RESEARCH ARTICLE

Responsiveness of Static and Dynamic Postural Balance Measures in Patients with Anterior Cruciate Ligament Reconstruction Following Physiotherapy Intervention

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Abstract

Background: The main goal of physiotherapy for patients with anterior cruciate ligament reconstruction (ACL-R) is to improve postural control and retain knee function. Therefore, clinicians need to use evaluative tools that assess postural changes during physiotherapy. To maximize the clinical utility of the results of these tools, the extracted measures should have appropriate psychometric properties of reliability, validity and responsiveness. No study has yet addressed responsiveness of postural measures in these patients. This study was designed to investigate the responsiveness and determine the minimal clinically important changes (MCIC) of static and dynamic postural measures in patients with (ACL-R) following physiotherapy.

Methods: Static and dynamic postural measures were evaluated at first occasion and again after four weeks physiotherapy. The static measures consisted of center of pressure (COP) parameters while dynamic measures included the stability indices. Correlation analysis and ROC curve were applied for assessing the responsiveness.

Results: The meanand SD velocity of COP had acceptable responsiveness in both conditions of standing on injured leg with open-eyes and on uninjured leg with closed-eyes, both with nocognitive task. For dynamic measures, stability indices in double-leg standing with closed-eyes with cognitive task condition attained acceptable responsiveness. MCICs for mean and SD velocity in anteroposterior and mediolateral directions were 0.28cm/s, 0.008cm/s, 0.02cm/s, respectively in standing on injured leg with open-eyes; and 0.14cm/s, 0.07cm/s, 0.06cm/s, respectively in uninjured leg with closed-eyes condition. Also, MCICs for anteroposterior, mediolateral and total stability indices were 0.51°, 0.37°, 0.34°, respectively in DCT condition.

Conclusion: Our findings provide evidence for selection of appropriate static and dynamic postural measures for assessment of changes in these patients. MCICs for these measures were determined, which provide practical information for clinicians to make decision on clinical significance of changes in patients' status.

Keywords: Anterior cruciate ligament reconstruction, Physiotherapy, Postural balance measures, Responsiveness

Introduction

Anterior cruciate ligament (ACL) is the most commonly injured ligament in the knee which accounts for approximately50% of all ligamentous injuries in sports (1). ACL injury may result in knee instability, decreased postural balance and subsequently diminished daily motor activities (1, 2). Therefore, ACL reconstruction (ACL-R) is frequently recommended to retain mechanical stability, improve postural performance and finally return to pre-injury levels of functional activities (2, 3). However, recent research has shown that although mechanical joint stability can be successfully returned after ACL-R (2), many patients may continue

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to display impaired postural balance (2, 3). Researchers have recently revealed that there is a reduced postural control under static and dynamic conditions of standing balance in patients with ACL-R compared to healthy matched controls (2). Therefore, rehabilitation programs are essential for patients undergoing ACL-R with the aim of increasing dynamic stability, improving postural balance and proper restoration of functional ability (4).

As improving postural control outcomes and retaining knee function are the main goals of rehabilitation interventions, both clinicians and researchers need to use evaluative measures to assess overtime postural changes in patients undergoing post-ACL-R physiotherapy (3, 4). Postural control can be identified as either static or dynamic. Static postural control is the capability of an individual to keep the center of mass within a stationary and immobile base of support such as standing on a stable force platform whereas dynamic postural control represents the ability of an individual to keep the center of mass over a moving base of support such as standing on a tilting platform (5, 6). The most extensively used static and dynamic postural balance assessment tools in rehabilitation-based research of musculoskeletal conditions such as ACL-R are the force and tilting platforms (6-8). The results retrieved from these tools must possess appropriate psychometric properties of reliability, validity and responsiveness to ensure clinical meaningfulness and utility (9-11). The reliability of force and tilting platforms measures has already been established (6, 8). In current years, there has been a growing emphasis on the responsiveness identified as the capability of a measure to detect clinically important overtime changes (12). The responsiveness can be regarded from both internal and external points of view (10, 11). Internal responsiveness is defined as the ability of a tool to detect overtime changes whereas external responsiveness represents the degree to which a change in a measure associates with a change in a reference standard of clinical status (10, 13). Obtained through external responsiveness, minimal clinically important change (MCIC) demonstrates the smallest score or change in a score that is important from the patient's point of view (14). It is necessary that both clinicians and researchers know MCIC values when using outcome measures during rehabilitation to assess whether the rehabilitation program achieves its goals or not (15).

To the best of our knowledge, no study has yet addressed the responsiveness and determined the MCICs of the postural balance measures in patients with ACL-R after physiotherapy intervention. The present study sought to investigate the responsiveness of the static and dynamic postural balance measures following physiotherapy intervention in patients with ACL-R, and also determine the MCIC values of these postural outcome measures for identifying a true change in clinical status of this patient population.

Materials and Methods

Participants

A total of 54 patients with ACL-R who were recruited between July 2015 and March 2016from several physiotherapy clinics in Ahvaz, Iran were enrolled in this longitudinal prospective cohort study. The inclusion criteria included: age of 18-45 years, ability to stand on the injured leg for at least 40 seconds (six weeks following ACL-R) and walk without assistant devices. Concomitant ligamentous injury, history of damage or surgery to the ankle and hip joints of the reconstructed sideand/or the contralateral leg, history of current neck and back pain, history of vestibular or neurological diseases, and uncorrected visual deficits were defined as exclusion criteria. The demographic and clinical characteristics of included patients are shown in table 1.

This study was approved by the Research Ethics Committee of Ahvaz Jundishapur University of Medical Sciences (No: pht-9416) and all participants signed an informed consent form.

Procedure

Since the aim of the responsiveness studies is to investigate the characteristics of a given evaluative measure rather than the effectiveness of a therapeutic intervention, controlling the physiotherapy interventions was not necessary in this study (9); However, all the patients received the same consistent post-operative rehabilitation interventions including electrotherapy (e.g., neuromuscular electrical stimulation), strengthening exercises of the lower-extremity muscles (e.g., the quadriceps femor is, hamstring and gluteus medius muscles), and neuromuscular training (e.g., balance, dynamic joint stability) for three sessions per week (3). All the patients were asked to perform both static and dynamic postural tests, by the same evaluator, both

Table 1. Demographic and clinical characteristics of patients completing the tests (n=54)

	unless stated n (%)
Demographic data	
Age (year), mean (SD)	26.37 (5.12)
Height (cm), mean (SD)	175.14 (8.42)
Weight (kg), mean (SD)	73.64 (5.79)
Sex	
Men	54 (100.0)
Women	0 (0.0)
Years of education	
9-12	17 (31.5)
> 12	37 (68.5)
Clinical data	
Side of reconstructed knee	
Right	31 (57.4)
Left	23 (42.6)
Time elapsed since reconstruction (week)	6
Duration of intervention (week)	4

SD: Standard deviation

at the first test occasion (six weeks following ACL-R) and after four weeks of physiotherapy in order to determine the responsiveness of static and dynamic postural balance measures. Patients were permitted to be tested in the initial test occasion six weeks after ACL-R as our pilot tests revealed that this time was the earliest time when the participants met the inclusion criteria and could carry out all static and dynamic postural tests. At post intervention occasion, participants were also asked to rate their overall perception of change in their knee function over the previous four weeks (i.e., since the first postural tests were conducted) using the seven-point global rating of change scale. This scale was used as a standard reference for patients' impressions of change (16). The global rating scale consists of seven levels where one represents very much worse, two: much worse, three: slightly worse, four: no change, five: slightly better, six: much better, seven: very much better. According to the change scores reported from the global rating scale, the patients were categorized as improved (including very much better and much better) and unimproved (including slightly better, no change, slightly worse, much worse and very much worse) (16).

