IS STRUCTURAL AND MILD LEG LENGTH DISCREPANCY ENOUGH TO CAUSE A KINETIC CHANGE IN RUNNERS' GAIT?

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SUMMARY

Leg length discrepancy (LLD) affects about 70% of the general population, and can be either structural - when the difference occurs in bone structures - or functional, because of mechanical changes at the lower limbs. The discrepancy can be also classified by its magnitude into mild, intermediate, or severe. Mild LLD has been particularly associated with stress fracture, low back pain and osteoarthritis, and when the discrepancy occurs in subjects whose mechanical loads are increased by their professional, daily or recreational activities, these orthopaedic changes may appear early and severely. The aim of this study was to analyze and compare ground reaction force (GRF) during gait in runners with and without mild LLD. Results showed that subjects with mild LLD of 0.5 to 2.0 cm presented higher values of minimum vertical GRF (0.57 ± 0.07 BW) at the shorter limb compared to the longer limb (0.56 ± 0.08 BW) Therefore, subjects with mild LLD adopt compensatory mechanisms that cause additional overloads to the musculoskeletal system in order to promote a symmetrical gait pattern as showed by the values of absolute symmetric index of vertical and horizontal GRF variables.

Keywords: *Biomechanics; Gait; Leg Length Inequality*

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INTRODUCTION

Small or mild length leg discrepancies (LLD), i.e., below 3.0 cm, have been considered as enough to cause orthopaedic changes such as lumbar pain, stress fractures and osteoarthritis on lower limbs (LLLL) joints(1,2). In addition to the classification by its magnitude, discrepancies can also be categorized according to etiology, being structural when a difference is noted between bone structures' length(3); or functional as a result of mechanical changes on the lower limb, and are found in 65% - 70% of the healthy population(4,5).

Several clinical and radiographic methods are available for measuring that discrepancy, but the biomechanical analysis of gait has recently been shown as an efficient method for detecting asymmetries between LLLL, since changes on gait's dynamics in individuals with LLD have been reported on literature(4,6-9). However, to the extent of our knowledge, there is no consensus in literature as to whether mild discrepancies are enough or not to cause any biomechanical change or asymmetry on gait.

When assessing 105 questionnaires answered by runners, Brunet et al(1) detected that biomechanical unbalances such as the LLD seem to be one of the contributing factors for the occurrence of injuries during running activities, and that such injuries can be explained by the overload supported by LLLL, which can reach to twice or four times an individual's body weight in recreational runs and in speed races, respectively(10).

When assessing gait in children with LLD, Kaufman et al(4) found that discrepancies above 2.0 cm result in gait asymmetry if compared to children without discrepancies. When assessing the kinetics and kinematics of gait in teenagers, Song et al(7) reported no offsetting mechanisms associated to discrepancies of 2.2 ± 4.5% of the longer lower limb, and also, that subjects with such discrepancies showed no kinematic or kinetic asymmetry on gait. When studying 30 14-year old young individuals, Liu et al(8) reported that discrepancies up to 2.33 cm led to a normal symmetric gait, and concluded that patients with LLD adopt offsetting mechanisms, such as: increased flexion of the long LL, increased extension of the short LL, foot pronation on the long LL, foot supination on the short LL, among others, in an attempt to compensate that discrepancy(7,11), while White et al(9), after comparing gait on adults without mild discrepancy and with sham discrepancy found that discrepancies higher than 1.0 cm result in load asymmetries based on values of the Symmetry Index of the vertical ground reaction force (GRF).

Due to the controversies found in literature, and considering that even mild discrepancies are able to cause some kind of

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change on dynamic patterns of locomotion and chronically in locomotive apparatus structures, assessing the effects of such mild discrepancies is key for subjects practicing running activities, once these support heavy overloads on their locomotive apparatus due to the cyclic and intensive routine of drills. Therefore, the objective of this study was to check if mid- to long-distance runners with structural and mild LLD (above 0.5 cm) present changes in the same variables when compared to runners without discrepancies.

