CASE REPORT

Detecting the presence of leg length discrepancy based on gait deviations and functional measurement of leg length during walking

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SUMMARY

Leg length discrepancy (LLD) is associated with many musculoskeletal disorders. Its clinical significance is unclear mainly due to limited functional measurement capacity. An integrated approach measuring true LLD, gait deviations and functional leg length during the gait cycle, based on location of joint centre and anatomical landmarks using a three-dimensional motion analysis system was performed on two patients. In one case, strong agreement was found between all measurements thus, leading to the same treatment intervention. However, in another case, true LLD was not correlated with functional LLD or gait deviations, which led to contradictory results. Functional LLD was found to be correlated with gait deviations in both cases. Our results indicate the effectiveness of integrating into the diagnostic regimen, a dynamic method of measuring LLD, together with the functional outcome of gait deviations as a basis for decision-making regarding the presence and clinical significance of LLD in musculoskeletal disorders.

BACKGROUND

Leg length discrepancy (LLD) is a controversial issue among researchers and clinicians. While its presence is not in doubt, there is little consensus regarding many aspects of the condition, including the degree of LLD considered to be clinically significant, its prevalence, the reliability and validity of the measuring methods, LLD's effect on function and the role that it has in various neuromusculoskeletal disorders. However, further evidence has been emerging as to the relationship between several clinical conditions and LLD.^{1,2} LLD can be associated with structural deformities originating from true bony leg length differences, known as true LLD.³⁻⁵ It is defined as the anatomical difference between the lengths of the femoral head to the distal tibia of the two limbs. LLD can be congenital or acquired. The proposed prevalence of true LLD is a complicated issue due to the inaccuracy of the clinical measurements, the different measuring methods and the disagreement as to the amount of difference considered clinically relevant.⁶⁻⁹ LLD can also be due to a functional deformity derived from an abnormal hip, knee, ankle and/or foot movements in each of the three planes of motion. This condition is known as functional LLD^{3,4,10} and may be caused by an alteration of lower limb mechanics, such as a joint contracture, static or

dynamic mechanical axis malalignment, muscle weakness or shortening. It is impossible to detect these faulty mechanics statically using a non-functional evaluation, that is, limited knee extension due to joint contractures, excessive dynamic knee joint valgus or varus can be associated with the functional alteration of the leg length.^{11,12} Presently, two common clinical methods are used to measure LLD: the direct method which measures the distance between two anatomical points in a supine position (using a tape measure) and the indirect method which measures LLD in a standing position, where lifts are used to level the pelvis, preferably using a pelvic levelling device.¹³ The height of the lifts needed to level the pelvis is the difference in leg length. The disagreement in the literature regarding the reliability and validity of these methods,^{9,14,15} where some authors favour the direct or indirect method could be attributed to several potential sources of error such as the difficulty of palpating bony landmarks, anatomical bony asymmetry, bony anomalies of the anterior superior iliac spine and malleoli, excess soft tissue due to overweight, differences in leg circumference and angular deformities. In addition, another important factor that might lead to this disagreement is the presence of biomechanical deviations leading to functional discrepancy, thus limiting the reliability and validity of these clinical methods. Various imaging techniques

Figure 1 Distance (in mm) from the HJC to the HEEL, AJC or FF at initial contact of the gait cycle. AJC, ankle joint centre; FF, forefoot; HEEL, heel; HJC, hip joint centre.

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Figure 2 Kinematic representation of the pelvis and lower extremity for patient 1. Left solid line, right dotted line, norm in grey.

have been used to measure true LLD.^{16 17} Radiography is considered the gold standard for measurement, with accepted methods including full limb radiographs, scanograms, CT and computerised digital radiographs. However, static imaging does not reveal any dynamic discrepancy. Another approach to measure LLD while walking and detect functional discrepancy is a three-dimensional (3-D) movement analysis system, measuring the distance between joint centres and anatomic landmarks during the gait cycle (figure 1). The length and alignment of the thigh, shank and foot, and the joint kinematics of the hip, knee, foot and ankle determined LLD. The main aim of the present case series is to check the feasibility of a functional measurement method of the lower limb length during walking based on gait data and to evaluate its relationship to true LLD and gait deviations. This will be a first step in evaluating this concept, which if found possible and clinically meaningful, could lead to further large sample studies.

