Research Paper: Comparing Plantar Pressure Distribution and Vertical Ground Reaction Force Between Healthy Subjects and Middle-aged Adults With Leg Length Discrepancy (LLD)

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ABSTRACT

Introduction: This study aimed to compare plantar pressure distribution and vertical ground reaction force between middle-aged adults with Leg Length Discrepancy (LLD) and healthy subjects.

Materials and Methods: This quasi-experimental study was conducted on 21 middle-aged adults with leg length discrepancy (1.5 to 3 cm), and 10 healthy subjects participated. The plantar pressure distribution of subjects was measured using five steps with an emed platform. The data were analyzed with paired t-test, 1-way ANOVA, and symmetry index ($P \leq 0.05$).

Results: While the symmetry index did not show much asymmetry in healthy subjects, in LLD subjects, it showed lower contact time in the heel region of short limb, lower pressure, and force of the middle region of short limb, the higher pressure of forefoot region of short limb and higher pressure and force of long limb.

Conclusion: It seems that the primary contact time and weight acceptance of short limb reduced that results in higher pressure of forefoot region of the foot before push-off phase. Therefore, to dispel this problem, the LLD subjects could use orthotics to make reasonable height to the heel region and thus increase the contact time.

Keywords: Leg length inequality, Gait, Plantar pressure distribution

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1. Introduction

Lower Limb Discrepancy (LLD) is when two lower limbs do not have the same length. From an etiological point of view, LLD is divided into skeletal and compensational. In the skeletal form, the inequality in thigh and tibia length is the main reason for LLD, while in the compensational form, the compensatory mechanism in the musculoskeletal system is the main reason [1].

LLD is a common problem in many populations, and as mentioned in some references, 40% to 70% of people have some form of LLD [2]. It was also noted that at least one person in a thousand is suffering from LLD [3]. Various studies investigated the effect of LLD on low back pain [3], stress fractures [4], balance [2], energy expenditure [1], and running gait-related injuries [5]. It seems that LLD could become even more challenging in middle-aged adults. Gurney et al. [6] reported that a 2-cm difference in lower limb length in middle-aged adults would significantly affect respiration, early fatigue, and musculoskeletal disorders.

Previous studies show that LLD affects walking ability [1, 6, 7]. Perttunen et al. [8] reported that LLD influences Ground Reaction Force (GRF) pattern, thus loading time and peak ground reaction force under the longer side are greater than the shorter side. Gurney et al. [6] reported the effect of LLD on energy consumption and kinetic energy during gait. Gurney et al. [6] studied the elderly of 44 to 80 years old. They indicated that LLD could increase quadriceps activity in the longer side and cause steppage gait in middle-aged adults. The symmetry of the gait pattern is one of the aspects of gait that LLD could affect. It has been suggested that there is an asymmetry instance time between long and short limbs, so stance time on the longer side was greater than that on the shorter side [5, 7]. Bhave et al. [7] showed that GRF in the vertical direction was greater on the longer side (106% vs 116% of body weight). Pereira et al. [5] stated that LLD causes asymmetry in drop after the first peak in the GRF curve. Therefore, it seems that LLD affects gait patterns in different aspects.

Plantar pressure distribution is one of the important parameters that provide much information regarding foot and ankle function during walking. Plantar pressure distribution data is applicable in detecting and modulating musculoskeletal disorders affecting gait patterns, including LLD. Several researchers indicated symmetry in plantar pressure value between the right and left limbs of healthy subjects [9]. However, Perttunen et al. [8] showed that in LLD children, long limbs bear more load in extensive duration compared to short limbs. In addition, the results of this study showed that pressure in the short toe is greater than that in the long limb. In the middle-aged adults, Memar et al. [10] showed asymmetry in plantar pressure parameters of middle-aged adults patients with LLD. These researchers indicated an asymmetry between peak pressure in midfoot and toe regions of the short and long limbs. However, there is no information regarding the evaluation of asymmetry in middle-aged adults and comparison of asymmetry between healthy and LLD middle-aged adults subjects. Thus, this study aimed to compare plantar pressure distribution and GRF between middle-aged adults with LLD and healthy subjects.

