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Original Article

Effect of footwear modification on postural symmetry and body balance in leg length Discrepancy: A randomized controlled study

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ABSTRACT

Background: Although structural leg length discrepancy is a physical problem that affects all populations, its measurement and correction is difficult.
Objectives: The purpose of this study was to investigate the effect of using a shoe insert for correcting mild structural leg length discrepancy on frontal and transverse plane spino-pelvic alignment and dynamic balance.
Study design: Pre-test post-test control group design (randomized controlled study).
Methods: Thirty one patients with structural discrepancies of 5–20 mm were randomly divided into two groups, those who used a shoe insert (group(A)) and those who formed a control group (group(B)). Their mean age, mass, and height were 31.5 ± 10y, 77.8 ± 10.4 kg, and 1.69 ± 0.08 m respectively. Spino-pelvic alignment measures (pelvic tilt, pelvic torsion, surface rotation, and lateral deviation) were assessed using raster-stereography, while dynamic balance was assessed using Star Excursion Balance Test (SEBT). Patients were assessed pre- and post-intervention over the eight-week study duration.
Results: Mixed Design MANOVA showed significant decreases in the mean values of all spino-pelvic alignment measures and significant increases in the mean (SEBT) scores with insert use ($p < 0.01$) in group(A) with opposite results being reported for group(B). In addition, group(A) showed significant decreases in all spino-pelvic alignment measures and significant increases in the balance test scores when compared with group(B) eight weeks post insert use ($p < 0.01$).
Conclusions: Using shoe insole for leg length discrepancy correction appears to assist in improving postural symmetry and dynamic balance. (Clinical trial registry www.pactr.org number PACTR201611001888975).
Implications for practice:

- Insert use for LLD correction may assist with improving spinal alignment.
- Insert use for LLD correction may assist with improving pelvic alignment.
- Insert use for LLD correction may assist with improving dynamic balance.

Introduction

Leg length discrepancy (LLD) is associated with a variety of musculoskeletal disorders such as hip osteoarthritis and chronic low back pain that impose high personal and social burden [1,2]. Yet, its incidence is unknown and there is little agreement regarding its prevalence [3,4]. LLD results from either true bone length difference (structural) or mechanical changes affecting the lower limbs (functional) [3,5,6]. It may be mild (up to 30 mm), moderate (30–60 mm), or severe (> 60 mm) [3,5]. Despite the reported disagreement regarding the prevalence of LLD [3,4], mild structural discrepancy has been reported to affect 90% of the adult population [5,6]. LLD causes changes in spino-pelvic alignment [5,7,8], body posture [1,9,10] and balance [11] by altering the distribution and magnitude of mechanical stresses and strains within the body [12].

Regarding its effect on pelvic posture, LLD induces pelvic motion in the sagittal and/or frontal plane with forward innominate bone rotation on the short limb and backward rotation on the long limb [7,12]. Differences in forward/backward rotation and leveling of both innominate bones may change the rotation and inclination of the sacrum that is located between them, producing alteration in the dynamics of the lumbar vertebrae and possibly developing low back pain and lumbar scoliosis with a convexity towards the short limb [8,10,13].

Pelvic posture is changed by mild degrees of LLD [14–16] while,

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compensations from the lower limbs begin to appear with LLD greater than 20 mm [17]. These compensations may include foot pronation and/or hip and knee flexion on the long limb, and foot supination and/or hip and knee extension on the short limb. These compensations produce muscle imbalance which causes sacroiliac dysfunction and low back pain [18], hip flexor contracture on the long limb or planter flexor contracture on the short limb [10]. Prolonged foot pronation on the long limb produces excessive internal rotation of the entire limb [19]. This rotation causes compensatory shortening of the iliopsoas on this side. Unilateral iliopsoas shortening draws the lumbar vertebrae downward and forward and rotate them contralaterally, in addition, it produces unilateral anterior pelvic tilt that alters the normal mechanics of the pelvis, sacroiliac joints and spine [19,20]. Thus, unilateral iliopsoas shortening produced by prolonged foot pronation on the long side changes normal spino-pelvic mechanics [19,20].

The aforementioned changes in the spino-pelvic alignment in addition to the compensatory mechanisms for the imbalance perceived by the patients produce muscle fatigue and pain that affect both static and dynamic balance [21]. When LLD causes foot pronation on the long limb or supination on the short limb, proprioceptive dysfunction of the feet occurs due to these biomechanical dysfunctions [19]. Therefore, the nervous system receives improper information that affects body balance and coordination [19].

