Biomechanical Evaluation and Comparison of Clinically Relevant versus Non-relevant Leg Length Inequalities

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Research Article

Keywords: Leg length inequalities, Leg length discrepancy, Rasterstereography, Gait, Surface topography

Posted Date: June 15th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-604566/v1

Abstract

Background

Leg length inequalities (LLIs) are a frequent condition in every population. It is common clinical practice to consider LLIs of 2cm and more as relevant and to treat those. However, the amount of LLIs that need treatment is not clearly defined in literature and the effect of real LLIs on the musculoskeletal system above and below 2cm have not been studied biomechanically before.

Research question: Are the spine and pelvis affected differently in patients with LLIs <2cm and ≥2cm.

Methods

By using surface topography, we evaluated 32 patients (10 females, 22 male) with real LLIs of ≥2cm (mean: 2.72cm; n=10) and compared their pelvic position and spinal posture to patients with LLIs <2cm (mean: 1.24cm; n=22) while standing and walking. All patients were measured with a surface topography system during standing and while walking on a treadmill. To compare patient groups, we used Student t-tests for independent samples.

Results

Pelvic obliquity was significantly higher in patients with LLI ≥2cm during the standing trial ($p=0.045$) and during the midstance phase of the longer leg ($p=0.023$) while walking. Further measurements did not reveal any significant differences ($p=0.06$-0.706).

Conclusion

The results of our study suggest that relevant LLIs of ≥2cm mostly affect pelvic obliquity and do not lead to significant alterations in the spinal posture during a standing trial. Additionally, we demonstrated that LLIs are better compensated when walking, showing almost no significant differences in pelvic and spinal posture between patients with LLIs smaller and greater than 2 cm. This study shows that LLIs ≥2cm can still be compensated; however, we do not know if the compensation mechanisms may lead to long-term clinical pathologies.

1. Introduction

Leg length inequalities (LLIs) are a common finding in every society with a prevalence of up to 90 percent. (1, 2). For decades research has been published, defining the amount of LLI that needs to be treated; however, a clear consensus in the medical community has not been reached yet (1, 3–8). In early work by Gross et al. in 1978, it was concluded that “there seems little indication for equalization of discrepancies less than 2 cm” (9), while treatment above this amount needs to be decided individually as relevant clinical and biomechanical data is missing. Biomechanical studies have suggested that LLIs of 2cm and more lead to relevant changes in the knee and ankle joints as well as to pelvic obliquity resulting in gait asymmetry (4, 5, 10). Based on these findings some authors suggest to treat LLIs of more than 2 cm, while others recommend even earlier interventions (1–3, 6, 7). Therefore, today LLIs of 2 cm and greater are widely considered clinically relevant and do warrant treatment, however without clear clinical evidence in literature (8).

Several studies have evaluated the temporary and permanent changes in pelvic position and spinal posture caused by LLIs (1, 11–14), which may cause musculoskeletal disorders, such as lower back pain, functional scoliosis, gait disorders and osteoarthritis of the hip and knee joints (3, 15, 16). However, the direct clinical effects and consequences of LLIs do vary between individuals and not all clinical symptoms do directly correlate with the amount of leg length asymmetry (1, 2, 17). Nonetheless, it seems recommended to treat LLIs that do exceed compensation mechanisms and lead to significant changes in pelvic position and spinal posture.

We consider it necessary to evaluate the clinically relevant amount of LLI in an objective and biomechanical setting. Therefore, purpose of this study was to examine and compare the effects on spinal posture and pelvic position caused by LLIs < 2cm and LLIs ≥ 2cm. We hypothesize that LLI ≥ 2cm lead to significantly greater effects on pelvic position and spinal posture.

2. Material And Methods

2.1. Participants

A total of 32 patients (10 females, 22 male) were examined for this study. Included were adults with structural LLIs greater 1 cm. Twenty-one patients had congenital LLIs, while 11 acquired LLIs were caused by total hip replacement (n = 6), total knee and hip replacement (n = 3), Perthes disease (n = 1) or previous fractures of the lower leg (n = 1). For the purpose of this study, we divided the overall cohort of 32 patients in two groups, one with LLI < 2cm (mean = 1.24 cm; n = 22) and one with LLI ≥ 2cm (mean = 2.72cm; n = 10). Overall, the were no differences between the two groups in terms of their demographic data (Table 1).

