

BIOMECHANICAL COMPENSATION IN AN INDIVIDUAL WITH LEG LENGTH DISCREPANCY: A CASE REPORT

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ABSTRACT

Leg length discrepancy (LLD) is a structural asymmetry that may lead to biomechanical compensations, including pelvic tilt and gait asymmetry, and may increase the risk of injury, particularly in physically active individuals. Management often requires a functional approach in addition to anatomical correction. Case: A 37-year-old woman presented with discomfort and aching in her left ankle and calf, particularly when wearing thin-soled footwear. She was diagnosed with a 3-cm structural LLD, with the left leg being shorter, and aimed to participate in long-distance running events of up to 10 km. Clinical examination confirmed bilateral iliotibial band syndrome (ITBS) and right-sided patellofemoral pain syndrome (PFPS). The patient underwent a conservative exercise program supervised 2–3 times per week, with each session lasting 60 minutes. The program emphasized lumbopelvic strengthening, particularly of the gluteal muscles, to improve postural stability, along with load management and footwear modification. Anatomical correction using a personalized insole was recommended through referral to an orthotist-prosthetist; however, this intervention had not been implemented at the time of this report. Following the exercise program, pain intensity decreased from a visual analog scale (VAS) score of 5 to 2. In addition, pelvic drop during the mid-swing phase was no longer observed on gait assessment. Adherence to the exercise program was 100%. Conclusion: A biomechanical management strategy combining functional rehabilitation with anatomical correction using an insole may be important in managing concomitant injuries associated with LLD, such as ITBS and PFPS. In physically active individuals, management should incorporate a comprehensive approach aimed at restoring movement efficiency and reducing the risk of further musculoskeletal injury.

Keywords: Biomechanics, Leg Length Discrepancy, Runner, Posture, Lower Limb

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INTRODUCTION

Leg length discrepancy (LLD), defined as a difference in lower-limb length, is a common clinical condition. Radiographic measurements have shown that approximately 90% of the general population has some degree of variation in leg length, with 20% exhibiting a discrepancy greater than 9 mm (Khamis and Carmeli, 2017). Although discrepancies of less than 10 mm are often considered clinically insignificant, recent evidence suggests that differences as small as 5 mm may induce measurable biomechanical changes (Tallroth, Ristolainen, and Manninen, 2017). The primary compensatory mechanisms associated with LLD involve adaptations of the lumbopelvic-hip complex. During upright standing, the pelvis tends to tilt toward the shorter limb, which may subsequently contribute to the development of compensatory spinal curvature (Hamada et al., 2022). These adaptations are thought to help maintain postural equilibrium and keep the visual axis approximately level with the horizontal plane (Applebaum, Nessim, and Cho, 2021).

During gait analysis, individuals with LLD demonstrate asymmetries in joint kinematics and kinetics. The longer limb may compensate through increased hip flexion, knee flexion, or ankle dorsiflexion during the stance phase, effectively shortening the functional length of the limb (Kamis, Leisman, and Carmeli, 2017; Michalik et al., 2022). In contrast, the shorter limb may compensate through an equinus gait pattern or excessive plantarflexion to increase the functional reach of the foot toward the ground (Fazreena Othman et al., 2019; Altiok et al., 2024). These adaptations may increase muscular workload and reduce gait efficiency by increasing energy expenditure. This case report aimed to evaluate the biomechanical profile and compensatory movement patterns in an individual with LLD. Through movement analysis and functional assessment, this case provides a comprehensive description of the body's adaptations to LLD. A better understanding of these adaptations is important for developing individualized and effective exercise therapy programs for individuals with LLD.