CASE PRESENTATION

Two subjects with suspected LLD as a factor associated with walking abnormalities were referred for a gait analysis evaluation to assess their gait deviations and the need for adjusting a heel or shoe lift.

Subject 1: A resection of the proximal tibia and endoprosthesis reconstruction was performed on a 21-year-old young female diagnosed with osteosarcoma of the left proximal tibia with. Postsurgery, she developed a severe left knee flexion contracture of 45 degrees and was subsequently operated on to release adhesions and restore knee range of motion, but, with no success. She walked independently with crutches and had full Activities of Daily Living abilities. She complained about pain in the left knee and lower back after prolonged walking. She was evaluated at the gait laboratory a year after commencing rehabilitation. Her clinical examination revealed a left knee joint range of motion: extension

Figure 3 Functional LLD represented by distance (in mm) throughout the gait cycle for patient 1. (A) HJC to HEEL, (B) HJC to AJC, (C) HJC to FF. Left solid line, right dotted line. AJC, ankle joint centre; FF, forefoot; HEEL, heel; HJC, hip joint centre; LLD, Leg length discrepancy.

–40 deg., flexion 75 degrees. Muscle strength indicated a weak left dorsi flexion (Manual Muscle Testing 0/5). No true anatomic LLD was found clinically which was measured from ASIS to the medial aspect of the knee joint line and then subsequently to the medial malleolus in a supine position (left, right 81 cm).

Subject 2: An 18-year-old young man, complaining of low back and left knee pain during prolonged walking. He had full functional motor ability. Clinical evaluation revealed no findings other than severe left genu varus observed clinically and true LLD of 25 mm (left 96.5 cm, right 99 cm) measured as the distance from ASIS to medial malleolus. Both findings were reinforced radiographically. His standing X-ray showed significant left genu varus (mechanical axis deviation left 44 mm, right 10 mm) and a shorter left lower limb by 24 mm as a result of true bony shortening and left genu varus; femur length (left 498 mm, right 517 mm), tibia length (left 420 mm, right 420 mm), total length (left 918 mm, right 937 mm).

INVESTIGATIONS

Participants underwent a gait lab evaluation using a 3-D motion analysis system (8 MX3 cameras, Vicon, Oxford Metrics, UK) according to the biomechanical model PlugInGait (PGM)¹⁸ to measure gait deviations in the lower extremities and pelvis. A thorough clinical evaluation was performed that included: a musculoskeletal evaluation of the lower extremity range of motion and anthropometric and skeletal alignment measurements. Patients were then supplied with 13 reflective passive skin markers which were applied to their pelvis and lower limb according to the PGM protocol.¹⁹ Three retroreflective markers were used to spatially define the pelvis, thigh, shank and foot. Joint centres were calculated according to the marker's placement and the patient's anthropometric parameters. Pelvic orientation was defined according to the laboratory's zero reference point. Hip joint angles were defined as thigh in respect to pelvic movements; knee angles were defined as shank with respect to thigh movements and ankle angles were defined as foot in reference to shank movements. Author SK, with 15 years of experience in gait analysis, performed all patient measurements, marker placements and alignments.

Measuring functional LLD from gait data

Functional leg length was based on measuring the distance from the hip joint centre (HJC) to the heel (HEEL), ankle joint centre (AJC) or forefoot (FF) during the gait cycle (figure 1). HJCs and AJCs were determined by PGM. HEEL and FF markers were placed along the foot axis, placed on the dorsal surface of the foot, over the second metatarsal head according to the PGM protocol. HEEL markers were placed on the back of the heel where the line joining it to the FF marker reflected the long axis of the foot, at the same height as the FF marker.

