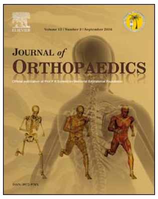
Journal of Orthopaedics 15 (2018) 128–130

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor



Original Article

Dynamic leg length asymmetry during gait is not a valid method for estimating mild anatomic leg length discrepancy

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ARTICLE INFO

Keywords:
Scanogram
X-Ray
Biomechanics
Motion analysis
Walking

ABSTRACT

The purpose of this study was to test the validity of dynamic leg length discrepancy (DLLD) during gait as a radiation-free screening method for measuring anatomic leg length discrepancy (ALLD). Thirty-three subjects with mild leg length discrepancy walked along a walkway and the dynamic leg length discrepancy (DLLD) was calculated using a motion analysis system. Pearson correlation and paired Student *t*-tests were applied to calculate the correlation and compare the differences between DLLD and ALLD ($\alpha = 0.05$). The results of our study showed DLLD is not a valid method to predict ALLD in subjects with mild limb discrepancy.

1. Introduction

Anatomic limb length discrepancy (ALLD) has been related to different orthopedic conditions, such as posterior tibial tendon dysfunction and hip osteoarthritis, due to an inadequate distribution of mechanical loads,[1,2] as well as gait kinematics asymmetries resulted from ALLD have been related to plantar fasciitis,[3] low back pain,[4] and anterior knee pain.[5] On the other hand, some studies have shown that limb length discrepancy (LLD) lower than 35 mm would not have a hazardous outcome in both function and etiology of orthopedic conditions.[6–8] Khamis and Carmeli[9] suggested that the controversy regarding the role of LLD on orthopedic conditions is related to the poor validity of measurement methods and the several abnormal biomechanical alterations that could be caused by LLD.

Although there is no established gold standard method for assessing ALLD, the most accurate and reliable tools used to assess this condition currently involve radiation emission.[10] Also, these methods are subject to minor errors, such as magnification or rotation and may require compliance of the patient to stand still for a long time.[11] Therefore, a radiation-free tool to provide information about the patients' LLD effects becomes very attractive.

Recently, Khamis and Carmeli[12] published a case report on a new promising concept for measuring LLD using a 3D motion analysis. The authors utilized a gait analysis biomechanical model to access dynamic leg length discrepancy (DLLD) and compared the results to ALLD, measured by standing x-ray, with concordant findings. Although 3D motion analysis (3DMA) is a recognized tool to analyze the consequences of LLD on gait parameters,[13,14] so far it has not been validated to determine ALLD.

The purpose of this study was to test the validity of dynamic leg length discrepancy (DLLD) during gait as a radiation-free diagnostic screening method for measuring anatomic leg length discrepancy (ALLD). To achieve that purpose, we calculated the correlation and difference between DLLS, acquired by a 3D motion analysis system during gait, and ALLD values, acquired by x-ray scanogram. It was expected that DLLD between hip joint center (HJC) and heel marker (HEE) and HJC and ankle joint center (AJC) in the loading response and single support phase would be a valid strategy, i.e. have high correlation and no significant difference, to measure ALLD. Following the same philosophy, DLLD between HJC and toe marker (TOE) was expected to be a valid strategy to measure ALLD during pre-swing phase, as proposed by Khamis and Carmeli.[12] These hypotheses relied on the presumption of the inverted pendulum model during support phase of gait[15] and the movement of the distal markers in relation to the ground during each gait phase.

2. Methods

2.1. Participants

Thirty-three subjects (17 females) with average age, mass and height of 43.0 ± 22.1 years, 71.2 ± 18.3 kg, 169.2 ± 11.8 cm,

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https://doi.org/10.1016/j.jor.2018.01.027
Received 17 August 2017; Accepted 14 January 2018

respectively, participated in the study. All subjects presented rearfoot strike during gait. The inclusion criteria were all subsequent subjects seen by the same Orthopedic Surgeon (L.M.), with lower-limb and/or lower back complaints that on clinical examination the LLD ranged from 0 to 2 cm. This range was chosen because the prevalence of LLD of 2 cm or less has been reported to be higher than 99% on the general population.[16] ALLD was assessed by measuring the length of the femur and tibia by the scanogram method as described in Sabharwal and Kumar.[11] All participants did the digital radiographic exam (Model DR-F, GE Hualum Medical Systems) in the same radiology laboratory and measurements performed by the same Radiologist. The exclusion criteria were history of lower limb fractures, realignment or joint reconstruction surgery, radiologic scoliosis 10° or higher according to Cobb angles, pregnancy, discomfort or inability to perform the exams accordingly. The study was approved by the local institutional Ethical Committee for Human Experiments. All participants were informed about the purpose of the study and risks and consented before participation.