Treatment of LLD ranges from conservative intervention to various surgical techniques [3,13]. The most common conservative treatment for mild LLD is the use of internal or external shoe lifts [3]. Yet, there is great debate on shoe lifts regarding their efficacy, the best thickness to be used, and even the strategies for their application [3,22–26]. Many researchers [22–25,27] reported positive findings with insert use with respect to symmetrical limb loading, pain reduction, functional disability, and lumbar scoliotic curve, while others [3,26,28] found limited data to support its use.

Regarding the best thickness of shoe lifts used for correction, variable thicknesses were tested. These included lifts equal to the amount of LLD [10], lifts few millimeters less than the amount of LLD [28], lifts equal to LLD minus 10% [27], and lifts that caused resolution of LBP symptoms [25]. Even the strategies for lift application were variable. Previous researchers [13] provided lifts that fully corrected LLD at once, while others [25,27] provided lifts that were gradually adjusted over time.

To the best of our knowledge, no rasterstereographic studies were conducted on patients with structural LLD. The conducted studies tested healthy individuals with simulated LLD not patients with structural LLD [14–16]. Additionally, they assessed the immediate biomechanical changes not the long term ones [14–16]. Another concern is the limited literature regarding the effect of LLD correction on dynamic balance. The conducted studies assessed postural sway [29,30], symmetrical limb loading [22–24], and gait asymmetries [31], and used them as indicators of balance affection. No previous studies used the Star Excursion Balance Test (SEBT) for examining dynamic balance in patients with LLD. The current study was conducted to investigate the effect of using corrective shoe inserts for eight weeks on frontal and transverse plane spino-pelvic alignment and dynamic balance. It was hypothesized that shoe insert use would improve spino-pelvic alignment and dynamic balance.

Methods

Patients

Forty seven patients with LLD were referred by three physicians. The ranges of patients' age, mass, height, and body mass index (BMI) were 20–60years, 55–92 kg, 1.56–1.83 m, and 18–35 kg/m^2 respectively. The inclusion criteria involved adult patients with structural LLD of 5–20 mm measured using CT scanogram. The BMI was $\leq$35 kg/m^2 as BMI > 35 kg/m^2 may impede rasterstereography from automatically detecting the bony landmarks [16]. Patients were excluded if they had pelvic obliquity due to functional LLD, or any serious medical condition that may affect their ability to perform SEBT (spine arthritis or disc lesions, and/or lower extremity ligamentous instability).

To ensure that the patient had structural LLD only, the following procedure was followed. After measuring LLD magnitude for each patient using CT scanogram, a lift with a height equivalent to LLD magnitude was placed under the foot of the short side. Rasterstereographic measurements were taken with and without the lift. If the measurements indicated that the pelvis was leveled after placing the lift under the foot (indicated by producing normal values of pelvic tilt and torsion which are 4 mm and 0.4° respectively [14]), the patient was included in the study and the insert was prescribed with the same lift height. If the rasterstereographic measurements showed un-leveling of the pelvis with the lift placed under the foot and that an additional height is required to level the pelvis, the patient was excluded from the study. Unleveling of the pelvis with lift use in this situation meant that the patient had pelvic obliquity due to functional LLD in addition to the structural LLD (one of the specified exclusion criteria). Thus, the rasterstereographic measurements provided us with objective quantification of the magnitude of pelvic tilt. Based on these measurements, the insert was prescribed and the patient was included or excluded. Full explanation of the study procedure was provided for patients and informed consents were collected. The study was performed in accordance with the Declaration of Helsinki and approved by the Research Ethical Committee of Faculty of Physical Therapy, Cairo University, Egypt. NO: P.T.REC/012/00809.

Study design

This study involved a pre-test post-test control group design in which patients were randomly assigned into experimental "group(A)" or control "group(B)" using a simple randomization method by selecting one of two folded papers of the tested groups placed in a container. Patients were blind to group enrollment. Both groups were tested twice with an eight-week period in-between during which group (A) used shoe inserts while standing or walking [25,32] and group(B) received no intervention. Group(A) was instructed not to use any therapeutic intervention during the study other than the corrective insert. The examiner kept a weekly telephone call to ensure that the patients followed the instruction and asked for any problems encountered with using the insert.