MATERIAL AND METHODS

Forty-seven asymptomatic volunteer mid- to long-distance runners of both genders and ages between 18 and 45 years, practicing running activities at a frequency of at least three times a week and over at least one year were assessed in this prospective study. All subjects were submitted to a questionnaire, and the length of LLLL was radiographically measured – by scanometry – performed by only one radiology technician. The subjects were asked to lay down at supine position on the X-ray table keeping the pelvis leveled and the LLLL at anatomical position. A radiopaque metallic ruler was placed on the table between subjects' LLLL, and a series of three X-ray images was taken with the X-ray ampoule sequentially focused onto hip, knee and ankle joints, as described by Cunha et al(12) and Terry et al(13). All subjects were asked to perform a biomechanical analysis of gait; however, 13 subjects refused to continue the study. The 34 remaining subjects signed an informed consent term as approved by the local Committee of Ethics for the Analysis of Research Projects. These were divided into 2 groups: discrepant group (n=22) with structural discrepancy $\geq$ 0,5 cm, and the control group (n=12) with structural discrepancy $<$ 0,5 cm(14).

On lower limb scanometry, femoral and tibial length were defined as described by Cunha et al(12). LLLL length was measured by the sum of femoral and tibial lengths, expressed in centimeters, and the LLD was measured from the absolute difference in centimeters of the longest lower limb length (LL_{long}) by the shortest lower limb length (LL_{short}). From that value, a normalized discrepancy between LLLL could be expressed by the percentage of the longest end length 4, defined by equation 1:

$$\text{Normalized discrepancy (\%)} = \frac{LL_{long} - LL_{short}}{LL_{long}\ (cm)} \qquad (1)$$

We also chose to use a normalized discrepancy in the analyses because we believe that the higher the patient's height, more tolerable the LLD will be(15).

The variables ground reaction force (GRF) vertical and horizontal component were measured during gait by means of an AMTI-type (model OR 62000) power platform built-in at the center of a 10m long runway. Five intermediate steps were collected for LL_{long} and five for LL_{short}. During capture, the subjects walked at a self-selected pace and wore the same tennis shoes they use to wear for running as a way to reduce retroactive effect.

Previous to data acquisition, subjects were guided to walk on the runway at a comfortable speed as many times as required to feel used to the collection environment; however, the acquisition of data itself could only begin when a similar pattern on the vertical GRF curve, i.e., a similar deceleration and acceleration impulse upon foot contact with the ground, was noted in two sequential attempts(16).

Data were acquired at a sampling frequency of 1000 Hz, and a low-pass 100Hz filter was used during mathematical arrangement of data respecting the results achieved by the FFT filter performed(17). Data were also normalized by each subject's body weight (BW).

The vertical component of GRF variables assessed were (Figure 1): first force peak (Fz_1); minimum force (Fz_{min}); second force peak (Fz_2); growth rate 1 ($TCz_1 = Fz_1/\Delta tz_1$); growth rate 2 ($TCz_2 = Fz_2/\Delta tz_2$); and the Push off (PO) rate or discharge rate $[Fz_2/(t_{final} - tz_2)]$. The horizontal GRF variables assessed were (Figure 2): deceleration force peak (Fx_{min}), acceleration force peak (Fx_{max}); Deceleration Impulse (DI), and; Acceleration Impulse (IA). Another variable assessed was the absolute symmetry index (ASI) for the following GRF variables: Fz_1; Fz_{min}; Fz_2; Fx_{max}; and Fx_{min}. A zero index indicates that there is no difference between variables for longer and shorter sides and, thus, gait is perfectly symmetric(18). This index is calculated through the following equation (2)(19):

$$ASI(\%) = \frac{|\, X_{Long} - X_{Short} \,|}{\frac{1}{2}\,(X_{Long} + X_{Short})} \cdot 100 \qquad (2)$$

where Xlong is the gait variable for the longer LL, and Xshort is the variable for the shorter LL.

The mathematical arrangement of data and the calculation of GRF variables were automated and done by means of a mathematic routine developed by Matlab code researchers. Statistical analyses were provided by a Statistica 6.0 software. Data were descriptively represented by means, standard deviations and frequencies. Data normality for GRF was tested by Shapiro Wilks test and upon the normal distribution pattern presented, the t-test was used for independent samples for intergroup comparisons, and the paired t-test for intragroup comparisons (between LL_{long} and LL_{short}). A α of 5% was adopted for statistically significant differences.