RESEARCH METHOD

Case

A 37-year-old woman presented with complaints of aching and discomfort that developed rapidly in the left ankle and calf. The symptoms became more pronounced when she wore thin-soled footwear, whereas she experienced greater comfort when wearing shoes with thicker cushioning. She had a history of structurally confirmed LLD since her university years but had never used a personalized insole. At the time of presentation, her goal was to achieve the ability to run a distance of 10 km. Anthropometric assessment showed a height of 168.5 cm, body weight of 68.9 kg, and body mass index (BMI) of 24.3 kg/m². Leg length was measured using a measuring tape with the patient in the supine position. True leg length, measured from the anterior superior iliac spine to the medial malleolus, was 90.5 cm on the right side and 87.5 cm on the left side, resulting in a 3-cm discrepancy. Apparent leg length, measured from the umbilicus to the medial malleolus, was 94.5 cm on the right and 93 cm on the left, corresponding to a 1.5-cm discrepancy. The greater difference in true leg length than in apparent leg length confirmed the structural nature of the discrepancy and suggested the presence of pelvic compensation that partially masked the magnitude of the discrepancy during functional assessment. Static postural assessment showed that the body was not aligned with the plumb line. The right

shoulder was lower than the left, while the right side of the pelvis was positioned higher than the left. Increased lumbar lordosis and excessive external rotation of the left ankle were also observed.

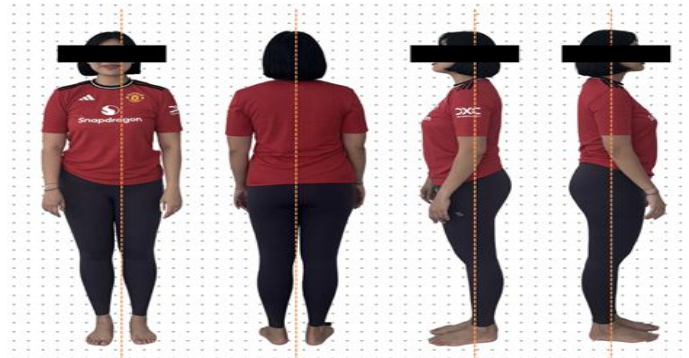


Figure 1. Static postural assessment of the patient

Gait analysis was performed through observational assessment based on visual documentation of the patient's walking pattern. The gait cycle was analyzed according to its individual phases, using the left limb as the reference limb because it was the shorter limb. The assessment covered the eight phases of the gait cycle: initial contact, loading response, mid-stance, terminal stance, pre-swing, initial swing, mid-swing, and terminal swing. Particular attention was given to pelvic obliquity, weight-bearing patterns, and interlimb swing symmetry. Gait assessment using the left limb as the reference limb revealed marked compensatory movement during the mid-stance phase, when the left limb served as the weight-bearing limb while the longer right limb was in the swing phase. During mid-swing, the left limb moved forward and was accompanied by a marked contralateral pelvic drop. This finding was suggestive of right hip abductor weakness and was consistent with a positive Trendelenburg sign.



Figure 2. Gait analysis of Patient

A subsequent musculoskeletal examination revealed tenderness over the left tensor fasciae latae (VAS 4–5), the right quadratus lumborum (VAS 3) and left quadratus lumborum (VAS 4–5), and the left erector spinae (VAS 4). The Ober test was positive bilaterally. The right patellar grind test was also positive, accompanied by right patellar crepitus and tenderness over the right quadriceps tendon (VAS 3–4). Based on these findings, the patient was diagnosed with bilateral iliotibial band syndrome (ITBS) and right-sided patellofemoral pain syndrome (PFPS). Conservative, non-pharmacological management consisted of three components: anatomical correction, supervised exercise therapy, and load management. Regarding anatomical correction, the patient was using a commercially available insole purchased online, with a thickness of approximately 1 cm. This provided insufficient correction for the 3-cm structural discrepancy and was not customized to the patient's foot morphology. The patient was therefore informed about these limitations and was referred to an orthotist-prosthetist for fabrication of a personalized insole.

Several clinical considerations were provided as a guide for the insole prescription: (1) the lift should be applied to the left side to address the 3-cm structural discrepancy; (2) correction should be introduced gradually rather than applied in full immediately, given the patient's chronic neuromuscular adaptations; an overly aggressive correction could disrupt an established compensatory movement pattern and potentially provoke new symptoms; and (3) the final degree of correction should be determined according to the patient's subjective response, including comfort and tolerance during functional activities, with periodic reassessment. At the time of this report, the personalized insole had not yet been fabricated. The patient was therefore advised to temporarily continue using footwear with a relatively thick outsole and adequate cushioning.