Intervention

Shoe inserts were used for LLD correction. The insert was only used in the shoe corresponding with the short leg. They were constructed in an orthotics and prosthetics factory under the supervision of a medical engineer. The inserts were made of hard foam and constructed of three layers; basic, corrective, and uppermost (Fig. 1). The basic was formed of a 3 mm-single layer of rubber extending throughout the whole length of the foot. The corrective layer was formed of the corrective wedge that was made of hard foam with its thickness equivalent to the amount of LLD at the hind-foot that gradually descended with a slope to reach 50% of its thickness at the mid-foot and 25% of its thickness at the forefoot [33]. The gradually descending slope of the corrective wedge prevents excessive compression on the metatarsal heads [33,34]. Finally, the uppermost layer was formed of natural leather for providing cosmetic appearance and protecting the skin from irritation and sweat. This design allows the patient to use the insert in any footwear easily without crowding the toe box [33,34].

The corrective insert was constructed with an initial height similar to that reported by the CT scanogram with an expected 10% reduction in its initial height upon use corresponding to material compressibility. Thus, the final insert height equals LLD-10% with use [27]. The percentage of compressibility was specified by the medical engineer

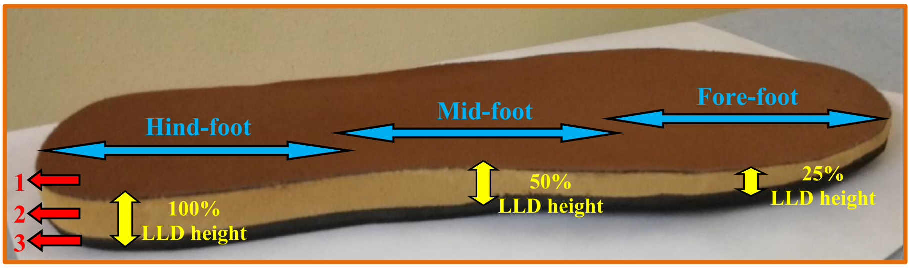

Fig. 1. Structure of the corrective insole (1) a basic 3 mm-single layer of rubber, (2) corrective layer of hard foam, and (3) the uppermost layer that is formed of natural leather.

according to the material used in construction. Inserts of 5–12.5 mm [33] were easily inserted in the shoes. Upon exceeding 12.5 mm, high-neck shoes were allowed to be used to provide support. Bigger shoes sizes were also allowed to provide easy accommodation of the insert.

Assessment

All patients were interviewed and assessed for spino-pelvic alignment and dynamic balance by the same examiner (a physical therapist with clinical experience of 15 years) to ensure consistency. The 3D rasterstereography Formetric II (Diers International GmbH, Schlangenbad, Germany) was used to assess the spino-pelvic alignment. The evaluated measures were pelvic tilt, pelvic torsion, and lateral deviation of the trunk in the frontal plane and spinal surface rotation in the transverse plane. Rasterstereography provides 3D analysis without contact, or exposure to radiation. It provides a spatial reconstruction of the spine through a specific 3D mathematical model. Rasterstereography is characterized by its high precision – error margin ≤0.1 mm (manual user guide) – and high speed of measurement – 0.04 s [35]. The reliability, reproducibility, and accuracy of rasterstereography were reported by several studies [35–40]. Reliability of rasterstereography was assessed through comparing rasterstereographic measurements with those of standard X-ray of 113 patients with scoliosis. A mean difference of 3° for surface rotation and 4 mm for lateral deviation were found between radiographic and rasterstereographic measurements [35]. Moreover, the intra-individual reliability of rasterstereography for assessing the spinal shape of 20 healthy volunteers was studied at different test–retest intervals (on the same day, between-day, and between-week). Reliability was reported with an intraclass correlation coefficient (ICC) with 95% confidence interval (95% CI) of 0.98 (0.97–0.99) for pelvic tilt, 0.89 (0.78–0.95) for pelvic torsion, 0.93 (0.87–0.97) for lateral deviation, and 0.84 (0.69–0.93) for surface rotation [39].

Analysis through rasterstereography is conducted with reference to a body-fixed coordinate system. The Y-axis passes through the vertebra prominence (C7) and the midpoint between the right and left dimples that correspond to the posterior superior iliac spines (PSIS) while the X-axis passes through both dimples. The coordinate system is defined by the patients themselves (i.e. it moves with the patient) [35].