2. Materials and Methods

This study is quasi-experimental with a defensive design. A total of 21 middle-aged adults with LLD with 2 to 3 cm limb inequality (with a Mean±SD age: 50.04±3.84 y; Mean±SD weight: 85.16±11.24 kg; Mean±SD height: 170.85±5.37 cm) and 10 healthy middle-aged adults (with a mean±SD age: 55.35±5.94 y; Mean±SD weight: 74.3±9.09 kg; Mean±SD height: 168.18±5.43 cm) participated in this study. A medical specialist performed the medical examination. LLD group had 2 to 3 cm inequality and had no other injury effective in gait pattern. In addition to the LLD group, 10 healthy middle-aged adults with no history of injury and musculoskeletal disorders effective on gait patterns were selected compared to the LLD group.

Lower limb length was measured using a measuring tape from the anterior superior iliac spine to medial malleolus [11]. An emed (novel Gmbh, Germany) platform was used to measure Vertical Ground Reaction Force (VGRF) and plantar pressure distribution. For measuring these variables, an emed platform was placed in the center of a 10-m walkway [12]. Then the subjects were asked to walk through the walkway at a self-selected pace. If the subject places their foot on the center of the platform with natural pattern and speed, the trial was selected as a true trial. Otherwise, the trial must be repeated. Five correct trials from each foot were recorded. The first and last steps were removed to avoid the familiarity process and fatigue effect, respectively. Then the average of three mid-steps was calculated, and AutoMask software was used to measure force and pressure data by considering five separated masks. These five regions are heel (mask 1), midfoot (mask 2), forefoot (mask 3), first toe (mask 4), and other toes (mask 5) [21]. An example of masking in one subject is presented in Figure 1.

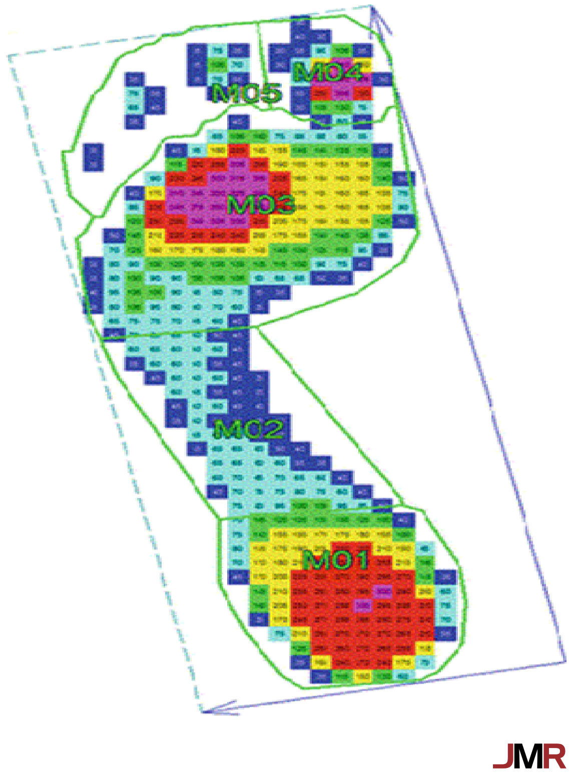

Figure 1. Five Masks of Plantar Region

Heel (Mask 1), Midfoot (Mask 2), Forefoot (Mask 3), First Toe (Mask 4), and Other Toes (Mask 5)

MultiMask evaluation software was then used to calculate the following variables in each mask: maximum VGRF (BW%), peak pressure (kPa), contact area (cm^2), contact time (ms), and pressure-time integral (kPa.s). Symmetry Index (SI) was used to determine the symmetry of the two lower limbs [13]:

$$SI\% = \frac{X_2 - X_1}{0.5 \times (X_1 + X_2)} \times 100$$

In this formula, X1 refers to right limb data and X^2 to left limb data. Ideal symmetry is when SI was 0, and asymmetry is considered when SI is greater than 10%. A positive sign shows greater value in the right limb, and a negative sign shows greater value in the left limb.