All the static and dynamic postural test sets were performed according to a randomized order, and a five min rest was allocated between the sets to minimize the undesirable impacts of fatigue.

Static postural balance test and testing protocol

A force platform (Kistler 9286BA, Kistler Inc, Switzerland) was used to extract the center of pressure (COP) parameters during standing to measure static postural balance (8). To evaluate the responsiveness of the COP parameters four levels of postural conditions were combined: 1) injured leg with open-eyes, 2) injured leg with closed-eyes,3) uninjured leg with open-eyes,4) uninjured leg with closed-eyes; along with two levels of cognitive conditions (i.e., with and without cognitive task). The participants were asked to wear a blindfold to eliminate vision for closed-eyes conditions. A quiet backward counting in steps of seven was considered as cognitive task, starting with a randomized number between 400 and 500. This quiet backward counting was selected in order to prevent motor disturbances that are typically associated with verbal or manual tasks (17).

During single-task (without cognitive task) conditions, participants were instructed to quietly stand barefoot on one leg on the center of the platform, looking straight ahead with arms relaxed and the free leg knee in slight flexion (30°). Data collection was started and finished with a computer keystroke, and lasted for the duration of completion of each trial. During dual-task (with cognitive task) conditions, the patients were instructed to stand as steady as possible while concurrently performing the cognitive task as precisely as possible. Before starting each test trial of static postural tests, the participants performed three familiarization trials with and without performing cognitive task. To summarize, every individual participant completed eight experimental conditions in each occasion. For each condition, three trials with one min rest between them were carried out. Since the reliability of the COP measures increases with increasing the duration of trial, the maximum continues time that the patients were supposed to be able to stand on the injured leg was considered as the criterion for choosing the duration of trials (18, 19). Therefore, based on the pilot tests, the durations of trials for open and closed eyes conditions were determined as 40 and 20 seconds, respectively. The eight experimental conditions in both occasions were performed according to a randomized order. The COP data were sampled at 100 Hz and filtered using a zero lag, fourth order Butterworth low-pass filter with a cut off frequency of 10 Hz. Following COP, the parameters were extracted from force platform data using a custom-written MATLAB code: mean velocity, standard deviation (SD) of velocity and amplitude in anteroposterior (AP) and mediolateral (ML) directions, and sway area (95% confidence ellipse). The rationale behind selecting several COP parameters was to assess different features of postural behavior (20). According to traditional perspective of postural control, higher scores of COP parameters often indicate decreased postural stability.

Dynamic postural balance tests and testing protocols

Techno-body Prokin tilting platform (Prokin PK254, Technobody Inc, Italy) was used to measure dynamic postural balance (21). To determine the responsiveness of dynamic postural balance measures, two levels of postural difficulty including double-leg standing at level 10 with open and closed-eyes were combined with two levels of cognitive difficulty (i.e., with and without cognitive task). According to the pilot tests performed by the researchers, the dynamic tests were conducted at level 10 on a scale of 1to 10 (1corresponds to the highest and 10 corresponds to the lowest flexibility of the platform). The rationale was that with a more flexible platform, maintaining the balance while keeping the platform near horizontal condition was too hard for the patients. The cognitive task used in the dynamic tests was the same as in static tests. Dynamic tests were performed with the participants' arms at sides and feet placed on the balance platform. The distance between the feet was 10 cms and the prominence of the maximum point of the medial arcs was on the X-axis (21). Before beginning the tests, the stability platform was chosen at level 10to assess the feet position coordinates and establish the subjects' ideal feet positioning. A 10 cm between-feet area was determined on the balance platform (21). The participants were asked to stand on the balance platform and try to adjust the feet position on this area and attempt to maintain their balance until they could hold the platform stability. The feet position coordinates were constant throughout the test session.

The equilibrium test was conducted while the patient had to remain in the range delimited by a circular line with10◦dimension of radius. Thus, the patients were instructed to maintain their pressure center in the smallest concentric ring (balance zones) of the monitor, named A zone.

The participants were asked to maintain the platform stable in horizontal condition for 30 seconds for single-task conditions. They were asked to perform a cognitive task while trying to keep the balance with the same duration for dual-task conditions. As only few test times are available on the Prokin system (30 and 60 seconds), and based on the pilot tests the patients could not perform the dynamic tests in 60 seconds, so the 30 second duration was selected for the dynamic tests. All 4 experimental conditions were carried out by each patient in three repetitions. All participants went through a5-minutetraining for adaptation before taking the dynamic tests. Participants performed 3 familiarization trials with and without cognitive task prior to each trial dynamic postural test. The orders of the 4experimental conditions were randomized in both sessions. The sampling rate was 20 Hz. The data for evaluation of responsiveness were calculated in terms of AP stability index (APSI), ML stability index (MLSI), and total stability index (TSI). These indices are determined by variations of displacement measures and represent the dispersions around the expected value (horizontal position of tilting platform) by the reference axis (equation 1). A higher stability index represents a higher variability and decreased postural stability.

$$\mathrm{SI} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - r)^2}{n}} \qquad (1)$$

Where:
xi is the obtained value (in degree),
r is the expected value (in degree), and
n is the number of obtained samples (test time∗ sampling frequency).

Statistical analysis

The SPSS version 18.0 (SPSS Inc., Chicago, IL) and Microsoft Excel (2013) were used for all data analyses. The level of statistical significance was set at $P<0.05$. For the values of COP parameters and stability indices, the follow up scores were subtracted from baseline scores. Thus, a positive change score was regarded as improvement in patient's clinical status while a negative change was defined as worsening in patient's clinical status.

In the present study, responsiveness was evaluated using the external responsiveness statistics. External responsiveness has received particular attention from the researchers conducting responsiveness studies because it detects a relation between a change in an external standard and a change in an evaluative measure (10). Moreover, the external responsiveness is related to the notion of clinical significance and involves the property of a measure to detect a clinically important change (13). External responsiveness for all parameters was examined using the correlation between the change scores of each parameter and the raw global rating scale; and the receiver operating characteristics (ROC) curve(10, 11, 13, 15). These change coefficients were selected for evaluating responsiveness because our sample included patients with expected different amounts of change (i.e., heterogeneous patient composition) during the study, (22).