The patient was asked to stand with an exposed trunk in a relaxed position in front of a black screen at a distance of two meters away from the scan system. The scan system consists of a video camera and a raster projector. For calibration and accurate measurement, the vertical height of the camera was adjusted till the horizontal line on the computer screen passes at the level of the inferior angle of the scapula on the patient image that was displayed on the screen. The position of patient's feet on the ground was marked to ensure that the patient stood in the same position for all trials. Patients were asked to take off the shoes during measurement to avoid any spinal deviation and variability in measurements by different types of shoes. Group (A) was tested with the insert at the eight-week follow-up session. The insert was kept in place by asking the patient to wear socks over it during assessment. The scanning time was set to a maximum of 40 ms to avoid movement effects as prescribed in the system manual. From the distorted raster lines that were projected from the rasterstereographic system and with the help of a personal computer, the 3D-model of the spine was reconstructed and the specified spino-pelvic measures were assessed [41,42]. Three trials were conducted and their mean scores were used for data analysis.

The Star Excursion Balance Test (SEBT) was used to assess dynamic balance. SEBT is a reliable, valid, highly representative, non-instrumented, and easily applied test that is used to assess dynamic balance for healthy individuals, athletes, and patients with lower limb problems [43]. It involves single limb standing at the center of a three-direction grid (Fig. 2) while trying to reach as far as possible with the other swinging limb [43,44]. Several researchers studied the reliability of the SEBT in the anterior, posteromedial, and posterolateral directions [45–47]. Plisky et al. [45] found good to excellent interrater reliability ICC (95% CI) = 0.99–1(0.92–1) and intrarater reliability ICC (95% CI) = 0.85–0.91(0.62–0.96). The raters in that study were a physical therapist and an athletic trainer, each with more than seven years of experience, and the study sample included 15 soccer players. Shaffer et al. [46] reported good interrater reliability with ICC (95% CI) = 0.85–0.93(0.75–0.96) and test-retest reliability with ICC (95% CI) = 0.80–0.85(0.68–0.91); that study involved multiple raters with limited experience and testing done over multiple days in a larger sample of 64 military service members.

The reach distances of both short and long limbs were measured. The trial was cancelled if the patient touched heavily or rested at the reaching point, contacted the ground by the reaching foot to maintain

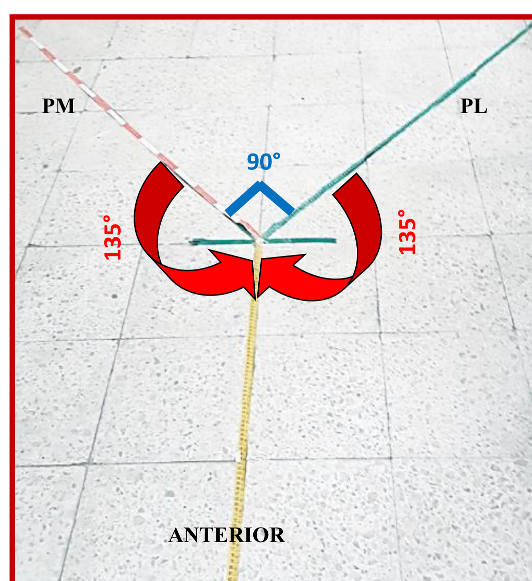

Fig. 2. The three-direction Star Excursion Balance Test grid, anterior (A), postromedial (PM), and postrolateral (PL) directions for the left leg.

balance, released or moved any part of the stance foot during the trial [43,48]. Four warm up trials and three testing trials were performed with five seconds rest after each trial [48,49]. The mean values of the three testing trials in the three directions were added to obtain a composite score for each limb [50]. The obtained scores were normalized to the corresponding limb length for making valid comparisons between the short and long limbs, and between both groups [44,51].

Data processing

As indicated by the rasterstereography manual, pelvic tilt was calculated as the difference in height (in mm) between the two lumbar dimples. A positive value indicates that the right dimple is higher than the left compared to a horizontal line of the measuring system. Pelvic torsion refers to twisting of the pelvis about a transverse axis and it was calculated from the mutual twist of the surface normals at the two lumbar dimples. A positive value indicates that the right innominate bone is oriented further forward than the left one.

