoskeletal conditions suggests that benefits of a training program decline over time and booster sessions are useful to maintain long-term benefits [54].

## Conclusion

The 6-week of OKC and CKC exercise programs improved parameters of postural control and subjective function in subjects with CAI. CKC, however, showed some superiority over OKC at improving postural control, self-reported function, and subjective sense of instability. CKC group demonstrated a greater level of satisfaction as compared to the other groups. The greatest improvement seen in CKC group could be attributed to the functional nature of these exercises. Hence, exercise programs should become more functional and task oriented. Further research, however, is needed in a larger cohort of subjects with CAI to determine the long-term effects of both training programs on ankle joint injury risk factors.

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