The virtual trajectories of the HJCs, AJCs and the real marker trajectories of the HEELs and FFs were used to measure the absolute distances from the HJC to the HEEL, AJC and FF throughout the gait cycle. Computer output included a graphic plot of the distance with respect to time, by commercial spreadsheet software (Excel, MS1 V.2010).

This distance is a result of the bone length (foot, shank and thigh segment) and kinematic angles of the lower extremity in the sagittal plane; ankle dorsi—plantar flexion, knee flexion—extension, hip flexion—extension; frontal plane: knee valgus—varus, hip adduction—abduction and horizontal plane: internal—external foot rotation. A data representation of the kinematics and the functional length of the lower extremities during the gait cycle was graphically plotted and interpreted to better understand the contribution of the lower limb deviations to the functional LLD. The average of the three walking trials data were sampled from six captured trials.

Figure 4 Kinematic representation of the pelvis and lower extremity for patient 2. Left solid line, right dotted line, norm in grey. AJC, ankle joint centre; FF, forefoot; HEEL, heel; HJC, hip joint centre; LLD, Leg length discrepancy.

OUTCOME AND FOLLOW-UP

Patient 1: Evaluation of the patient's gait deviation ([figure 2](#)) revealed significant functional LLD during gait ([figure 3A-C](#)) due to knee flexion contracture and the inability to extend the knee which has been found associated with significant shortening of the left lower limb during the left stance phase. Significant elongation was found during the swing phase related to limited knee flexion, which in turn was associated with left clearance insufficiency. In addition, shortening of the patient's left lower limb was associated with right clearance insufficiency. Compensation for a shorter left lower limb can be seen in excessive right ankle dorsiflexion, right hip flexion and right pelvic hike all during the right swing phase. Compensation for the patient's limited ability to clear the left side during the swing phase included excessive left hip flexion, left pelvic hike at left midswing and limited left plantar flexion during the preswing

phase and the initial swing phase (to prevent elongation). Measuring patient 1's functional leg length; HJC to HEEL, AJC and to FF, revealed significant shortening of the left lower limb during the stance phase and the inability to achieve shortening of the leg during the swing phase ([figure 3A-C](#)). The patient's average functional leg length (HJC to AJC) during midstance was 679 mm on the left and 738 mm on the right and during midswing 706 mm on the left and 687 mm on the right, thus revealing a significant difference between sides. Significant functional LLD during gait, measured by the distance of HJC to HEEL, AJC and FF marker was found associated with patient 1's gait deviations despite the fact that no significant true LLD was found clinically or by X-ray measurement. An intervention of left shoe lift to compensate for a functionally short left lower limb could not be justified due to the patient's inability to achieve left clearance. A lift on the left side could lead to further

Figure 5 Functional LLD represented by distance (in mm) throughout the gait cycle for patient 2: (A) HJC to HEEL, (B) HJC to AJC, (C) HJC to FF. Left dotted line, right solid line. AJC, ankle joint centre; FF, forefoot; HEEL, heel; HJC, hip joint centre; LLD, Leg length discrepancy.

deterioration of left clearance insufficiency. The patient's functionally short left leg during the at stance phase and long left leg during the swing phase was due to her structural abnormality of limited knee extension during the stance phase and limited knee flexion during the swing phase.

Patient 2: Major gait deviations observed on the left side (figure 4) are known to achieve functional elongation including vaulting during midstance, excessive ankle plantar flexion and knee extension during left mid to terminal stance. Compensation for clearance was also seen on the right, with a right pelvic hike and increased right external foot progression during the midswing phase. Measuring patient 2's functional LLD also revealed a significant discrepancy, which explains his need for compensation strategies (figure 5A-C). His functional LLD during gait revealed a significant shortening of the left lower limb in all three measurements, HJC to HEEL, to AJC and to FF mainly during the stance phase. His functional leg length measurements from HJC to AJC during the midstance were 865 mm on the left and 889 mm on the right. These findings indicate that his true LLD found clinically and by X-ray was also observed functionally and led to compensatory gait deviations.