The change scores of COP parameters and stability indices were correlated with the external standard evaluating change using correlation analysis, (i.e., global rating scale). Gamma correlation coefficient was used due to the ordinal data associated with the global rating scale categories. Higher correlation coefficients imply a stronger association between the results of a measurement and the external standard. Correlation coefficients of: less than 0.25, 0.25-0.50, 0.50-0.75, and >0.75 were considered as: little or no relationship, fair relationship, moderate to good relationship, and good to excellent relationship, respectively (15).

In ROC analysis method, a measure of interest can be described similar to the diagnostic test in its ability to correctly detect individuals that have an important clinical change (10, 13, 23-25). Thus, for conducting this analysis all measures including COP parameters and stability indices were considered as a diagnostic test and the global rating scale was regarded as a reference standard. Participants were dichotomized into two groups of improved and unimproved patients according to the scores reported from the global rating scale (10). Responsiveness is described in terms of sensitivity and specificity (10, 13). Sensitivity is defined as the ability of a measure to correctly detect patients who are improved based on the reference standard (i.e. true positive rate); while specificity is defined as the ability of a measure to correctly detect patients who are not improved based on the reference standard (i.e. true negative rate) (13). Sensitivity and specificity were calculated using numerous change scores as cutoff points. An AUC greater than 0.70 was considered as an indicator of acceptable external responsiveness (26).

Results

The results of descriptive statistics for baseline, follow-up, change scores of COP parameters, and stability indices were shown in tables 2 and 3. According to the global rating scale, among 54 patients, 34 (63%) were

Table 2. Mean (SD) of baseline, follow-up and change scores for COP parameters

Postural-Cognitive Conditions		Baseline Mean (SD)	Follow-up Mean (SD)	Change Mean (SD)	*P value*
Standing on the injured leg with open-eyes with no cognitive task					
Mean velocity	Total (n=54)	4.16 (1.67)	3.52 (0.80)	0.64 (1.50)	**0.001**
	Improved (n=34)	4.30 (1.98)	3.30 (0.67)	1.00 (1.77)	**0.00**
	Not improved (n=20)	3.92 (0.94)	3.89 (0.88)	0.03 (0.52)	0.76

Continuous of Table 2.					
SD velocity (AP)	Total (n=54)	2.03 (0.74)	1.81 (0.55)	0.22 (0.59)	**0.004**
	Improved (n=34)	2.06 (0.81)	1.67 (0.45)	0.38 (0.64)	**0.00**
	Not improved (n=20)	1.99 (0.62)	2.04 (0.65)	-0.04 (0.38)	0.60
SD velocity (ML)	Total (n=54)	2.50 (0.87)	2.18 (0.43)	0.31 (0.84)	**0.008**
	Improved (n=34)	2.57 (1.03)	2.06 (0.39)	0.51 (0.98)	**0.001**
	Not improved (n=20)	2.39 (0.50)	2.40 (0.44)	-0.006 (0.36)	0.93
SD amplitude (AP)	Total (n=54)	0.74 (0.16)	0.76 (0.15)	-0.02 (0.15)	0.30
	Improved (n=34)	0.75 (0.19)	0.77 (0.17)	-0.01 (0.18)	0.53
	Not improved (n=20)	0.73 (0.10)	0.75 (0.11)	-0.02 (0.11)	0.30
SD amplitude (ML)	Total (n=54)	0.59 (0.12)	0.57 (0.11)	0.02 (0.11)	0.37
	Improved (n=34)	0.59 (0.14)	0.53 (0.06)	0.05 (0.14)	**0.04**
	Not improved (n=20)	0.60 (0.09)	0.64 (0.14)	-0.03 (0.14)	0.27
Area	Total (n=54)	8.57 (3.62)	7.72 (2.19)	0.85 (2.81)	0.18
	Improved (n=34)	8.70 (4.27)	7.56 (2.22)	1.13 (4.11)	0.16
	Not improved (n=20)	8.35 (2.29)	7.93 (2.19)	0.37 (2.15)	0.44
Standing on the uninjured leg with open-eyes with no cognitive task					
Mean velocity	Total (n=54)	3.76 (1.46)	3.41 (0.83)	0.34 (1.27)	**0.02**
	Improved (n=34)	3.86 (1.72)	3.27 (0.76)	0.58 (1.48)	**0.003**
	Not improved (n=20)	3.59 (0.87)	3.65 (0.90)	-0.05 (0.67)	0.70
SD velocity (AP)	Total (n=54)	1.92 (0.57)	1.85 (0.63)	0.07 (0.60)	0.05
	Improved (n=34)	1.88 (0.55)	1.72 (0.50)	0.15 (0.49)	0.08
	Not improved (n=20)	2.00 (0.62)	2.07 (0.77)	-0.06 (0.75)	0.68
SD velocity (ML)	Total (n=54)	2.24 (0.77)	2.07 (0.49)	0.16 (0.65)	**0.03**
	Improved (n=34)	2.28 (0.90)	1.97 (0.46)	0.31 (0.73)	**0.005**
	Not improved (n=20)	2.17 (0.51)	2.25 (0.51)	-0.07 (0.43)	0.42
SD amplitude (AP)	Total (n=54)	0.79 (0.17)	0.82 (0.21)	-0.02 (0.15)	0.25
	Improved (n=34)	0.79 (0.19)	0.83 (0.23)	-0.03 (0.13)	0.15
	Not improved (n=20)	0.79 (0.13)	0.80 (0.17)	-0.01 (0.19)	0.81
SD amplitude (ML)	Total (n=54)	0.59 (0.11)	0.57 (0.10)	0.02 (0.10)	0.10
	Improved (n=34)	0.59 (0.12)	0.55 (0.08)	0.03 (0.10)	**0.01**
	Not improved (n=20)	0.59 (0.11)	0.60 (0.12)	-0.01 (0.12)	0.66
Area	Total (n=54)	8.87 (3.05)	8.77 (3.40)	0.10 (3.18)	0.41
	Improved (n=34)	9.09 (3.48)	8.95 (3.56)	0.14 (2.68)	0.40
	Not improved (n=20)	8.51 (2.23)	8.50 (3.20)	0.01 (2.67)	0.98
Standing on the injured leg with closed-eyes with no cognitive task					
Mean velocity	Total (n=54)	7.67 (2.13)	7.37 (2.09)	0.29 (1.99)	0.27
	Improved (n=34)	7.36 (2.25)	6.85 (1.68)	0.51 (2.13)	0.17
	Not improved (n=20)	8.19 (2.36)	8.26 (2.43)	-0.06 (1.73)	0.86
SD velocity (AP)	Total (n=54)	4.37 (1.89)	4.10 (1.91)	0.27 (1.81)	0.27
	Improved (n=34)	4.13 (1.88)	3.54 (1.25)	0.59 (1.85)	0.06
	Not improved (n=20)	4.78 (1.88)	5.06 (2.44)	-0.27 (1.65)	0.46