The exercise therapy program was prescribed according to the FITT principle, as presented in Table 1. The program primarily focused on strengthening the right gluteus medius and gluteus minimus to address gluteal insufficiency and improve control of pelvic drop during the stance phase. Side plank and hip thrust exercises were prescribed to strengthen the hip abductors and extensors, whereas dead bug and bird-dog exercises targeted lumbopelvic stability. Soleus raises and squat-plus-heel-raise exercises were included to improve the capacity of the left gastrocnemius–soleus complex, which was exposed to greater mechanical loading. Single-leg balance on a pad was used to improve proprioception and neuromuscular control during the single-leg stance phase.

Table 1. FITT-based exercise program

Component	Prescription
Frequency	Two supervised sessions per week
Intensity	Moderate intensity (60–70% of 1-RM)
Time	60 minutes per session; 3 sets × 12 repetitions
Type	Strength training

In parallel with the exercise program, load management was implemented by temporarily reducing the volume of high-intensity running to allow recovery of the iliotibial band and patellar tendon. The patient was nevertheless encouraged to maintain a daily activity target of approximately 8,000 steps.

RESULT AND DISCUSSION

Treatment success was assessed based on pain intensity, the presence of pelvic drop during gait analysis, and adherence to and tolerance of the exercise program. Following the supervised exercise program and load management, the intensity of aching and discomfort in the left ankle and calf decreased from a VAS score of 5 to 2. Repeat gait assessment showed that pelvic drop was no longer observed during the mid-swing phase, suggesting improved right hip abductor capacity to maintain pelvic alignment during the stance phase. Leg length discrepancy (LLD) is relatively common in clinical practice but may be overlooked when the difference is considered small. From a biomechanical perspective, even a subtle asymmetry at the foundation of the body can trigger compensatory adaptations throughout the kinetic chain. Although the human body has a remarkable capacity to adapt and maintain functional movement, these adaptations may increase the mechanical demands placed on specific structures and, over time, may contribute to an increased risk of musculoskeletal injury.

When an individual with LLD aims to engage in activities such as 10-km running, the biomechanical challenge becomes more substantial. Running involves repetitive high-impact loading, and asymmetries that may be well tolerated during walking can translate into considerably greater mechanical stress during running. Therefore, understanding how the body responds to differences in leg length is not simply a matter of equalizing limb length, but also of preserving movement integrity so that the patient's functional goals can be achieved without compromising musculoskeletal health.

Kinematic Compensation

Several studies have shown that individuals with LLD develop kinematic compensation strategies to maintain a stable center of mass (COM) throughout the gait cycle. Siebers et al. reported that the longer limb compensates through increased hip and knee flexion, greater ankle dorsiflexion, and increased hip adduction, thereby functionally shortening the limb. In contrast, the shorter limb demonstrates increased hip and knee extension, ankle plantarflexion, and hip abduction to functionally lengthen the limb. Increased pelvic obliquity and trunk lateral flexion during the stance phase of the longer limb have also been reported. These adaptations help maintain an upright posture and minimize vertical COM displacement during walking (Siebers et al., 2021). These findings are consistent with those of Michalik et al., who reported that an LLD of ≥ 2 cm primarily affects pelvic obliquity during both standing and the mid-stance phase of gait, whereas changes in spinal posture remain relatively limited because of dynamic compensatory mechanisms during walking (Michalik et al., 2022). These findings suggest that the pelvis represents an important site of compensation in individuals with LLD before more pronounced spinal adaptations develop.