It was also observed that his functional leg length of HJC to FF was equalised during the preswing phase due to his compensation of excessive left ankle plantar flexion. This dynamic compensation supports the need for an intervention of a lift adjusted from heel to toe, to eliminate the need to compensate by left plantar flexion. Both of his dynamic measurements and imaging results were highly correlated and a shoe lift of 24 mm was recommended for this patient.

DISCUSSION

LLD is a common finding and its contribution to symptoms is still controversial due to the validity and functionality of the measuring method. Functional LLD is very common in pathological conditions; thereby a dynamic measurement is warranted for these conditions. As can be seen in the two cases presented here, we cannot rely solely on static parameters to determine the type of intervention needed but rather require a dynamic measuring approach. It is essential to measure functional leg length during walking and gait deviations. The integration of functional LLD measurement and gait deviation leads to changes in the nature of the intervention required. Patient 1's results demonstrate no anatomic discrepancy, however, based on clinical observation prior to the gait evaluation, a lift on the left side was recommended to compensate for her functional short left lower limb due to knee flexion contracture, which indeed was found in the functional measurement, (59 mm functional LLD during midstance) along with significant gait deviations. In spite of these findings, a lift on the left side cannot be recommended. A lift on the left would elongate the left lower limb and assist with right clearance. However, it would concomitantly worsen

Learning points

- ▶ True LLD might not correlate with gait deviations and might lead the clinician to erroneous decision-making.
- ▶ Functional LLD can be determined by employing a three-dimensional movement analysis system that can measure the distance between joint centres and anatomic landmarks during the gait cycle.
- ▶ The length and alignment of the thigh, shank and foot and joint kinematics of the hip, knee, foot and ankle determine functional discrepancy.
- ▶ This is a first step in evaluating the feasibility of a functional measurement method of LLD during gait to achieve a more in-depth understanding of the presence of LLD; however, further large sample research studies should be performed.

the patient's ability to clear the left side which is associated with limited knee flexion. No intervention was performed regarding the adjustment of a lift. When examining the results of patient 2, a shorter left femur of 19 mm and total structural shortening of 24 mm were found on X-ray. Comparing the functional leg length during midstance; HJC to HEEL 26 mm, HJC to AJC 24 mm, HJC to FF 22 mm, a high correlation between functional and structural LLD was demonstrated. Patient 2's difference in HJC to FF distance (as described in figure 1) between sides during the terminal stance was only 2–4 mm due to compensation of the left plantar flexion. Notwithstanding that prior to the gait evaluation, anatomic LLD was clearly diagnosed and the recommendation for a left lift was obvious, the contribution of the functional measurements lends support to the clinical findings and confirms the recommended intervention. The HJC to FF distance (see figure 1) during the preswing phase implies that a lift should be recommended for the left side and it is immense to be given also under the forefoot to decrease the need for compensatory strategy of plantar flexion. Thus, we conclude that an integrated approach of measuring LLD, clinically, radiographically, during gait and gait deviations are essential in determining functional LLD and establishing the type of intervention needed. Compensatory gait strategies should be evaluated. Compensation of the short lower limb during the stance phase are intended to elongate the limb, whereas during the swing phase there is no requirement for excessive shortening of the lower limb for clearance. However, the longer leg will use deviations that will shorten the lower limb during the stance and swing phases. Compensatory gait deviations for LLD can simultaneously occur in both the long and short lower limb. In summary, the authors recommend further research, employing a large sample size to determine the reliability and validity of this functional method in measuring LLD and determine the clinical importance of this integrated approach which might assist the clinician to formulate a more reliable and valid clinical decision.

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