Surface rotation refers to horizontal rotation of the vertebrae from the symmetry line (line connecting the spinous processes). It refers to the angle formed by the symmetry line and a line that connects the midpoint of the vertebral body with the tip of its spinous process [15,35]. Lateral deviation refers to the deviation of the spinal midline from the line that connects C7 with the dimple midpoint in the frontal plane. The root mean square values for both surface rotation and lateral deviation were used for data analysis. Illustrative figures of the measured parameters are present in Betsch et al. [15].

Data analysis

Subsequent statistical analyses were conducted during the study to determine the sample size sufficient to produce a minimum power level of 80%. Power analysis (using G*power 3.0.10) revealed that 18 patients were sufficient to produce a power level of 97% with a detected effect size of 2.3.

All statistical analyses were performed using SPSS v.20 (Armonk, NY: IBM Corp). Data were screened for normality (using Shapiro-Wilk's and Kolmogorov-Smirnov normality tests) and homogeneity of variance assumptions. Once data were found not violate both assumptions, parametric analysis was conducted. 2 × 2 Mixed Design MANOVA was used to compare the six selected measures (pelvic tilt, pelvic torsion, surface rotation, lateral deviation, and SEBT scores for both limbs) between both groups (between-subject effect "group effect"), and between pre and post insert use (within-subject effect "time effect"), and to detect the interaction between both factors. Mixed Design MANOVA was followed by subsequent multiple pairwise comparison tests that were conducted with Bonferroni adjustment of the alpha level that was set at 0.05. The standard error of measurement (SEM) values for all measured parameters was calculated as: SEM = (standard deviation)$\sqrt{(1-r_x)}$, where r_x is the reliability coefficient for each parameter calculated using the three test trials data.

Results

Of the 47 patients who were referred, 36 met the inclusion criteria that were verified by the same researcher. Five patients were lost during the follow-up period because of travelling, having health problems, and having surgical correction. Finally, 31 (16 in group(A) and 15 in group(B)) completed the eight-week study duration (Fig. 3).

Regarding the demographic data, the statistical analysis revealed insignificant differences between both groups ($p > 0.05$) (Table 1). The Mixed Design MANOVA showed significant between-subject effect ($F = 5.19$, $p = 0.001$), within-subject effect ($F = 32.7$, $p < 0.01$), and interaction ($F = 67.8$, $p < 0.01$).

Considering the group effect, the pairwise tests revealed that there were no significant differences in all dependent variables between both groups pre-insert use ($p > 0.05$). However, there were significant decreases in all spino-pelvic alignment measures and significant increases in the SEBT scores for both limbs in group(A) compared with group(B) post-insert use ($p < 0.01$).

Regarding the time effect, the pairwise tests revealed that there were significant decreases in all spino-pelvic alignment measures with significant increases in the SEBT scores for both limbs post-insert use compared with pre-use in group(A) ($p < 0.01$). On the other hand, there were significant increases in all spino-pelvic alignment measures except for the pelvic tilt, with significant decreases in the SEBT scores for both limbs after the eight-week period in group(B) ($p < 0.05$). Tables (2) and (3) present the conducted statistical analysis. The standard error of measurement (SEM) values for all measured parameters in both groups pre and post the eight-week study duration were calculated and presented in Table 2.

Discussion

The non-significant differences in all dependent variables between both groups pre-insert use indicated homogeneity between groups. However, there were significant decreases in all spino-pelvic alignment measures and significant increases in SEBT scores for both limbs in group(A) compared with group(B) post-insert use. The reduction in the degrees of both pelvic tilt and torsion might be attributed to improving pelvic posture and mechanics by correcting the inequality between both limbs. During standing, the body weight is typically transferred to the pelvis inducing force vectors over the femoral heads downwards to the feet [5]. Leg length discrepancy forces the pelvis to rotate over the femoral heads by these force vectors [5,14]. We hypothesized that by correcting this discrepancy there was no need for the pelvis to rotate resulting in reduction in the degree of torsion. Additionally, elevation of both anterior and posterior iliac spines at the short limb by the corrective insole might have produced leveling of the pelvic crests and reduction in the degree of pelvic tilt.