Average and standard deviation were used to demonstrate descriptive statistics data in 5 masks. One-way Analysis of Variances (ANOVA) was used to compare variables in the same limb between LLD and healthy groups. Also, the paired t-test was used to compare variables between the right and left limbs ($P \leq 0.05$). All statistical analysis was performed using SPSS version 16.

3. Results

Tables 1 and 2 present the results of descriptive statistics, including average and standard deviation of maximum VGRF, peak pressure, contact area, contact time, mean pressure, and pressure-time integral. Also, they present the results of ANOVA between the short leg and the long leg of the LLD group with the right leg of the healthy group. The results of ANOVA show significant differences in contact time under the first toe region between the short leg of the LLD group with healthy group ($P<0.05$). In addition, the ANOVA results show that contact time under the first toe and other toes was greater than those in the healthy group ($P<0.05$).

On the other hand, the results of paired t-test (Table 3) show no significant differences between variables in the right and left limb of the LLD group ($P>0.05$). Also, the paired t-test results (Table 4) show no significant differences between variables of the right and left limb of the healthy group ($P>0.05$). However, SI shows asymmetry in both LLD and healthy groups, but the asymmetry in the LLD group was more than the healthy group. SI shows that in mask 3 (forefoot), the mean pressure and pressure-time integral of the short limb were higher than those in the long limb, but contact time under the heel, maximum force, and mean pressure of midfoot of the long limb were higher than those in the short limb. Eventually, the results of SI show asymmetry in most of the toes variables in the LLD group. SI in the healthy group show asymmetry in maximum force of midfoot and other toes, maximum pressure of the first toe, and pressure-time integral of other toes.

4. Discussion

This study aimed to compare plantar pressure distribution and ground reaction force between middle-aged adults with leg length discrepancy and healthy subjects. All LLD subjects have structural lower limb discrepancy. Based on Gurney et al. [1] findings, this type of LLD is associated with bony structures and is not the result of altered alignment or body mechanics. Although statistical analysis (paired t-test and ANOVA) did not show any significant differences in most variables between the long and short limb of the LLD group and between the short and long limb of the LLD group with the right limb of the healthy group, SI showed asymmetry in both LLD and healthy group. SI shows symmetry in the contact time of healthy adults, but in the LLD group, the contact time in the heel, first toe, and other toes of the long limb were greater than those in the short limb. It seems that in the structural type of LLD, this compensatory asym-

Table 1. Results of comparison between the short limb of the LLD group and right limb of the healthy group

Variables	Groups	Mean±SD 1	P	2	P	3	P	4	P	5	P
Maximum force (BW%)	Healthy	57.94±9.03	0.69	22.0±7.25	0.46	81.14±10.26	0.16	14.79±2.86	0.52	8.23±5.34	0.96
	LLD	55.81±14.6		25.63±13.2		89.23±15.3		17.44±11.88		8.32±4.54	
Peak pressure (kPa)	Healthy	224±33.33	0.65	14.5±24.31	0.53	306.6±47.8	0.94	260±75.82	0.94	182±91.29	0.83
	LLD	23.84±11.1		14.63±35.32		309.7±12.4		32.94±89.52		17.38±56.15	
Mean pressure (kPa)	Healthy	13.06±20.18	0.2	59.57±16.06	0.74	11.81±10.43	0.2	10.83±21.37	0.99	45.97±13.79	0.74
	LLD	12.8±28.9		57.57±14.87		12.07±23.45		10.88±59.83		48.14±18.57	
Contact area (cm^2)	Healthy	38.55±3.11	0.47	33.79±6.11	0.69	58.03±5.93	0.6	12.82±1.77	0.8	13.89±4.39	0.81
	LLD	37.45±4.18		35.34±11.6		56.76±6.42		13.16±4.13		14.26±3.96	
Contact time (s)	Healthy	68.17±12.15	0.53	65.07±9.39	0.33	85.11±3.07	0.37	69.04±3.6	0.01	61.62±8.17	0.21
	LLD	71.36±13.22		72.05±21.04		87.26±7.07		74.36±5.65		66.73±11.31	

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Table 2. Results of comparison between the long limb of the LLD group and right limb of the healthy group