Table 1
Demographic data of patient groups used in this study. Patients were distributed in two groups with structural LLIs < 2cm and ≥ 2cm. The table presents mean value of demographic data and standard deviation.

	Group A: Patients with LLI < 2cm	**Group B:** Patients with LLI ≥ 2cm	**p-value**
n	22	10	
LLI (cm)	1.24 ± 0.2	2.72 ± 1.18	0.003
Age (years)	44 ± 21	48 ± 20	0.647
Weight (kg)	79 ± 12	80 ± 14	0.743
Height (cm)	175 ± 0.009	179 ± 0.12	0.367
BMI	25.58 ± 3.77	25.04 ± 3.77	0.709

We excluded patients with acute injuries or pain of the spine, pelvis or lower extremities as well as obesity with a body mass index (BMI) > 35 kg/m^2. All patients gave their oral and written consent to participate in this study. The study protocol was approved by the local ethics committee (EK 111/15).

2.2. Measurement protocol

Patients were clinically examined and the leg length and their differences was measured with a tape from the anterior superior iliac spine to the tip of the medial malleolus (18), which has been proven to be valid and reliable compared to CT measurements (19, 20). The measurement protocol used was described previously (12). In our study, we evaluated pelvic position and spinal posture with a surface topography system (DIERS 4D motion ® Lab, Diers International GmbH, Schlangenbad, Germany), which consists of a multi-camera system and a treadmill that was used for the dynamic measurements. This setup does allow to evaluate gait phases, so that spine and pelvic measurements can be synchronized with the respective gait phases (11–13, 21).

First, static measurements were conducted with the patients standing in an upright position with in a neutral standing position. Secondly, for the dynamic measurements all patients walked for 30 seconds with a velocity of 3 km/h barefoot on the treadmill and values measured were averaged over this time. Gait phases were analyzed based on the gait phases described by Perry et al. and previous work (12, 22, 23). The stance phase of each leg was subdivided into initial contact of the foot touching the ground (t0), mid-stance when the whole foot has contact (t1) and the terminal contact phase before the foot lifts off the ground (t2).

2.3. Surface topography

To image and analyze the patients under static conditions and while walking we used radiation free surface topography. The system has been used previously and it has shown its validity and reliability in multiple studies (24–27).

The following pelvic and spinal parameters were evaluated in this study and are briefly described here and in previous work (11–13, 26):

Pelvic obliquity is the amount of tilt of the right (DR) or the left lumbar dimple (DL) from a horizontal line measured in millimeters (Table 2). Pelvic torsion is the rotation of DL and DR measured in degrees. The third pelvic parameter evaluated is the pelvic inclination, which is defined as the mean vertical torsion of the two surface normals of the lumbar dimples. The surface rotation of the spine is the value of the horizontal components of the surface normals on the line connecting the spinous processes of the vertebrae. It is calculated as root mean square in degrees. Lateral deviation is the root mean square of the deviation of the spinal midline (from spinal process of the 7th cervical vertebra to a midpoint between DL and DR) in the frontal plane. It is measured in millimeters. Kyphotic angle is the angle between the surface tangents on points VP (vertebra prominence) and the calculated spinous process of the 12th thoracic vertebrae (T12). Lordotic angle is the angle between the surface tangents on points T12 and the midpoint between DL and DR. Both angles are measured in degrees.

Table 2
Pelvic parameters measured and their interpretation.

Parameter	Positive value	Negative value
Pelvic obliquity (mm)	DR higher	DL higher
Pelvic torsion (°)	DR further anterior	DL further anterior
Pelvic inclination (°)	Anterior inclination	Posterior inclination

2.4. Statistical analysis

For the statistical analysis patients were grouped in patients with LLIs < 2cm and LLIs ≥ 2cm.

For further calculations the LLIs were evaluated as side independent. Side specific data of patients with a longer left leg were multiplied by -1, while data of patients with a longer right leg were not changed. For further analysis, the terms of a longer (+) and a shorter (-) leg were used.

All data were checked for Gaussian distribution by the Chi square test and presented as means with standard deviations or 95% confidence interval. To compare patient groups, we used Student t-tests for independent samples. Levene - test was used for variance testing and Welch-correction used in case of variance - inhomogeneity.

The level of significance was set at $p < 0.05$. Statistical analysis was performed using SPSS software (IBM SPSS Statistics, Version 24, Chicago, IL, USA).