Improving spinal posture is another reason for improving body mechanics. Reduction in the degrees of both pelvic torsion and tilt by insert use might have caused reduction in the obliquity and rotation of the sacrum leading to sacral base leveling. As the sacrum is in a quite rigid junction with L5, this correction might have inhibited potential faulty mechanics in the lumbar spine [8,13]. Consequently, pelvic posture correction resulted in improvement in spinal posture as indicated by reduction in the degrees of surface rotation and lateral deviation.

Similarly, this improvement in the spino-pelvic alignment was seen in group(A) after wearing the insert for eight weeks. This might be attributed to the neuromuscular adaptation of the body to the correction of its mechanics. Our findings are supported by those reported by Zabjek et al. [52] who found that a heel lift of 5–15 mm reduced the amount of pelvic torsion in patients with lumbar scoliosis.

On the contrary, Young et al. [53] found that correction of pelvic tilt for patients with LLD (15–34 mm) did not cause reduction in the amount of pelvic torsion. This contradiction might be attributed to sampling, instrumentation, as well as test duration differences. In the current study, 31 patients with mild structural LLD (5–20 mm) were investigated pre- and eight weeks post-insert use using rasterstereography. In contrast, Young et al. [53] examined the immediate effect of a lift placed under the short limb for eight patients only with LLD (15–34 mm) using an inclinometer.

As opposed to group(A), group(B) showed significant increases in all spino-pelvic alignment measures except for pelvic tilt whose increase was not significant. This deterioration might be explained by the onset of LLD in the included patients. The current study included four patients (13% of the sample) only who had LLD since childhood. The majority (87%) had LLD that was acquired due to trauma, surgery, or fracture for at least six months prior to the study. Thus, the age of onset may be a causal factor for the significant deterioration found in the

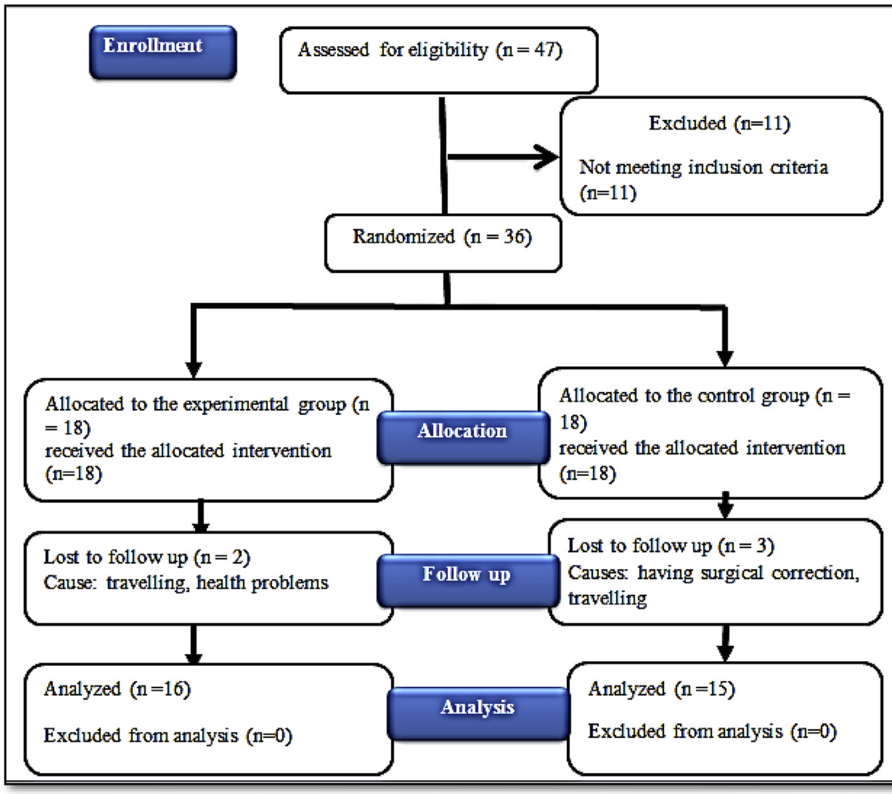

Fig. 3. CONSORT flow chart for patients' enrollment.

control group. This observation was reported by Gurney [13] who demonstrated that patients who acquire LLD later in life are more debilitated by LLD of the same magnitude when compared with patients who had LLD since childhood.