Variables	Groups	Mean±SD 1	P	2	P	3	P	4	P	5	P
Maximum force (BW%)	Healthy	57.94±9.03	0.76	22.07±7.25	0.06	81.14±10.26	0.6	14.79±2.86	0.18	8.23±5.34	0.32
	LLD	59.12±9.73		31.57±13.7		83.66±12.67		18.96±14.79		10.42±5.34	
Peak pressure (kPa)	Healthy	224±32.23	0.75	149.5±24.31	0.91	306.6±47.84	0.92	260±75.82	0.14	182±91.39	0.43
	LLD	217.94±53.44		150.88±32.27		302.06±149.29		355±187.77		181.47±88.06	
Mean pressure (kPa)	Healthy	136.06±20.18	0.2	59.57±16.06	0.62	117.81±10.43	0.67	100.83±21.37	0.31	45.97±13.79	0.41
	LLD	126.99±20.86		63.11±18.97		115.09±18.15		114.09±37.62		51.66±19.06	
Contact area (cm^2)	Healthy	38.55±3.11	0.8	33.79±6.11	0.14	58.03±5.93	0.25	12.82±1.77	0.65	13.89±4.39	0.31
	LLD	38.99±5.03		39.42±10.89		60.84±6.21		13.2±2.26		15.57±3.96)	
Contact time (s)	Healthy	68.17±12.15	0.06	65.07±9.39	0.2	85.11±3.07	0.15	69.04±3.6	0.00	61.62±8.17	0.0001
	LLD	78.29±14.12		71.88±17.16		87.56±4.67		78.35±5.91		71.47±7.1	

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metry in the long and short limb is attributed to the initial contact, where shorter contact time on the short side disrupts weight acceptance after initial contact.

Consequently, force and pressure will be higher on the longer side. These findings agree with previous researchers that believed contact time in longer limb was greater than that in the shorter side [7, 8, 10]. The isokinetic evaluation shows that the longer side extensors of the LLD group were stronger [8], and it seems that the compensatory mechanism in the longer side because of higher contact time led to this reason.

Table 3. Paired t-test and SI results in the Lower Limb Discrepancy (LLD) group

Parameter		Mean±SD SI%	P
Mask 1	Maximum force (BW%)	-2.83±26.89	0.76
	Peak pressure (Kpa)	-3.11±24.97	0.44
	Mean pressure (kPa)	2.37±16.77	0.16
	Contact area (cm²)	-4.66±13.26	0.96
	Contact time (s)	-11.26±25.33	0.84
Mask 2	Maximum force (BW%)	-16.68±38.68	0.83
	Peak pressure (kPa)	-4.65±50.53	0.55
	Mean pressure (kPa)	-12.45±22.93	0.75
	Contact area (cm²)	-10.82±25.05	0.72
	Contact time (s)	0.48±47.61	0.57
Mask 3	Maximum Force (BW%)	5.22±20.71	0.9
	Peak pressure (kPa)	7.30±36.29	0.97
	Mean pressure (kPa)	10.91±19.01	0.98
	Contact area (cm²)	-6.53±11.56	0.67
	Contact time (s)	-5.60±14.88	0.75
Mask 4	Parameter	SI%	P
	Maximum force (BW%)	-19.06 (46.29)	0.5
	Peak pressure (kPa)	-24.31 (51.36)	0.58
	Mean pressure (kPa)	-6.67 (49.9)	0.16
	Contact area (cm²)	6.23 (28.57)	0.47
	Contact time (s)	-11.33 (13.94)	0.43
Mask 5	Maximum force (BW%)	-17.33 (83.21)	0.9
	Peak pressure (kPa)	-16.03 (63.34)	0.53
	Mean pressure (kPa)	-6.62 (49.32)	0.71
	Contact area (cm²)	-13.04 (55.53)	0.76
	Contact time (s)	-13.32 (22.21)	0.59

Underline indicate asymmetry based on SI%.