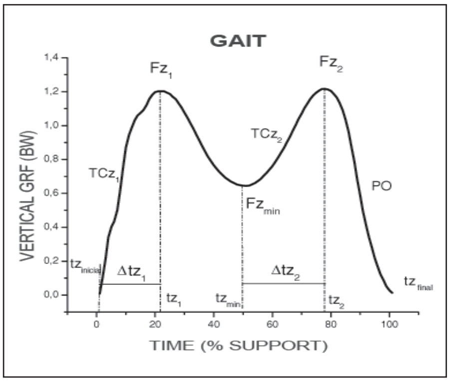

***Figure 1** - Illustration of the vertical GRF variables studied during gait: Fz_1, first force peak; Fzmin, minimum force; Fz_2, second force peak; TCz_1, growth rate 1, TCz_2, growth rate 2, and PO, push off rate.*

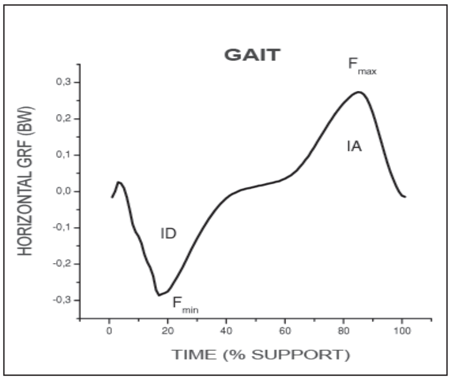

***Figure 2** - Illustration of the horizontal GRF variables studied during gait: Fx_{min}, minimum force; $Fx_{máx}$, maximum force; deceleration impulse (DI); and, acceleration impulse (AI).*

RESULTS

Of the 47 subjects assessed in the study (33 men and 14 women; mean age: 31.3 ± 5.3 years), only 10.6% (5) reported being aware of the LLD, and 8.5% of the subjects (4) wore or had worn some kind of orthosis on the shoes. The absolute mean discrepancy between LLLL showed by these 47 subjects ranged from zero to 2.25 cm. About 6% (3) of the subjects did not present structural discrepancy between LLLL, in 10.6% (5) of the subjects, discrepancy resulted from a difference on femoral length, in 10.6% (5) from a difference on tibial length, and, in 72.3% (34) of the subjects LLD resulted from a difference in both femoral and tibial lengths.

The discrepant group (DG) was constituted by 16 males and 6 females; mean age: 30.6 ± 3.9 years; absolute mean discrepancy of 1.0 ± 0.5 cm; and normalized mean discrepancy of 1.1 ± 0.5%; and the control group (CG) was constituted by 8 males and 4 females; mean age: 30.8 ± 5.4 years; absolute mean discrepancy of 0.2 ± 0.2 cm; and normalized mean discrepancy of 0.3 ± 0.2%.

The results of the biomechanical analysis of the gait are described on Table 1 and no statistically significant differences were seen for vertical and horizontal GRF variables in intergroup comparisons, both in the LL_{long} and in the LL_{short}. Figures 3 and 4 illustrate the mean vertical and horizontal ground reaction force for the studied groups.

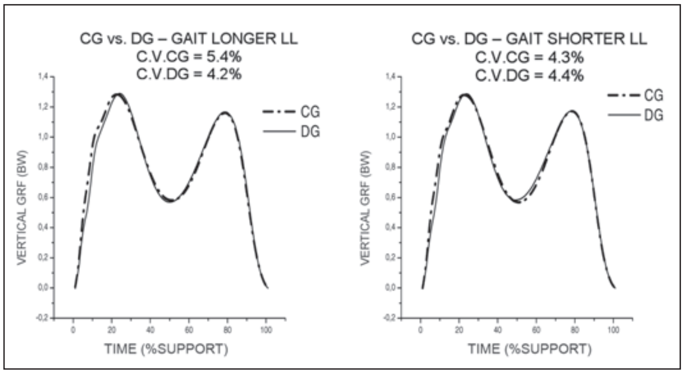

Figure 3: *Mean vertical GRF curves for Control Group (CG) and Discrepant Group (DG), and CV (%), for longer and shorter sides.*