Continuous of Table 2.					
SD velocity (ML)	Total (n=54)	4.64 (1.29)	4.57 (1.03)	0.06 (1.31)	0.71
	Improved (n=34)	4.47 (1.36)	4.35 (0.95)	0.12 (1.42)	0.62
	Not improved (n=20)	4.92 (1.15)	4.95 (1.09)	-0.02 (1.12)	0.91
SD amplitude (AP)	Total (n=54)	1.15 (0.24)	1.11 (0.28)	0.03 (0.28)	0.36
	Improved (n=34)	1.10 (0.24)	1.01 (0.17)	0.09 (0.25)	0.05
	Not improved (n=20)	1.24 (0.22)	1.29 (0.35)	-0.05 (0.31)	0.42
SD amplitude (ML)	Total (n=54)	1.07 (0.18)	1.04 (0.17)	0.03 (0.12)	0.09
	Improved (n=34)	1.03 (0.19)	0.97 (0.12)	0.06 (0.19)	**0.02**
	Not improved (n=20)	1.13 (0.13)	1.14 (0.20)	-0.01 (0.15)	0.65
Area	Total (n=54)	23.68 (8.26)	21.23 (7.89)	2.45 (7.64)	**0.02**
	Improved (n=34)	21.99 (8.34)	18.07 (4.13)	3.91 (8.13)	**0.004**
	Not improved (n=20)	2.63 (7.56)	2.62 (9.79)	0.10 (8.12)	0.95
Standing on the uninjured leg with closed-eyes with no cognitive task					
Mean velocity	Total (n=54)	7.36 (2.04)	7.11 (2.09)	0.24 (1.73)	0.30
	Improved (n=34)	7.07 (1.83)	6.28 (1.34)	0.79 (1.48)	**0.004**
	Not improved (n=20)	7.85 (2.33)	8.53 (2.41)	-0.67 (1.77)	0.10
SD velocity (AP)	Total (n=54)	4.85 (2.45)	4.42 (2.50)	0.42 (2.03)	0.06
	Improved (n=34)	4.35 (2.07)	3.47 (1.23)	0.87 (2.12)	**0.02**
	Not improved (n=20)	5.69 (2.85)	6.03 (3.23)	-0.33 (1.64)	0.19
SD velocity (ML)	Total (n=54)	4.52 (1.22)	4.52 (1.17)	-0.003 (1.14)	0.98
	Improved (n=34)	4.36 (1.22)	4.11 (0.97)	0.25 (1.12)	0.19
	Not improved (n=20)	4.79 (1.21)	5.23 (1.16)	-0.44 (1.06)	0.07
SD amplitude (AP)	Total (n=54)	1.17 (0.24)	1.19 (0.27)	-0.01 (0.29)	0.66
	Improved (n=34)	1.12 (0.23)	1.09 (0.19)	0.02 (0.28)	0.54
	Not improved (n=20)	1.27 (0.24)	1.36 (0.31)	-0.09 (0.31)	0.19
SD amplitude (ML)	Total (n=54)	1.10 (0.29)	1.09 (0.32)	1.01 (0.22)	0.56
	Improved (n=34)	1.04 (0.19)	1.00 (0.23)	0.04 (0.29)	0.11
	Not improved (n=20)	1.19 (0.39)	1.23 (0.40)	-0.03 (0.14)	0.28
Area	Total (n=54)	25.62 (12.06)	25.09 (13.19)	0.53 (12.13)	0.37
	Improved (n=34)	22.64 (8.26)	21.33 (8.76)	1.30 (11.55)	0.11
	Not improved (n=20)	3.04 (15.42)	3.11 (16.74)	-0.69 (8.32)	0.71
Standing on the injured leg with open-eyes with cognitive task					
Mean velocity	Total (n=54)	3.78 (1.60)	3.27 (0.87)	0.51 (1.28)	**0.001**
	Improved (n=34)	3.89 (1.92)	3.12 (0.91)	0.77 (1.51)	**0.001**
	Not improved (n=20)	3.59 (0.84)	3.52 (0.76)	0.06 (0.54)	0.57
SD velocity (AP)	Total (n=54)	1.74 (0.52)	1.60 (0.52)	0.16 (0.38)	**0.003**
	Improved (n=34)	1.74 (0.50)	1.49 (0.45)	0.24 (0.38)	**0.001**
	Not improved (n=20)	1.81 (0.55)	1.80 (0.56)	0.01 (0.34)	0.87
SD velocity (ML)	Total (n=54)	2.31 (0.84)	2.03 (0.54)	0.28 (0.68)	**0.004**
	Improved (n=34)	2.35 (1.01)	1.95 (0.62)	0.39 (0.80)	**0.008**
	Not improved (n=20)	2.26 (0.44)	2.16 (0.36)	0.10 (0.35)	0.22

Continuous of Table 2.