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Another finding of this study indicated that maximum force, maximal pressure, and pressure-time integral in the longer limb are greater than those in the shorter side. This finding indicates that the Center of Pressure (COP) in the short side does not reach the toe region and in the push-off phase only reaches the forefoot region, thus higher pressure-time integral in the short side is attributed to the higher loading time in the forefoot, especially during the push-off phase. It seems that in subjects with structural LLD, this compensatory asymmetry in the long and short limb is attributed to the initial contact, where shorter contact time on the short side disrupts weight acceptance after initial contact. Consequently, force and pressure will be higher on the longer side. This finding is in agreement with Perttunen et al. [8], who believed maximum pressure in the first toe is greater on the longer side, and also with other researchers that believed VGRF is greater in the long side during push-off where toes are in contact with the ground [2-5]. Previous studies also indicate that in LLD, COP cannot reach the toe region, and given the results of this study, mean pressure in the forefoot of the shorter side was higher

Table 4. Paired t-test and SI results in the healthy group

Parameter		Mean±SD SI%	P
Mask 1	Maximum force (BW%)	1.85±17.37	0.95
	Peak pressure (kPa)	-5.59±17.89	0.4
	Mean pressure (kPa)	-1±13.62	0.68
	Contact area (cm²)	-0.27±5.89	0.87
	Contact time (s)	-9.82±22.66	0.26
Mask 2	Maximum Force (BW%)	-14.39±23.78	0.08
	Peak pressure (kPa)	-5.22±11.78	0.38
	Mean pressure (kPa)	-11±15.70	0.12
	Contact area (cm²)	-2.4±13.52	0.96
	Contact time (s)	-3.27±19.41	0.57
Mask 3	Maximum force (BW%)	-.25±4.66	0.76
	Peak Pressure (Kpa)	-3.42±14.05	0.42
	Mean Pressure (kpa)	-1.73±7.57	0.24
	Contact area (cm²)	0.15±9.49	0.48
	Contact time (s)	1.68±6.87	0.52
Mask 4	Maximum force (BW%)	-1.72±34.01	0.77
	Peak pressure (kPa)	19.29±50.21	0.19
	Mean pressure (kPa)	5±27.62	0.43
	Contact area (cm²)	4.06±17.2	0.45
	Contact time (s)	0.91±9.58	0.59
Mask 5	Maximum Force (BW%)	-22.64±59.94	0.42
	Peak Pressure (kPa)	-8.31±50.04	0.53
	Mean Pressure (kPa)	-5.48±36.19	0.59
	Contact area (cm²)	-9.49±26.80	0.67
	Contact time (s)	2.09±15.63	0.98

Underline indicate asymmetry based on SI%

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than that in the longer side [8]. Given the statement of previous studies, applying high pressure for a long period, especially in the forefoot and under metatarsal, lead to a stress fracture and overuse injuries, such as growing bony abnormalities [14]. The study results indicate that the first toe and metatarsal region of middle-aged adults with LLD are at risk of overuse injury and stress fracture due to the higher loading time and pressure.

One of the important notes of our results based on SI and statistical analysis did not show significant differences in most variables. According to Herzog et al. [13], in the asymmetry situation, mean differences did not show functional behavior of the lower limb. In addition, variables with high value and low inter-limb differences tend to show symmetry in the results [15].

According to the study results, middle-aged adults with LLD have lower contact time compared to longer limb, and the forefoot in this limb bears higher pressure compared to the longer side. Therefore, special orthotics could increase contact time, especially in the early phase of gait. Also, textured insoles have ultra-effect on improving exteroception and proprioception [16]. Moreover, using an appropriate corrective method can improve the symmetry of both sides of the middle-aged adults during gait and lower the risk of injury in the forefoot region. Finally, as this study was to determine the symmetry of plantar pressure data in LLD and healthy people, evaluating symmetry in kinematic and kinetic variables might lead to changes in conclusion. As such, this could be considered for future study.

Ethical Considerations

Compliance with ethical guidelines

All procedures were followed in accordance with the Helsinki Declaration of 1975. This study was approved by the Ethical Committee of Kharazmi University (IR-KHU.KRC.1000.138).

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Authors contributions

All authors equally contributed to preparing this article.

Conflict of interest

The author declared no conflict of interest.

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