The non-significant increase in pelvic tilt might be explained by the different compensatory reactions to the un-corrected LLD. These reactions may include knee extension, ankle planter flexion and/or foot pronation on the short limb, knee extension, and/or foot supination on the long one. Considering that the lower limb acts as one kinematic chain and there is a complex interaction between this chain and the pelvis, so, these compensations might decrease the magnitude of pelvic tilt and cause it to be insignificant. Another explanation is that pelvic tilting is the main compensatory reaction and the most sensitive parameter to LLD [16]. From this regard, we can say that the most response from the pelvis to LLD in the form of tilting might have appeared initially with the onset of LLD with no further tilt to occur. So, this response can be observed with less magnitude thereafter (insignificant).

Regarding dynamic balance, there were significant increases in SEBT scores for both limbs post-insert use in group(A). Improved spinopelvic alignment and regained balanced body load on both lower limbs post insole use might have been the cause for the improved body balance [23,24]. It was found that the short limb sustains greater load than the long one when LLD is simulated [17]. This asymmetrical limb loading produces premature fatigue during standing and affects patient's balance. For that, when D'Amico et al. [22] corrected LLD by under-foot wedge for patients after total hip replacement, the patients gained symmetrical limb loading that improved their postural balance. Moreover, previous researchers [31,54] reported that mild LLD correction prevents gait abnormalities due to regaining postural symmetry and symmetrical limb loading. Another reason for improving balance with insert use is the improved proprioceptive function produced from correcting foot posture [19].

It was suggested that LLD increases the mechanical work of the long limb leading to increased vertical displacement of the body center of gravity [55] with shifting of the line of gravity to the loaded short limb. Dropping of the pelvis on the short limb with leaning of the trunk to the opposite side occurs as a compensatory mechanism to equalize the leg length and compensate for center of gravity shifting [31,55]. However, equalization of the leg length by shoe insert prevents these dramatic changes and regains the dynamic control for both limbs. Various studies [25,27] demonstrated pain reduction as a result of LLD correction which controls the compensatory reactions of the spine, pelvis, and

Table 1
Demographic data of the experimental and control groups.

	Experimental	Control	Unpaired t- test		Chi-square test	
	(n = 16)	(n = 15)	t-value	p-value	χ^2-value	p-value
Gender	8 males/8 females	7 males/8 females			0.034	0.569
LLD (cm)	1.34 ± 0.47	1.35 ± 0.50	-0.055	0.748		
Age (y)	32.9 ± 11.39	30.1 ± 8.49	0.791	0.241		
Mass (kg)	79.9 ± 9.47	75.7 ± 11.29	1.108	0.605		
Height (m)	1.68 ± 0.077	1.69 ± 0.086	-0.507	0.598		
BMI (kg/m^2)	27.8 ± 4.3	25.8 ± 4.0	1.334	0.963		

*Significant at alpha level < 0.05, data are expressed as Mean ± SD.

Table 2
Descriptive statistics of the dependent variables in the experimental and control groups pre and post the eight-week study duration.

Dependent variables	Experimental group				Control group			
	Pre		Post		Pre		Post	
	Mean ± SD	SEM	Mean ± SD	SEM	Mean ± SD	SEM	Mean ± SD	SEM
Pelvic tilt (mm)	12 ± 5.8	0.317	4.7 ± 3.1	0.098	9.9 ± 4.1	0.129	11.3 ± 4.8	0.151
Pelvic torsion (°)	3.7 ± 1.1	0.115	1.3 ± 0.6	0.084	2.9 ± 1.2	0.131	3.5 ± 1.1	0.120
Surface rotation rms (°)	5.3 ± 0.9	0.155	3.3 ± 1.1	0.170	4.5 ± 1.4	0.132	5.5 ± 1.7	0.161
Lateral deviation rms (mm)	7.1 ± 1.7	0.318	4.6 ± 1.5	0.212	5.7 ± 2.3	0.145	6.5 ± 2	0.089
SEBT short limb (%)	201.25 ± 15.43	0.487	287.5 ± 28.63	0.90	217.33 ± 41.45	1.31	207.33 ± 46.67	1.47
SEBT long limb (%)	183.31 ± 49.32	1.55	280 ± 23.09	0.72	213.6 ± 42.72	1.35	182.8 ± 64.67	2.04

SEBT = Star Excursion Balance Test, rms = root mean square, data are expressed as Mean ± SD, SEM = Standard error of measurement.

Table 3
Multiple pairwise comparison tests of the dependent variables in the experimental and control groups pre and post the eight-week study duration.