SD amplitude (AP)	Total (n=54)	0.66 (0.14)	0.66 (0.14)	-0.002 (0.17)	0.91
	Improved (n=34)	0.65 (0.14)	0.64 (0.15)	0.01 (0.17)	0.68
	Not improved (n=20)	0.67 (0.13)	0.69 (0.11)	-0.02 (0.17)	0.49
SD amplitude (ML)	Total (n=54)	0.56 (0.11)	0.55 (0.12)	0.01 (0.12)	0.25
	Improved (n=34)	0.55 (0.10)	0.52 (0.10)	0.03 (0.10)	**0.007**
	Not improved (n=20)	0.57 (0.14)	0.61 (0.13)	-0.03 (0.18)	0.38
Area	Total (n=54)	7.24 (3.30)	6.49 (2.36)	0.75 (3.01)	**0.03**
	Improved (n=34)	7.04 (2.78)	6.27 (2.51)	0.76 (2.30)	**0.03**
	Not improved (n=20)	7.55 (4.06)	6.84 (2.11)	0.70 (4.06)	0.68
Standing on the uninjured leg with open-eyes with cognitive task					
Mean velocity	Total (n=54)	3.85 (1.63)	3.45 (0.88)	0.40 (1.45)	**0.006**
	Improved (n=34)	3.91 (1.93)	3.22 (0.70)	0.69 (1.70)	**0.002**
	Not improved (n=20)	3.75 (0.98)	3.83 (1.04)	-0.07 (0.70)	0.62
SD velocity (AP)	Total (n=54)	1.89 (0.67)	1.79 (0.66)	0.10 (0.53)	**0.01**
	Improved (n=34)	1.88 (0.69)	1.67 (0.59)	0.21 (0.57)	**0.04**
	Not improved (n=20)	1.91 (0.65)	1.99 (0.73)	-0.07 (0.42)	0.8
SD velocity (ML)	Total (n=54)	2.31 (0.85)	2.14 (0.51)	0.16 (0.75)	**0.04**
	Improved (n=34)	2.31 (0.99)	2.02 (0.44)	0.29 (0.88)	**0.02**
	Not improved (n=20)	2.30 (0.56)	2.33 (0.57)	-0.03 (0.41)	0.68
SD amplitude (AP)	Total (n=54)	0.69 (0.13)	0.70 (0.16)	-0.17 (0.10)	0.22
	Improved (n=34)	0.70 (0.14)	0.72 (0.18)	-0.01 (0.11)	0.39
	Not improved (n=20)	0.66 (0.08)	0.68 (0.12)	-0.02 (0.10)	0.39
SD amplitude (ML)	Total (n=54)	0.58 (0.11)	0.56 (0.15)	0.03 (0.13)	**0.006**
	Improved (n=34)	0.58 (0.11)	0.55 (0.18)	0.03 (0.19)	**0.001**
	Not improved (n=20)	0.58 (0.10)	0.58 (0.10)	-0.003 (0.08)	0.86
Area	Total (n=54)	7.75 (2.77)	7.57 (4.82)	0.18 (3.16)	**0.01**
	Improved (n=34)	8.01 (3.10)	7.81 (5.87)	0.20 (5.29)	**0.009**
	Not improved (n=20)	7.35 (2.16)	7.19 (2.45)	0.15 (1.32)	0.6
Standing on the injured leg with closed-eyes with cognitive task					
Mean velocity	Total (n=54)	7.10 (1.89)	7.08 (1.83)	0.01 (1.75)	0.93
	Improved (n=34)	7.08 (1.84)	6.71 (1.90)	0.36 (1.79)	0.24
	Not improved (n=20)	7.12 (2.01)	7.70 (1.56)	-0.57 (1.55)	**0.02**
SD velocity (AP)	Total (n=54)	4.01 (1.50)	3.77 (1.30)	0.24 (1.48)	0.23
	Improved (n=34)	3.89 (1.42)	3.52 (1.29)	0.37 (1.56)	0.16
	Not improved (n=20)	4.21 (1.66)	4.20 (1.23)	0.01 (1.35)	0.96
SD velocity (ML)	Total (n=54)	4.31 (1.11)	4.50 (1.16)	-0.19 (1.14)	0.22
	Improved (n=34)	4.25 (1.09)	4.26 (1.23)	-0.01 (1.15)	0.95
	Not improved (n=20)	4.41 (1.16)	4.91 (0.94)	-0.49 (1.08)	0.05
SD amplitude (AP)	Total (n=54)	1.03 (0.23)	1.07 (0.21)	-0.04 (0.24)	0.19
	Improved (n=34)	0.98 (0.25)	0.99 (0.14)	-0.01 (0.24)	0.77
	Not improved (n=20)	1.10 (0.18)	1.20 (0.24)	-0.09 (0.24)	0.09

Continuous of Table 2.					
SD amplitude (ML)	Total (n=54)	0.97 (0.15)	1.01 (0.19)	-0.04 (0.13)	0.82
	Improved (n=34)	0.97 (0.13)	0.97 (0.16)	0.00 (0.19)	0.27
	Not improved (n=20)	0.96 (0.18)	1.07 (0.23)	-0.1 (0.24)	0.06
Area	Total (n=54)	19.07 (6.87)	19.67 (5.80)	-0.6 (5.18)	0.94
	Improved (n=34)	18.43 (7.27)	18.38 (5.41)	0.05 (8.23)	0.44
	Not improved (n=20)	2.01 (6.21)	2.17 (5.94)	-1.63 (6.29)	0.25
Standing on the uninjured leg with closed-eyes with cognitive task					
Mean velocity	Total (n=54)	7.24 (1.98)	7.26 (1.89)	-0.02 (1.69)	0.52
	Improved (n=34)	6.85 (1.76)	6.68 (1.53)	0.17 (1.39)	0.48
	Not improved (n=20)	7.90 (2.20)	8.25 (2.07)	-0.35 (2.09)	0.74
SD velocity (AP)	Total (n=54)	4.77 (2.52)	4.48 (2.50)	0.29 (2.19)	0.33
	Improved (n=34)	4.08 (2.06)	3.56 (1.05)	0.51 (2.01)	0.14
	Not improved (n=20)	5.94 (2.83)	6.03 (3.38)	-0.08 (2.46)	0.87
SD velocity (ML)	Total (n=54)	4.42 (1.30)	4.58 (1.18)	-0.16 (1.13)	0.68
	Improved (n=34)	4.12 (1.07)	4.27 (1.07)	-0.14 (1.15)	0.47
	Not improved (n=20)	4.91 (1.52)	5.13 (1.20)	-0.21 (1.11)	0.29
SD amplitude (AP)	Total (n=54)	1.12 (0.28)	1.08 (0.23)	0.03 (0.27)	0.95
	Improved (n=34)	1.05 (0.25)	1.00 (0.17)	0.05 (0.23)	0.20
	Not improved (n=20)	1.23 (0.30)	1.22 (0.25)	0.01 (0.33)	0.88
SD amplitude (ML)	Total (n=54)	1.06 (0.25)	1.04 (0.29)	0.02 (0.21)	0.23
	Improved (n=34)	0.99 (0.24)	0.93 (0.16)	0.06 (0.22)	0.12
	Not improved (n=20)	1.17 (0.23)	1.22 (0.37)	-0.05 (0.34)	0.80
Area	Total (n=54)	23.66 (11.93)	22.56 (13.66)	1.10 (11.03)	0.14
	Improved (n=34)	20.48 (10.34)	17.86 (5.16)	2.61 (9.38)	0.10
	Not improved (n=20)	2.87 (12.78)	3.00 (18.99)	-1.34 (17.85)	0.68

COP: center of pressure; SD: standard deviation; AP: anteroposterior; ML: mediolateral.
Units of COP parameters are as follows: cm/s (mean and SD velocity), cm (SD amplitude), and cm2 (area). Significant P-values are in bold.

Table 3. Mean (SD) of baseline, follow-up and change scores for stability indices

Postural-Cognitive Conditions		Baseline Mean (SD)	Follow-up Mean (SD)	Change Mean (SD)	*P value*
Double-leg standing with open-eyes with no cognitive task					
APSI	Total (n=54)	4.97 (1.96)	4.09 (1.60)	0.88 (1.94)	**0.002**
	Improved (n=34)	5.30 (2.24)	4.20 (1.73)	1.09 (2.29)	**0.009**
	Not improved (n=20)	4.42 (1.20)	3.90 (1.37)	0.52 (1.07)	**0.04**
MLSI	Total (n=54)	8.42 (2.80)	5.54 (2.33)	2.88 (2.86)	**0.00**
	Improved (n=34)	8.46 (2.91)	5.25 (2.04)	3.20 (3.31)	**0.00**
	Not improved (n=20)	8.36 (2.67)	6.04 (2.75)	2.32 (1.78)	**0.00**
TSI	Total (n=54)	9.85 (3.05)	6.92 (2.32)	2.93 (3.01)	**0.00**
	Improved (n=34)	10.07 (3.23)	6.63 (2.13)	3.44 (3.50)	**0.00**
	Not improved (n=20)	9.48 (2.75)	7.42 (2.59)	2.06 (1.64)	**0.00**

Continuous of Table 3.