3. Results

3.1. Static measurements

We compared the two groups (LLIs < 2cm versus LLIs > 2cm) regarding their differences in spinal and pelvic parameters during neutral standing. The results show, as expected, a significant higher pelvic obliquity ($p = 0.05$) in patients with LLIs ≥ 2cm (group B). However, there were no other significant differences found between the groups for pelvic torsion and inclination ($p = 0.11–0.79$) (Fig. 1A).

Besides pelvic parameters, we also evaluated the influence of LLIs on the spinal posture. The results show a trend of increasing surface rotation and lateral deviation in patients with higher LLIs (group B). However, the differences between groups were not statistically significant (Table 3).

Table 3
Results for static evaluation of pelvic and spinal parameters in patients with LLI < 2cm (group A) and LLI ≥ 2cm (group B).

	Group A LLI < 2cm		**Group B LLI ≥ 2cm**		
	mean	SD	mean	SD	p- value
Pelvic Obliquity (mm)	6.50	3.92	12.28	7.64	**0.045**
Pelvic Torsion (°)	-1.54	3.78	-1.93	3.71	0.79
Pelvic Inclination (°)	17.72	6.15	15.40	7.03	0.35
Kyphotic Angle (°)	54.12	7.30	51.41	14.15	0.58
Lordotic Angle (°)	37.46	6.24	34.91	9.01	0.36
Surface rotation (°)	3.71	1.87	3.92	1.96	0.78
Lateral deviation (mm)	4.06	2.82	5.91	3.26	0.11

A trend for a higher kyphotic angle was found in group A (54.12°) compared to group B with LLI ≥ 2cm (51.41°), which was not significant ($p = 0.58$). Measurements of the lordotic angle showed similar results ($p = 0.36$) with a trend towards higher lordotic angles in the group with smaller LLIs.

3.2. Dynamic measurements

We also analyzed and compared the effects of different LLIs on pelvic position and spinal posture during walking on a treadmill.

3.2.1. Pelvic obliquity

The pelvic obliquity was constantly higher in group B, which was significant during the t1 phase of the longer leg ($p = 0.023$). The highest value for pelvic obliquity was found in the initial contact phase of the longer leg ($p = 0.252$). Lower values were found during the midstance and terminal contact phase ($p = 0.121$) of the longer leg (Fig. 2).

3.2.2. Spinal parameters

The kyphotic angle was not significantly different between both groups during all gait phases ($p = 0.451–0.92$). Also, both groups showed similar lordotic angles while walking ($p = 0.526–0.706$). The analysis of the lateral deviation of the spine revealed a trend towards a higher lateral deviation in the group with LLIs ≥ 2cm throughout the gait cycle, which was not statistically significant ($p = 0.060–0.263$) (Fig. 3A).

The investigation of surface rotation of the spine showed similar results. The rotation of the spine was orientated towards the longer leg (positive value). The rotation trended higher values in group B with the highest differences between groups in the initial contact phase of the longer leg ($p = 0.065$). In all other gait phases no significant differences between the groups were found ($p = 0.065–0.549$) (Fig. 3B).

4. Discussion

LLIs can lead to acute or chronic musculoskeletal changes and clinical symptoms (1, 8). However, there still exist some controversies in the literature regarding the exact amount of LLI that is considered to be clinically significant and which needs to be treated (1, 3–6, 14). Purpose of this study was to compare pelvic position and spinal posture in patients with LLI < 2cm versus patients with LLIs > 2cm during standing and while walking. The hypothesis was that patients with LLIs > 2cm will have significantly altered pelvic position and spinal posture compared to patients with LLIs < 2cm due to their larger LLIs.

The results of this present study show that patients with LLIs > 2cm presented only with significant greater pelvic obliquity and not with any other pelvic parameter compared to patients with LLIs < 2cm. In addition, no differences in spinal posture were found between the two groups. During our walking trials, when comparing pelvic position and spinal posture between the groups, our analysis found mostly no differences between the LLIs > 2cm and the LLIs < 2cm groups, indicating that LLIs are even more compensated during walking than while standing.

The effects of LLIs on the patient’s pelvis and spine while standing are supported by the current literature. Pelvic obliquity increases with increasing LLIs on the side of the longer leg as previously confirmed in real and simulated LLIs (4, 12, 13). In addition, previously it was shown that LLIs lead to an increase in pelvic torsion, which is known to cause an anterior rotation of the hemipelvis on the side of the shorter leg (28). Studies that use similar/equivalent imaging techniques to measure the effects of LLIs do support the findings of our study, regarding the effects of LLIs.