Kinetic Compensation

LLD affects not only movement patterns but also the distribution of forces and mechanical loads across the lower extremities. Azizan et al. reported that individuals with LLD experienced greater vertical ground reaction force (VGRF) on the shorter limb than on the longer limb, particularly during single-leg stance. In addition, the center of pressure (COP) distribution was more pronounced on the shorter limb, suggesting greater

asymmetrical loading during walking (Azizan et al., 2018a). As the magnitude of LLD increases, alterations in COM and COP distribution also become more pronounced, particularly in the mediolateral direction, which is closely related to dynamic stability. Another study showed that artificially induced LLD of as little as 1 cm was sufficient to alter spatiotemporal gait parameters and produce asymmetry in ground reaction forces (GRF) during walking. During running, however, significant biomechanical compensations were observed only when the leg length difference reached 2 cm (Korontzi, Kafetzakis, and Mandalidis, 2023). The increased loading of the shorter limb represents an adaptive response aimed at maintaining postural stability. Persistent asymmetrical loading may, over time, increase the risk of degenerative changes and overuse injuries. In the present case, the rapid onset of fatigue and discomfort in the left ankle and calf may reflect accumulated mechanical stress associated with increased loading of the shorter limb.

Energy Efficiency

From a biomechanical perspective, leg length asymmetry has the potential to increase the energetic demands of walking. However, one study reported that individuals with LLD develop gait compensation strategies that minimize COM displacement and thereby reduce the additional energetic cost. Interestingly, individuals with established LLD demonstrated greater energy efficiency than both healthy individuals and those with artificially induced LLD, suggesting that chronic neuromuscular adaptation may allow the body to accommodate persistent leg length asymmetry (Assogba et al., 2018). The primary goal of walking is to propel the body forward efficiently. From a biomechanical perspective, greater vertical or lateral displacement of the COM resulting from LLD increases the mechanical work required from the muscles to maintain forward progression. The body therefore tends to develop energy-conserving compensatory strategies, including pelvic tilt, alterations in joint angles, and modifications in step length. Although these strategies may preserve overall movement efficiency, asymmetrical muscle activation and uneven load distribution may still increase mechanical stress and localized fatigue in specific tissues.

Stability and Postural Control

Dynamic stability is an important consideration in individuals with LLD because lower-limb asymmetry can alter the position and trajectory of the COM and COP during walking. Increasing LLD has been associated with significant changes in COM and COP displacement, particularly in the mediolateral direction, as well as an increase in the root mean square (RMS) COP–COM distance, indicating greater postural control demands. These changes become more pronounced at an LLD of approximately 2.5–3 cm (Azizan et al., 2018b). Physiologically, the neuromuscular system increases postural control activity to maintain balance during single-leg stance. This process requires coordinated control of the trunk, pelvis, hip abductors, ankle stabilizers, and sensorimotor systems. In individuals with chronic LLD, the sustained increase in postural control demands may contribute to neuromuscular fatigue and increase the risk of maladaptive compensatory strategies.

This case report has several limitations. First, it describes a single case; therefore, the findings are descriptive and cannot be generalized to the broader population. Second, gait analysis was performed observationally without instrumented gait analysis. Consequently, kinetic parameters discussed in the present report, such as vertical ground

reaction force and center of pressure distribution, were not objectively measured in this patient and represent interpretations based on previously published literature. Third, long-term follow-up was not available, and therefore the effects of the intervention on symptom recurrence and achievement of the patient's 10-km running goal could not be determined. Fourth, outcome assessment did not include objective measurement of hip abductor strength using a dynamometer or validated functional outcome instruments. Thus, assessment of improvement was partly based on the patient's subjective report and observational clinical assessment.