Multiple pairwise comparison tests				
Between-subject effect (Experimental vs. Control)				
Experimental vs. Control	Time	Variables	P-value	Cohen Effect Size
	Pre	Pelvic tilt	0.257	0.51
		Pelvic torsion	0.063	0.72
		Surface rotation	0.112	0.71
		Lateral deviation	0.065	0.72
		SEBT short limb	0.158	−0.36
		SEBT long limb	0.113	−0.72
	Post	Pelvic tilt	0.000[a]	−1.6
		Pelvic torsion	0.000[a]	−2.6
		Surface rotation	0.000[a]	−1.6
		Lateral deviation	0.007[a]	−1.1
		SEBT short limb	0.000[a]	2.4
		SEBT long limb	0.000[a]	2.9
Within-subject effect (pre vs. post)				
pre vs. post	Group	Variables	P-value	Cohen Effect Size
	Experimental	Pelvic tilt	0.000[a]	1.6
		Pelvic torsion	0.000[a]	2.8
		Surface rotation	0.000[a]	2
		Lateral deviation	0.000[a]	1.6
		SEBT short limb	0.000[a]	−3.9
		SEBT long limb	0.000[a]	−5.3
	Control	Pelvic tilt	0.087	−0.3
		Pelvic torsion	0.013[a]	−0.54
		Surface rotation	0.000[a]	−0.66
		Lateral deviation	0.002[a]	−0.38
		SEBT short limb	0.048[a]	0.26
		SEBT long limb	0.001[a]	0.52

[a] Significant at alpha level < 0.05, SEBT = Star Excursion Balance Test.

lower limbs. Pain alleviation could also be considered as a reason for improving body balance [21].

Concerning balance assessment for group(B), there was significant reduction in SEBT scores. This deterioration might be attributed to abnormal pelvic and spinal posture, improper proprioceptive function, pain, or asymmetrical loading. These findings are supported by those of D'Amico et al. [22] who found improvement in balance when patients with LLD after total hip replacement wore an under foot wedge for three months. In contrast, patients who did not wear the prescribed wedge showed significant deterioration.

Detection and measurement of LLD could not be performed by observing the asymmetry of the pelvic crests [5,14]. Thus, the current study measured the degree of LLD by CT scanogram. Scanogram has the benefits of reduced radiation exposure compared with standard radiography, high sensitivity in detecting even one mm LLD and good reproducibility [3,13,56]. To improve the accuracy and reproducibility of the current study, rasterstereographic measurements were taken prior to insole prescription to provide objective quantification of pelvic tilt. Additionally, the current study used SEBT that appeared to be an accurate and sensitive tool in detecting changes in dynamic postural control [43].

Our findings are limited to the tested insole materials as well as design, the eight-week test duration, the equipment used for assessment and the tested adult population. The current study investigated the spino-pelvic alignment measures in the frontal and transverse planes only. The changes in sagittal plane measures were not measured as previous studies [14–16] reported minor changes in these measures with simulated mild LLD. So, additional studies are required to ascertain these findings for patients with true LLD. The positive findings for dynamic balance were detected by a reliable manual tool (SEBT) that could be compared with other objective measuring systems such as the Biodex balance system. Further studies are recommended to detect the implication of insole use on human performance.

Conclusion

Using CT scanogram with its benefits of reduced radiation exposure, high sensitivity and good reproducibility, enabled us to accurately measure the magnitude of LLD and objectively determine the appropriate height of shoe insert. The accuracy of LLD measurement in the current study was further improved with rasterstereographic assessment. Both CT scanogram and rasterstereography enable identification of patients with structural LLD only. Based on the rasterstereographic and dynamic balance assessments that were conducted on our patients before and after an eight-week testing duration, it was concluded that shoe insert use is beneficial in improving spino-pelvic alignment (pelvic tilt and torsion and vertebral rotation and lateral deviation) and dynamic balance. This might help improve spinal function and prevent the development of dynamic balance problems.

Conflicts of interest

Declarations of interest: None.

Role of funding sources

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Ethical approval

The study was performed in accordance with the Declaration of Helsinki and approved by the Research Ethical Committee of Faculty of Physical Therapy, Cairo University, Egypt. NO: P.T.REC/012/00809.

Clinical trial registry

Clinical trial registry www.pactr.org.

Clinical trial registry number

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