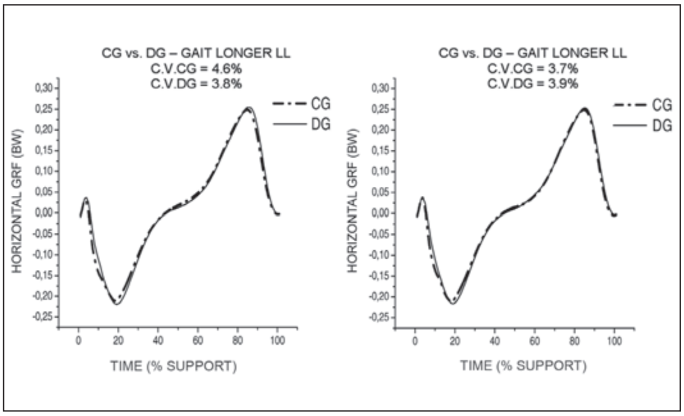

Figure 4: *Mean horizontal GRF curves for Control Group (CG) and Discrepant Group (DG), and CV (%), for longer and shorter sides.*

In the intragroup comparison, CG did not show statistically significant differences between LLLL for all variables, as expected, and the DG showed a significantly higher Fz_{min} variable in the LL_{short} compared to the longer one (p=0.0412).

None of the ASI values measured for the assessed vertical and horizontal GRF variables was statistically different between DG and CG. And, in general, we found that both in DG and in CG, ASI values remained small for vertical GRF variables, and very close to zero for horizontal GRF variables, as we can see on Table 2.

VARIABLES	GD (n=22)	GC (n=12)	p
Fz1 (%)	3.5 ± 1.8	4.0 ± 2.0	0.4093
Fzmin (%)	2.1 ± 0.9	1.9 ± 0.9	0.6362
Fz2 (%)	3.4 ± 1.6	3.9 ± 1.5	0.4141
Fxmax (%)	0.6 ± 0.4	0.5 ± 0.2	0.2898
Fxmin (%)	0.6 ± 0.4	0.6 ± 0.3	0.5710

t-test for independent samples (p < 0,05).

Table 2 *– Mean, standard deviation and p values for Absolute Symmetry Indexes of vertical and horizontal GRF variables in Discrepant Group (DG) and Control Group (CG).*

	DG (n=22)			**CG (n=12)**		
VARIABLES	**Longer LL**	**Shorter LL**	**p**	**Longer LL**	**Shorter LL**	**p**
Fz1 (PC)	1.30 ± 0.09	1.29 ± 0.10	0.5502	1.29 ± 0.12	1.29 ± 0.10	0.7336
Fz2 (PC)	1.17 ± 0.07	1.18 ± 0.06	0.4415	1.16 ± 0.08	1.17 ± 0.06	0.2219
Fzmin (PC) *	0.56 ± 0.08 *	0.57 ± 0.07*	0.0412	0.57 ± 0.10	0.56 ± 0.10	0.1062
TC1 (PC/s)	9.66 ± 1.79	9.68 ± 1.73	0.9026	10.44 ± 1.72	10.42 ± 1.62	0.9323
TC2 (PC/s)	6.75 ± 0.92	6.73 ± 0.86	0.8885	7.04 ± 0.86	7.16 ± 0.80	0.4363
PO (PC/s)	8.70 ± 1.33	8.57 ± 1.17	0.3714	8.89 ±1.34	8.89 ± 1.41	0.9917
Fxmax (PC)	0.26 ± 0.03	0.25 ± 0.03	0.6248	0.25 ± 0.03	0.25 ± 0.03	0.8455
Fxmin (PC)	0.22 ± 0.04	0.22 ± 0.04	0.4741	0.21 ± 0.04	0.21 ± 0.03	0.9128
Imp Deceleration	4.33 ± 0.76	4.22 ± 0.96	0.3991	4.39 ± 1.02	4.23 ± 0.82	0.2178
Imp Acceleration	5.90 ± 0.65	5.87 ± 0.70	0.8135	5.89 ± 0.81	5.75 ± 0.78	0.1677