CONCLUSION

Leg length discrepancy (LLD) can alter gait biomechanics through kinematic and kinetic compensations, changes in load distribution, increased postural control demands, and adaptations in energy efficiency. Nevertheless, in chronic LLD, the body can develop neuromuscular compensation strategies that preserve functional mobility and limit additional energy expenditure during physical activity. In the present case, the worsening of symptoms when the patient wore footwear with minimal support suggested the need to address the underlying biomechanical factors. At the same time, the presence of overuse injuries indicated that the body's compensatory capacity has functional limits and may eventually contribute to localized muscular and musculoskeletal dysfunction. Notably, meaningful clinical improvement in this case, reflected by reduced pain and the disappearance of pelvic drop during gait assessment, was achieved through exercise therapy and footwear modification, despite the fact that anatomical correction with a personalized insole had not yet been implemented. These findings suggest that the management of LLD should not rely solely on anatomical correction but should also address functional capacity, movement efficiency, and injury prevention through individualized exercise therapy and biomechanical modification. Anatomical correction remains a recommended subsequent intervention to support the patient's goal of returning to long-distance running.

REFERENCES

- Altioek, H. et al. (2024) "The Effect of Knee Height Asymmetry on Gait Biomechanics," *Journal of Pediatric Orthopedics*, 44(7), pp. e598–e603. Available at: <https://doi.org/10.1097/BPO.0000000000002704>.
- Applebaum, A., Nessim, A. and Cho, W. (2021) "Overview and Spinal Implications of Leg Length Discrepancy: Narrative Review," *Clinics in Orthopedic Surgery*, 13(2), pp. 127–134. Available at: <https://doi.org/10.4055/cios20224>.
- Assogba, T.F. et al. (2018) "The effects of real and artificial Leg Length Discrepancy on mechanical work and energy cost during the gait," *Gait & Posture*, 59, pp. 147–151. Available at: <https://doi.org/10.1016/j.gaitpost.2017.10.004>.
- Azizan, N.A. et al. (2018a) "Leg Length Discrepancy: Dynamic Balance Response during Gait," *Journal of Healthcare Engineering*, 2018, p. 7815451. Available at: <https://doi.org/10.1155/2018/7815451>.
- Fazreena Othman, N. et al. (2019) "The effect of leg length inequality on joint contact forces of lower limbs during walking," *Acta of Bioengineering and Biomechanics*, 21(1), pp. 55–62.

- Hamada, T. et al. (2022) "Correlation Analysis between Leg-length Discrepancy and Lumbar Scoliosis Using Full-length Standing Radiographs," *Strategies in Trauma and Limb Reconstruction*, 17(3), pp. 144–147. Available at: <https://doi.org/10.5005/jp-journals-10080-1566>.
- Kamis, S., Leisman, G. and Carmeli, E. (2017) "Detecting the presence of leg length discrepancy based on gait deviations and functional measurement of leg length during walking," *BMJ Case Reports*, 2017, p. bcr2017219645. Available at: <https://doi.org/10.1136/bcr-2017-219645>.
- Khamis, S. and Carmeli, E. (2017) "A new concept for measuring leg length discrepancy," *Journal of Orthopaedics*, 14(2), pp. 276–280. Available at: <https://doi.org/10.1016/j.jor.2017.03.008>.
- Korontzi, M., Kafetzakis, I. and Mandalidis, D. (2023) "Effects of Artificially Induced Leg Length Discrepancy on Treadmill-Based Walking and Running Symmetry in Healthy College Students: A Lab-Based Experimental Study," *Sensors*, 23(24), p. 9695. Available at: <https://doi.org/10.3390/s23249695>.
- Michalik, R. et al. (2022) "Biomechanical evaluation and comparison of clinically relevant versus non-relevant leg length inequalities," *BMC musculoskeletal disorders*, 23(1), p. 174. Available at: <https://doi.org/10.1186/s12891-022-05113-2>.
- Siebers, H.L. et al. (2021) "Changes in muscle activities and kinematics due to simulated leg length inequalities," *Biomedizinische Technik. Biomedical Engineering*, 66(5), pp. 437–447. Available at: <https://doi.org/10.1515/bmt-2020-0266>.
- Tallroth, K., Ristolainen, L. and Manninen, M. (2017) "Is a long leg a risk for hip or knee osteoarthritis?," *Acta Orthopaedica*, 88(5), pp. 512–515. Available at: <https://doi.org/10.1080/17453674.2017.1348066>.