In a recent study, simulated LLIs of > 1cm caused a significant increase in lateral deviation and surface rotation of the spine (12). Although, our groups differed on average more than 1.5 cm in their leg length inequalities, we did not find any differences in spinal position between the two patient groups, indicating that patients can acutely compensate LLIs > 2cm without causing significant alterations in their spinal posture (2).

To the best of our knowledge, this is the first study to directly compare and evaluate two patient groups with LLIs smaller and greater than 2cm. Previous studies have supported that LLIs ≥ 2cm need to be treated clinically since they can lead to back and hip pain and to an increased risk in knee and hip osteoarthritis (1–3, 8). Contrary to these findings, our results show that the group with LLIs > 2cm only differed in pelvic obliquity and no other differences were found. These results are clinically meaningful and relevant as it raises the question on the necessity of the treatment of LLIs of two and more centimeters.

Further comparison of the patient groups under dynamic conditions, revealed almost no significant differences for pelvic obliquity throughout the gait cycle and no significant differences for the spinal parameters. These findings support earlier work with simulated LLIs, that demonstrated greater compensation of LLIs during walking (4, 6, 12). For our walking trials we found a significant difference between the two groups for pelvic obliquity during the midstance phase of the longer leg. The different compensation strategies for pelvic obliquity of patients with LLIs while walking were previously confirmed by Song et al. who analysed a collective of 35 children with various LLIs (0.6-11.1cm). Their study showed that only two patients presented with increased pelvic obliquity, which was not correlated with the degree of limb-length discrepancy. The authors stated that patients with LLIs and non-relevant co-morbidities are likely to develop various compensation strategies of the lower limb to compensate for the LLIs while walking (29). Kakushima et al. simulated LLIs of 3cm and found a significant increase in lateral bending of the spine (30), while Needham et al, identified only minimal differences in pelvic and spinal motion in subjects with simulated LLIs (31). These studies again confirm that there must exist various compensation strategies in different cohorts of subjects with LLIs, highlighting the fact that a more individualized approach might be necessary to understand and examine the effects of LLIs on the body.

There do exist some limitations of this present study that need to be addressed. The present investigation does focus on the biomechanical effects of LLIs on the spine and pelvis. However, it does not allow to compare the effects of LLIs on the ankle, knee and hip joint due to the type of imaging system chosen, which could also be clinically relevant. Further studies should therefore include measurements of the lower extremities in order to examine the role of the lower extremities on the compensation of LLIs. Another limitation is the relatively small number of patients included and the heterogeneity of the aetiology of the LLIs, which may not allow to generalize our findings. Further, we did not compare our two patient groups with a control group, which would have allowed a more comprehensive analysis of the effects of LLIs. However, the primary focus of our work was to compare patients with LLIs of a certain extend to each other biomechanically. In future studies, we intend to evaluate a greater patient collective with a larger amount of LLI and an additional comparison to a healthy control group for further clarification regarding the amount of LLI that requires treatment.

5. Conclusion

The results of our study suggest that relevant LLIs of ≥ 2cm mostly affect pelvic obliquity and do not lead to significant alterations in the spinal posture during a standing trial. Additionally, we demonstrated that LLIs are better compensated when walking, showing almost no significant differences in pelvic and spinal posture between patients with LLIs smaller and greater than 2 cm. This study shows that even LLIs ≥ 2cm can be compensated; however, we do not know if the compensation mechanisms may lead to long-term clinical symptoms and pathologies. These findings raise the question, which LLIs need to be clinically treated and which can still be compensated for by the patient?

Declarations

Ethics approval and consent to participate

Study registration at the local ethic committee (study number EK 111/15).

Consent for publication

All authors have reviewed the final version of this manuscript and agreed to publication in the Journal of Orthopaedic Surgery and Research

Availability of data and materials

The data that support the findings of this study are available from Marcel Betsch and Roman Michalik, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

Competing interests

There are no competing interests.

Fundings

No funding was received for this study.

Authors` contributions

Marcel Betsch, and Viola Rissel were responsible for study design, data collection and interpretation of this manuscript. Filippo Migliorini contributed in writing and drafting this manuscript. Roman Michalik and Hannah Siebers contributed in data interpretation and analyzation, writing and drafting this manuscript.