Double-leg standing with closed-eyes with no cognitive task					
APSI	Total (n=54)	8.59 (2.01)	7.67 (1.47)	0.92 (1.53)	**0.00**
	Improved (n=34)	8.23 (2.38)	7.22 (1.58)	1.01 (1.92)	**0.004**
	Not improved (n=20)	9.19 (0.87)	8.42 (0.87)	0.77 (0.38)	**0.00**
MLSI	Total (n=54)	10.04 (1.84)	8.95 (1.62)	1.09 (1.74)	**0.00**
	Improved (n=34)	9.79 (2.07)	8.40 (1.61)	1.39 (1.94)	**0.00**
	Not improved (n=20)	10.48 (1.30)	9.88 (1.19)	0.60 (1.24)	**0.04**
TSI	Total (n=54)	13.25 (2.39)	11.19 (3.59)	2.05 (3.59)	**0.00**
	Improved (n=34)	12.84 (2.82)	10.71 (3.18)	2.12 (2.91)	**0.00**
	Not improved (n=20)	13.95 (1.15)	12.02 (4.17)	1.92 (4.60)	0.05
Double-leg standing with open-eyes with cognitive task					
APSI	Total (n=54)	5.29 (2.63)	3.95 (1.61)	1.34 (1.66)	**0.00**
	Improved (n=34)	5.38 (3.16)	3.94 (1.68)	1.43 (2.03)	**0.00**
	Not improved (n=20)	5.14 (1.37)	3.97 (1.54)	1.17 (0.70)	**0.00**
MLSI	Total (n=54)	7.70 (3.31)	6.22 (2.68)	1.48 (3.36)	**0.002**
	Improved (n=34)	7.19 (3.30)	5.86 (2.40)	1.33 (4.00)	0.06
	Not improved (n=20)	8.58 (3.22)	6.83 (3.06)	1.75 (1.90)	**0.00**
TSI	Total (n=54)	9.63 (3.48)	7.49 (2.71)	2.14 (2.89)	**0.00**
	Improved (n=34)	9.34 (3.68)	7.15 (2.54)	2.18 (3.45)	**0.001**
	Not improved (n=20)	10.13 (3.16)	8.06 (2.97)	2.07 (1.61)	**0.00**
Double-leg standing with closed-eyes with cognitive task					
APSI	Total (n=54)	9.09 (2.04)	8.18 (1.83)	0.87 (1.59)	**0.00**
	Improved (n=34)	8.85 (2.39)	7.49 (1.52)	1.33 (1.71)	**0.00**
	Not improved (n=20)	9.49 (1.21)	9.37 (1.72)	0.11 (1.03)	0.61
MLSI	Total (n=54)	10.30 (2.01)	9.47 (1.97)	0.80 (1.57)	**0.00**
	Improved (n=34)	10.17 (2.05)	8.84 (1.80)	1.30 (1.64)	**0.00**
	Not improved (n=20)	10.53 (1.96)	10.54 (1.80)	-0.1 (1.05)	0.95
TSI	Total (n=54)	13.83 (2.18)	12.55 (2.41)	1.24 (1.65)	**0.00**
	Improved (n=34)	13.57 (2.39)	11.58 (2.04)	1.96 (1.51)	**0.00**
	Not improved (n=20)	14.25 (1.78)	14.19 (2.10)	0.05 (1.10)	0.24

APSI: anteropsterior stability index; MLSI: mediolateral stability index; TSI: total stability index. Significant P-values are in bold.

classified as improved and 20 (37%) as unimproved. The number of patients represented as very much better, much better, slightly better, no change, slightly worse, much worse, and very much worse were 4 (7.4%), 30 (55.6%), 10 (18.5%), 8 (14.8%), 2 (3.7%), 0 (0%), and 0 (0%), respectively.

ROC curves showed that three COP parameters (mean velocity as well asSD of velocity in AP and ML directions) had acceptable responsiveness levels (fair) in both conditions of standing on both injured and uninjured leg with open- and closed eyes without cognitive task [Table 4]. The remaining COP parameters had responsiveness ratings of "poor" or "failed" [Table 4]. Consistent with AUC values, Gamma correlation coefficients were higher for mean velocity, SD of velocity in AP and ML directions in both aforementioned conditions (fair relationships) [Table 4].

With respect to the dynamic postural measures, APSI, MLSI, and TSI in the condition of double-leg standing with closed-eyes and cognitive task attained acceptable responsiveness levels (ranging from "fair" to "good") [Table 5]. Also, the results of Gamma correlation coefficients showed stronger relationships between these indices and raw global rating scale in double-leg standing condition with closed-eyes and cognitive task [Table 5].

The optimal cutoff scores representing the MCIC values

Table 4. Gamma correlation coefficient and area under the receiver operating characteristic (AUC) curve for each COP parameter under different conditions of postural and cognitive difficulty according to external, dichotomized measure of global rating scale (improved versus unimproved) (n=54)