*Paired t-test, t-test for independent samples (p < 0,05). * represents a statistically significant difference.*

Table 1 *– Mean, standard deviation, and p values for vertical and horizontal GRF variables normalized by body weight (BW) during gait for Discrepant Group (DG) and Control Group (CG).*

DISCUSSION

Even in the presence of a mild structural LLLL discrepancy, only when LLL of subjects with discrepancies above 0.5 cm were compared, changes could be seen for vertical GRF during gait. And even with the presence of discrepancy and GRF change, subjects on control group as well as the subjects on discrepant group showed a symmetric gait, according to the values measured for ASI.

This study demonstrated by means of a biomechanical analysis of gait that mild structural discrepancies of up to 2.25 cm were not enough to cause any changes on horizontal and vertical GRF when compared to subjects without discrepancies. But, when comparing longer and shorter LLLL as a function of discrepancy of 0.5 – 2.0 cm (99% confidence interval), the LL_{short} of subjects with discrepancy showed higher Fz_{min} values, which may suggest a lower mechanical efficiency on this limb due to a reduced energy absorption, once the lower the Fz_{min} value the higher the energy absorption by the activity of ankle, knee and hip muscles during medium support(17). Another potential justification for such difference between LLLL of subjects with mild discrepancy would be the adoption of some offsetting mechanism, as previously described in literature(7,8,11), in an attempt to balance the length of limbs and develop a symmetric gait pattern.

According to Liu *et al*(8), subjects with LLD may adopt a higher supination of the subtalar joint, which would result in a stiffer foot, thus less able to dampen impact, and a functionally longer lower limb for increasing the vertical distance between foot and ground. However, the foot is expected to pronate its subtalar joint during medium support intending to absorb the impact imposed to the lower limb during gait. Kaufman *et al*(4) also suggested that these adaptations made in an attempt to functionally level discrepancy may lead to an increased overload on one of the limbs, favoring the onset of symptoms and/or injuries. Therefore, the higher Fz_{min} values found on LL_{short} of subjects with mild LLD may indicate, in addition to a lower mechanical efficiency and potential overload, an offsetting mechanism employed by these subjects in an attempt to balance the length of their lower limbs and perform a symmetric gait. And, once the values of the Absolute Symmetry Index (ASI) for all vertical and horizontal GRF variables assessed in the present study were too small or close to zero, one may say that regardless of the adopted offsetting mechanism, subjects on discrepant group showed a symmetric gait.

It is worthy to highlight that these compensations may have occurred on any region or joint; however, the failure to provide a kinematic assessment in this study precluded an accurate identification of the mechanisms adopted by these subjects.

For Brunet *et al*(1) and Hreljac(20) biomechanical unbalances such as the LLD seem to be one of the major contributing factors for the occurrence of injuries during running activities. And, according to reference values reported by Friberg(14), the discrepancies showed by the subjects on the DG would be enough to cause orthopaedic changes and, indeed, about 50% of the subjects assessed in this study had already experienced lumbar pain and/ or knee pain, and approximately 30% of these had already experienced hip pain and/ or stress fracture, even though these changes cannot be directly attributed to the discrepancies presented. Also, we cannot say that the differences found in the present study on the lower limbs of subjects with mild discrepancy, despite of the symmetry showed on gait, are not representative of an overload to the locomotive apparatus of these runners.

Thus, by the analysis of the biomechanical variables investigated in this study, we can say that the self-selected speed of gait suggested to the subjects assessed did not represent a challenge to these subjects' musculoskeletal system, possibly because they are adapted to heavier overloads, since they were all mid- to long-distance runners. Furthermore, GRF values are known to increase with higher speeds, and, as a result, changes could be more evident. Hence, further studies performing the same analyses, but with higher speeds, could more evidently reproduce the potential overloads imposed to subjects with mild lower limbs discrepancies.

CONCLUSION

The findings in this study indicate that, in order to provide a symmetric gait, mid- to long-distance runners with mean structural lower limbs discrepancy on the order of 1.0 ± 0.5 cm adopt offsetting mechanisms able to generate an additional overload to musculoskeletal system.

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