All authors read and approved the submitted version of the manuscript.

Acknowledgements

not applicable

Authors´ information

not applicable

Conflict of interests

The authors have none to declare.

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Figures

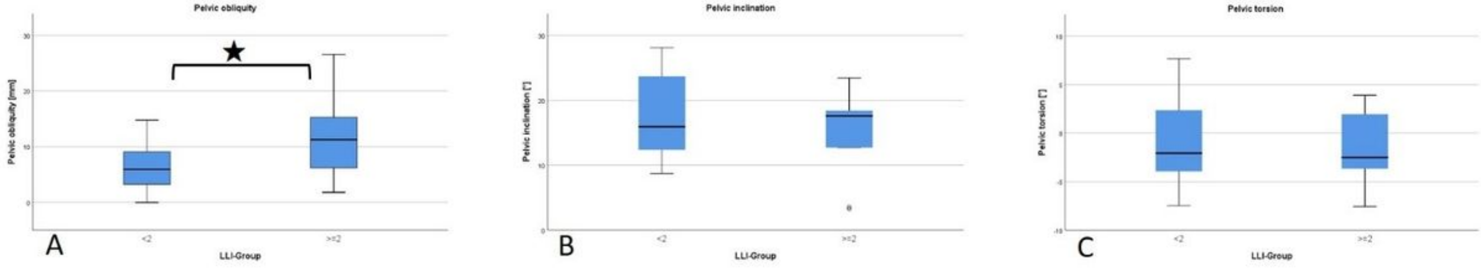

Figure 1

Boxplot graphics of measured pelvic parameters showing significant higher pelvic obliquity (A) in group B (LLI ≥2cm). Pelvic inclination was smaller in the group with higher LLI (B). This difference between groups, however was not significant (p=0.35). For pelvic torsion the results showed no significant differences in neutral standing (p= 0.79). The negative value indicates that the left dimple is orientated further anterior (C).