Postural-Cognitive Conditions	Gamma coefficient (*P value*)	AUC (95% CI)	Optimal cutoff value	Sensitivity (95% CI)	Specificity (95% CI)
Standing on the injured leg with open-eyes with no cognitive task					
Mean velocity	0.30 (0.01)	**0.72** (0.59-0.86)	0.28	0.67 (0.49-0.82)	0.85 (0.61-0.96)
SD velocity (AP)	0.30 (0.01)	**0.77** (0.64-0.90)	0.008	0.79 (0.61-0.90)	0.75 (0.50-0.90)
SD velocity (ML)	0.27 (0.03)	**0.70** (0.55-0.84)	0.02	0.73 (0.55-0.86)	0.65 (0.40-0.83)
SD amplitude (AP)	-0.001 (0.99)	0.48 (0.33-0.64)	0.09	0.23 (0.11-0.41)	0.95 (0.73-0.99)
SD amplitude (ML)	0.35 (0.006)	0.68 (0.53-0.83)	0.01	0.55 (0.38-0.72)	0.70 (0.45-0.87)
Area	0.16 (0.19)	0.57 (0.41-0.72)	0.79	0.47 (0.30-0.64)	0.80 (0.55-0.93)
Standing on the uninjured leg with open-eyes with no cognitive task					
Mean velocity	0.20 (0.07)	0.62 (0.47-0.78)	0.02	0.67 (0.49-0.82)	0.70 (0.45-0.87)
SD velocity (AP)	0.15 (0.14)	0.62 (0.46-0.78)	0.03	0.64 (0.46-0.79)	0.60 (0.36-0.80)
SD velocity (ML)	0.27 (0.01)	0.67 (0.52-0.82)	0.01	0.73 (0.55-0.86)	0.70 (0.45-0.87)
SD amplitude (AP)	-0.02 (0.86)	0.47 (0.30-0.65)	0.04	0.29 (0.15-0.47)	0.70 (0.45-0.87)
SD amplitude (ML)	0.27 (0.04)	0.65 (0.49-0.80)	0.02	0.58 (0.40-0.74)	0.65 (0.40-0.83)
Area	0.08 (0.51)	0.52 (0.36-0.68)	0.28	0.55 (0.38-0.72)	0.65 (0.40-0.83)
Standing on the injured leg with closed-eyes with no cognitive task					
Mean velocity	0.03 (0.76)	0.51 (0.35-0.67)	1.28	0.32 (0.17-0.50)	0.85 (0.61-0.96)
SD velocity (AP)	0.11 (0.29)	0.57 (0.42-0.73)	1.31	0.23 (0.11-0.41)	1.00 (0.79-1.00)
SD velocity (ML)	0.01 (0.86)	0.49 (0.33-0.65)	1.07	0.23 (0.11-0.41)	0.95 (0.73-0.99)
SD amplitude (AP)	0.15 (0.20)	0.61 (0.45-0.77)	0.06	0.52 (0.35-0.69)	0.70 (0.45-0.87)
SD amplitude (ML)	0.27 (0.01)	0.63 (0.48-0.78)	0.14	0.38 (0.22-0.56)	0.90 (0.66-0.98)
Area	0.22 (0.07)	0.63 (0.48-0.78)	0.44	0.64 (0.46-0.79)	0.70 (0.45-0.87)
Standing on the uninjured leg with closed-eyes with no cognitive task					
Mean velocity	0.33 (0.03)	**0.76** (0.63-0.89)	0.14	0.73 (0.55-0.86)	0.90 (0.66-0.98)
SD velocity (AP)	0.26 (0.01)	**0.73** (0.59-0.87)	0.07	0.73 (0.55-0.86)	0.80 (0.55-0.93)

Continuous of Table 4.					
SD velocity (ML)	0.25 (0.04)	**0.74** (0.60-0.87)	0.06	0.73 (0.55-0.86)	0.90 (0.66-0.98)
SD amplitude (AP)	0.14 (0.21)	0.59 (0.44-0.75)	0.01	0.50 (0.32-0.67)	0.75 (0.50-0.90)
SD amplitude (ML)	0.23 (0.03)	0.66 (0.51-0.80)	0.14	0.38 (0.22-0.56)	0.95 (0.73-0.99)
Area	0.20 (0.07)	0.63 (0.48-0.78)	0.1	0.61 (0.43-0.77)	0.70 (0.45-0.87)
Standing on the injured leg with open-eyes with cognitive task					
Mean velocity	0.33 (0.01)	0.69 (0.55-0.83)	0.83	0.38 (0.22-0.56)	0.95 (0.73-0.99)
SD velocity (AP)	0.24 (0.04)	**0.70** (0.55-0.84)	0.03	0.79 (0.61-0.90)	0.60 (0.36-0.80)
SD velocity (ML)	0.23 (0.1)	0.61 (0.46-0.76)	0.59	0.26 (0.13-0.44)	1.00 (0.79-1.00)
SD amplitude (AP)	0.13 (0.30)	0.58 (0.42-0.73)	0.03	0.47 (0.30-0.64)	0.85 (0.61-0.96)
SD amplitude (ML)	0.36 (0.004)	**0.70** (0.55-0.86)	0.003	0.76 (0.58-0.88)	0.70 (0.45-0.87)
Area	0.23 (0.03)	0.62 (0.47-0.77)	0.91	0.50 (0.32-0.67)	0.85 (0.55-0.93)
Standing on the uninjured leg with open-eyes with cognitive task					
Mean velocity	0.28 (0.01)	0.67 (0.53-0.82)	0.19	0.61 (0.43-0.77)	0.75 (0.50-0.90)
SD velocity (AP)	0.30 (0.005)	0.69 (0.55-0.83)	0.09	0.67 (0.49-0.82)	0.75 (0.50-0.90)
SD velocity (ML)	0.20 (0.07)	0.61 (0.46-0.76)	0.25	0.38 (0.22-0.56)	0.90 (0.66-0.98)
SD amplitude (AP)	0.06 (0.60)	0.52 (0.36-0.67)	0.02	0.47 (0.30-0.64)	0.70 (0.45-0.87)
SD amplitude (ML)	0.36 (0.002)	**0.71** (0.57-0.85)	0.02	0.64 (0.46-0.79)	0.75 (0.50-0.90)
Area	0.26 (0.02)	0.63 (0.48-0.78)	0.18	0.64 (0.46-0.79)	0.70 (0.45-0.87)
Standing on the injured leg with closed-eyes with cognitive task					
Mean velocity	0.25 (0.004)	0.69 (0.55-0.83)	0.02	0.64 (0.46-0.79)	0.85 (0.61-0.96)
SD velocity (AP)	0.11 (0.35)	0.58 (0.43-0.74)	0.2	0.61 (0.43-0.77)	0.80 (0.55-0.93)
SD velocity (ML)	0.18 (0.08)	0.64 (0.49-0.79)	0.009	0.52 (0.35-0.69)	0.85 (0.61-0.96)
SD amplitude (AP)	0.22 (0.07)	0.60 (0.44-0.76)	0.003	0.52 (0.35-0.69)	0.75 (0.50-0.90)
SD amplitude (ML)	0.30 (0.01)	0.67 (0.52-0.82)	0.01	0.64 (0.46-0.79)	0.80 (0.55-0.93)

Continuous of Table 4.