2.2. Procedures

Initially, a standing trial in a static position was collected for each subject to individualize marker position, calculate joint centers and segment positions during walking. Then, participants performed a barefoot walk along an eight meters long walkway. Subjects were instructed to walk at their self-selected speed performing six trials along the walkway, and the last three gait cycles for each lower limb captured by the motion analysis system were used for analysis.

2.3. Data reduction

Kinematic data were collected using an 8 high-speed cameras motion analysis system (Vicon, Oxford, UK) with a sample rate of 100 Hz. Markers, segments and joint centers were set according to Plug-In Gait recommendations.[12] Data were filtered by a fourth order zero-lag low pass Butterworth filter, with a cut-off frequency of 6 Hz, and Euler angles of lower limbs were calculated using Nexus software (Vicon, Oxford, UK). To determine stance and swing phases of each cycle, the Foot Velocity Algorithm[17] was used.

Dynamic leg length (DLL) was defined as the effective length of the lower limb, measured by three variables, according to Khamis and Carmeli[12]: (i) the distance from the HJC to the HEE (HJC-HEE); (ii) the distance from the HJC to the AJC (HJC-AJC); (iii) the distance from the HJC to the TOE (HJC-TOE). Dynamic leg length discrepancy (DLLD) was measured by the difference between functional leg lengths of both sides. Predictor variables were the peak and average DLLD (HJC-HEE; HJC-AJC; HJC-TOE) during loading response, single limb support, and pre-swing phases of gait. Interest variable was ALLD.

2.4. Data analysis

Pearson correlation coefficients were calculated to determine the associations between predictors (peak and average DLLD, in cm, in the three gait phases described above) and interest (ALLD) variables. Predictor variables that presented significant correlations with coefficient higher than 0.4 were included in a multiple linear regression with ALLD as output. Stepwise approach was used to find the best model among all predictor variables possibilities, using the Akaike information criterion (AIC) to include variables into the models. To assess the fitting of the model, a leave-one-out cross-validation procedure was used. All coefficients of the models were calculated using data from 38 subjects, and data from the subject left out of the analysis were used to simulate ALLD. Paired Student *t*-tests were applied to compare the differences between each predictor variable and ALLD. To estimate the magnitude of the difference between groups, Cohen's d effect size was calculated.[18] Cohen[18] classified effect sizes as small ($d < 0.2$), medium ($0.2 < d < 0.5$), and large ($d > 0.8$). Significance level was set at 5%. Statistical significance was set at $\alpha = 0.05$. All statistical analyses were performed using MATLAB (version 8.6.0, The Mathworks, USA).

Table 1
Coefficients (r) and p-values of the correlation between peak DLLD and ALLD during each support phase of gait.

	Loading Response		Single Leg Support		Pre-Swing	
	r	p-value	r	p-value	r	p-value
HJC-HEE	− 0.22	0.21	− 0.25	0.16	− 0.09	0.61
HJC-AJC	− 0.22	0.22	− 0.16	0.37	− 0.03	0.88
HJC-TOE	− 0.28	0.12	− 0.17	0.34	− 0.17	0.34

DLLD: Dynamic leg length discrepancy; ALLD: Anatomic leg length discrepancy; HJC-HEE: Distance between the hip joint center and heel marker; HJC-HAJC: Distance between the hip joint center and ankle joint center; HJC-TOE: Distance between the hip joint center and toe marker.

3. Results

The subjects showed a mean ALLD of 1.0 ± 0.7 cm. There were no significant correlations between predictors and interest variables (Tables 1 and 2). As no predictor variable showed significant results, no multiple linear regression models were possible to be developed.

Peak DLLD values presented significant difference from ALLD in loading response (Peak HJC-TOE), single leg support (Peak HJC-AJC and Peak HJC-TOE) and Pre-Swing (Peak HCJ-HEE), although all effect sizes had medium values (Table 3). There were no significant differences between average DLLD and ALLD in any phase of gait. All effect sizes values were lower than 0.8 (Table 3).