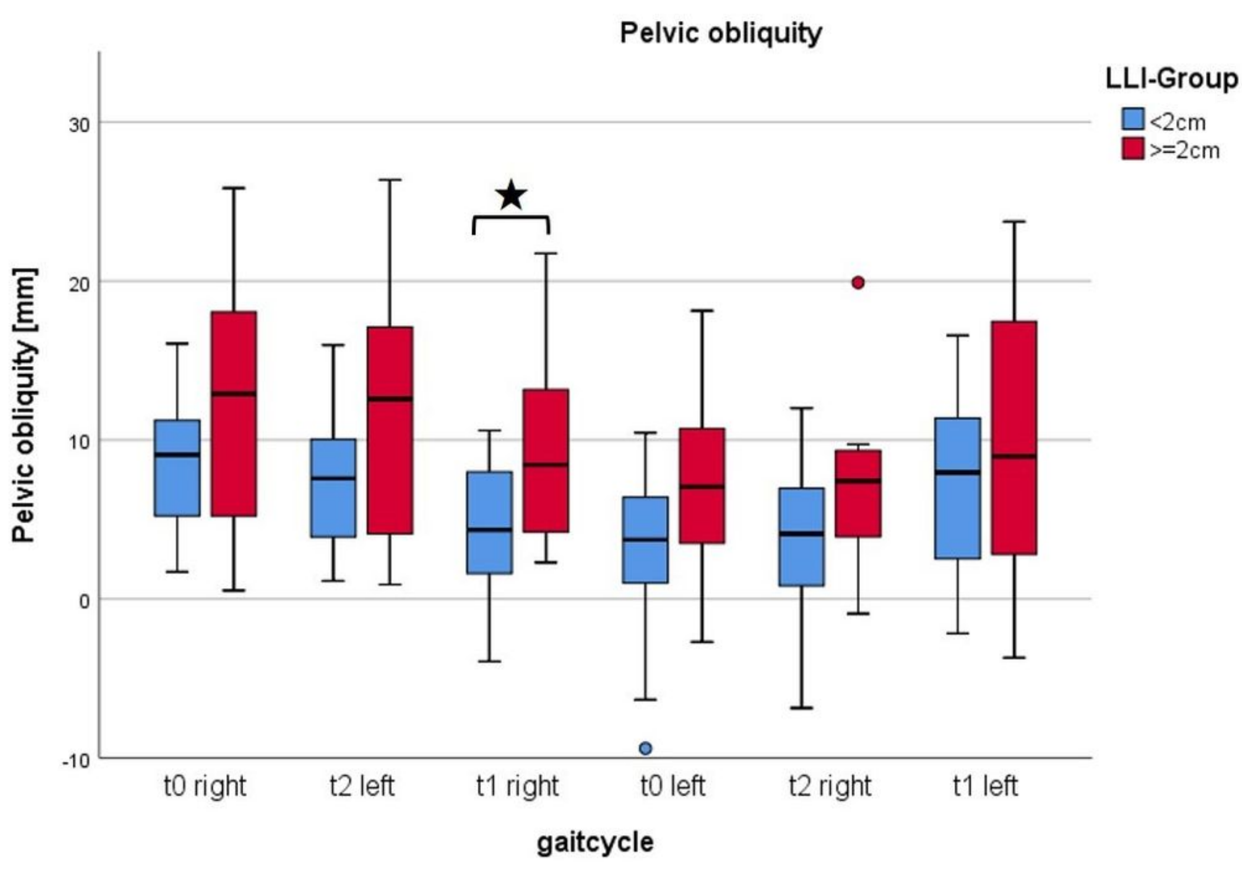

Figure 2

Boxplot graphics of measured pelvic obliquity in subjects with LLI<2cm (blue) and LLI ≥2cm (red) while walking on a treadmill. Gait phases (t0: initial contact, t1: mid-stance, t2: terminal contact) of one gait cycle are listed on the x-axes. A significant (*) higher pelvic obliquity was shown in the t1 phase of the right (longer) leg (p=0.023).

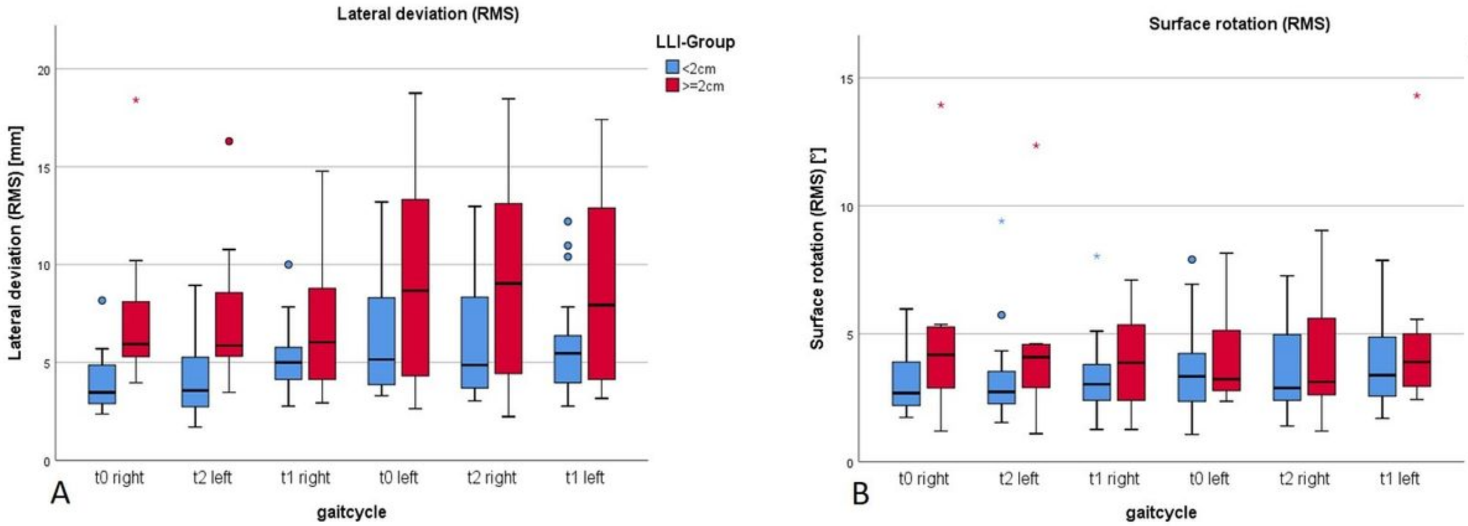

Figure 3

Boxplot graphics shows mean lateral deviation calculated as the root mean square while walking (A) and surface rotation (B) in subjects with LLI<2cm (blue) and LLI ≥2cm (red). Gait phases of one gait cycle are listed on x-axes. Lateral deviation and surface rotation show orientation to the longer leg, which is indicated by positive values.