Area	0.21 (0.08)	0.60 (0.45-0.76)	0.02	0.61 (0.43-0.77)	0.75 (0.50-0.90)
Standing on the uninjured leg with closed-eyes with cognitive task					
Mean velocity	0.05 (0.68)	0.54 (0.38-0.71)	0.02	0.52 (0.35-0.69)	0.65 (0.40-0.83)
SD velocity (AP)	0.13 (0.30)	0.60 (0.44-0.77)	0.03	0.64 (0.46-0.79)	0.70 (0.45-0.87)
SD velocity (ML)	-0.03 (0.77)	0.50 (0.34-0.66)	0.05	0.50 (0.32-0.67)	0.75 (0.50-0.90)
SD amplitude (AP)	0.15 (0.23)	0.61 (0.44-0.77)	0.002	0.61 (0.43-0.77)	0.70 (0.45-0.87)
SD amplitude (ML)	0.14 (0.23)	0.58 (0.42-0.74)	0.005	0.58 (0.40-0.74)	0.60 (0.36-0.80)
Area	0.12 (0.36)	0.56 (0.40-0.72)	0.76	0.52 (0.35-0.69)	0.75 (0.50-0.90)

AUC (area under curve) equal or greater than 0.70 are in bold.
SD: standard deviation; AP: anteroposterior; ML: mediolateral.
Units of COP parameters are as follows: cm/s (mean and SD velocity), cm (SD amplitude), and cm^2 (area). CI: Confidence interval

Table 5. Gamma correlation coefficient and area under the receiver operating characteristic (AUC) curve for each stability index under different conditions of postural and cognitive difficulty according to external, dichotomized measure of global rating scale (improved versus unimproved) (n=54)

Postural-Cognitive Conditions	Gamma coefficient (*P value*)	AUC (95% CI)	Optimal cutoff value	Sensitivity (95% CI)	Specificity (95% CI)
Double-leg standing with open-eyes with no cognitive task					
APSI	0.14 (0.22)	0.56 (0.41-0.72)	2.41	0.32 (0.17-0.50)	1.00 (0.79-1.00)
MLSI	0.28 (0.02)	0.66 (0.51-0.81)	2.78	0.61 (0.43-0.77)	0.85 (0.61-0.96)
TSI	0.31 (0.01)	0.66 (0.51-0.81)	2.46	0.70 (0.52-0.84)	0.85 (0.61-0.96)
Double-leg standing with closed-eyes with no cognitive task					
APSI	0.16 (0.24)	0.58 (0.42-0.74)	1.27	0.50 (0.32-0.67)	1.00 (0.79-1.00)
MLSI	0.24 (0.04)	0.65 (0.50-0.79)	1.35	0.55 (0.38-0.72)	0.85 (0.61-0.96)
TSI	0.33 (0.005)	0.68 (0.53-0.84)	1.28	0.67 (0.49-0.82)	0.75 (0.50-0.90)
Double-leg standing with open-eyes with cognitive task					
APSI	-0.01 (0.88)	0.44 (0.28-0.59)	1.68	0.38 (0.22-0.56)	0.90 (0.66-0.98)
MLSI	-0.08 (0.51)	0.44 (0.28-0.60)	1.51	0.50 (0.32-0.67)	0.80 (0.55-0.93)
TSI	0.10 (0.44)	0.54 (0.37-0.70)	1.71	0.64 (0.46-0.79)	0.75 (0.50-0.90)

Continuous of Table 5.

Double-leg standing with closed-eyes with cognitive task					
APSI	0.49 (0.00)	**0.77** (0.64-0.91)	0.51	0.78 (0.60-0.90)	0.90 (0.66-0.98)
MLSI	0.40 (0.001)	**0.77** (0.64-0.89)	0.37	0.72 (0.54-0.86)	0.80 (0.55-0.93)
TSI	0.49 (0.00)	**0.83** (0.70-0.95)	0.34	0.87 (0.70-0.96)	0.80 (0.55-0.93)

AUC (area under curve) equal or greater than 0.70 are in bold.
APSI: anteroposterior stability index; MLSI: mediolateral stability index; TSI: total stability index. CI: Confidence interval.
Units of stability indices are degrees.

of COP parameters, and the stability indices are presented in tables 4 and 5, respectively.

Discussion

To the best of our knowledge, this is the first study which examined the responsiveness of COP parameters and stability indices in patients with ACL-R and determines MCIC values in static and dynamic postural measures. The results of this study could provide useful information to assist in choosing appropriate static and dynamic postural measures for assessment of changes following physiotherapy intervention in patients with ACL-R.

The results of static postural measures indicate the mean and the SD of velocity in AP and ML directions as the most responsive COP parameters for discriminating between improved and unimproved patients. Previous studies have also demonstrated that mean and SD of velocity are the most reliable parameters in different populations such as elderly and patients with musculoskeletal conditions (low back pain, ACL injury, and functional ankle instability) (7, 27). Although there has been no study to date on the responsiveness of the COP parameters, several studies have used a variety of COP parameters to detect the differences in balance performance between various patient populations (e.g., patients with chronic ankle instability and/or low back pain as well as elderly population with a history of falling) and controls (25, 28, 29). Interestingly, the same pattern of findings reveals that COP velocity is the most discriminative measure between the balance-impaired and control participants (25, 28, 29). Thus, our results provide evidence for selection of mean and SD of velocity as two selective COP parameters for evaluating static postural performance in patients with ACL-R undergoing physiotherapy intervention. We also found that these COP parameters had acceptable responsiveness in two conditions as follows: standing on injured leg with open-eyes without cognitive task and standing on uninjured leg with closed-eyes without cognitive task. Therefore, it seems that these two conditions could be the most reasonable conditions to track the changes in COP parameters over time or following a physiotherapy intervention in patients with ACL-R.

For the dynamic postural measures, the results of ROC and correlation analyses showed that APSI, MLSI, and TSI had adequate responsiveness in double-leg standing with closed-eyes and cognitive task. A possible explanation for the higher responsiveness compared to other conditions can be attributed to the increased difficulty level. These results are in line with a previous study demonstrating a higher reliability of stability indices of Biodex Balance System (BBS) in patients with ACL-R under more difficult postural conditions (i.e., single-leg stance with closed-eyes during dual tasking) (6). In addition the highest reliability of stability indices of BBS in elderly population have been acquired under the most demanding test conditions (i.e., low stability level or eyes closed) (5).

The information about MCIC values is helpful for clinicians and researchers to determine if their patients have perceived a true change after a physiotherapy intervention. For instance, the MCIC of 0.28 cm/s obtained for COP mean velocity while standing on the injured leg with open-eyes and no cognitive task indicated that the change scores of at least 0.28 cm/s are necessary to ascertain that the patient has a true change following a physiotherapy intervention (11).

A few limitations have to be considered in the present study. Firstly, a number of authors have challenged using a retrospective global rating scale as an external criterion owing to the problem of recall bias (15, 30). However, we decided on a short time follow-up in this study (i.e., 4 weeks) to reduce the probability of finding a recall bias concomitant with the retrospective global rating scale. Secondly, as responsiveness depends on the population characteristics, the results of this study can be generalized only to similar male ACL-R patients.

Among static postural measures, mean and SD of velocity in AP an ML directions have been found to be responsive while standing on the injured leg with open-eyes and on the uninjured leg with closed-eyes, both without cognitive task. In dynamic postural measures, APSI, MLSI, and TSI could be considered as responsive outcome measures of dynamic postural performance in double-leg standing with closed-eyes and cognitive task. The MCIC values identified for these measures will provide practical information for the clinicians and researchers to make decision on the clinical significance of changes in patients' status.

The authors report no conflict of interest concerning the materials or methods used or the findings specified in this study.

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