4. Discussion

The aim of this study was to test the validation of a radiation-free method to predict anatomic leg length discrepancy (ALLD). The results of our study did not support our initial hypothesis. There were no significant correlations between DLLD measures with ALLD during the different support phases of gait. As the coefficients of correlation were not significant, no regression equation was developed to predict ALLD from dynamic leg length asymmetries. This result suggests DLLS during gait is not a valid metric to predict ALLD. On the other hand, most of paired *t*-tests did not reveal differences between all DLLD measures and ALLD, what may explain the similar value found by Khamis and Carmeli[12] in their case report.

Although gait analysis is a valid and reliable tool to calculate joint angles and moments, such alterations may occur to compensate ALLD, in order to minimize the deleterious effect of LLD and decrease displacement of center of mass due to the limb discrepancy.[9]

Pelvic elevation of the longer leg in single limb support phase of gait is a kinematic variable that has been found in patients with different ALLD magnitudes.[13] Alterations in sagittal plane as hip, knee and ankle

Table 2
Coefficients (r) and p-values of the correlation between average DLLD and ALLD during each support phase of gait.

	Loading Response		Single Leg Support		Pre-Swing	
	r	p-value	r	p-value	r	p-value
HJC-HEE	− 0.26	0.15	− 0.24	0.18	− 0.14	0.43
HJC-AJC	− 0.26	0.14	− 0.18	0.32	− 0.09	0.64
HJC-TOE	− 0.25	0.16	− 0.21	0.24	− 0.18	0.32

DLLD: Dynamic leg length discrepancy; ALLD: Anatomic leg length discrepancy; HJC-HEE: Distance between the hip joint center and heel marker; HJC-HAJC: Distance between the hip joint center and ankle joint center; HJC-TOE: Distance between the hip joint center and toe marker.

Table 3
P-values (Effect Size) of the paired Student *t*-tests between DLLD and ALLD during each support phase of gait.

	Loading Response	Single Leg Support	Pre-Swing
Peak HJC-HEE	0.33 (0.27)	0.10 (0.46)	0.008[**] (0.72)
Peak HJC-AJC	0.35 (0.26)	0.04[*] (0.55)	0.03 (0.55)
Peak HJC-TOE	0.03[*] (0.62)	0.02[*] (0.64)	0.18 (0.37)
Average HJC-HEE	0.78 (0.08)	0.86 (0.05)	0.50 (0.18)
Average HJC-AJC	0.93 (0.03)	0.57 (0.15)	0.64 (0.12)
Average HJC-TOE	0.40 (0.24)	0.70 (0.11)	0.60 (0.14)

DLLD: Dynamic leg length discrepancy; ALLD: Anatomic leg length discrepancy; HJC-HEE: Distance between the hip joint center and heel marker; HJC-HAJC: Distance between the hip joint center and ankle joint center; HJC-TOE: Distance between the hip joint center and toe marker.

[*] $p < 0.05$.

[**] $p < 0.01$.

flexion were found in some studies.[13,14] Despite the lack of validity of DLLD to predict ALLD, there are evidences of association between the magnitudes of limb discrepancy and compensatory strategies during gait.[9] This could explain the negative correlation coefficients between predictor and interest variables found in the present study. Therefore it is recommended further research to determine if joint angles in the sagittal and frontal planes could provide a more accurate prediction of ALLD.

Our study included only subjects with mild discrepancy so, it is acceptable that our negative results may be related to the lack of significant biomechanical alterations associated to leg length asymmetry and it is not possible to predict accurately ALLD without image exams. The purpose of this study was to test the validation of DLLD during gait to predict ALLD with a radiation free strategy, so we decided to include all subjects with ALLD lower than 2 cm to be more realistic with clinical practice. A possible strategy to deal with that is developing non-linear models, as neural networks to predict ALLD to take into consideration these subjects without clinically significant asymmetries. Further studies should include subjects with higher asymmetry to develop a more general model to screen subjects with significant ALLD.

5. Conclusion

The data analysis revealed no correlation between anatomic leg length discrepancy and dynamic leg length discrepancy, measured by a 3d motion analysis. Although the dynamic leg length discrepancy during gait analysis is an interesting tool to depict movement asymmetries, it was not proved to be a valid method to predict ALLD in subjects with mild limb discrepancy. So, DLLD during gait should not be used as a screening tool to predict ALLD in orthopedic injured patients.

Conflicts of interest

There is no conflict of interest.

Acknowledgements

The authors thank Thiago Marinho, Tainá Oliveira, Carla Oliveira and Anna Paula Moraes and Fernanda Cavallieri for his/her assistance with data collection.

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