International Journal of Current Research and Review
DOI: http://dx.doi.org/10.31782/IJCRR.2021.131533

Original Article

IJCRR
Section: Healthcare
ISI Impact Factor (2019-20): 1.628
IC Value (2019): 90.81
SJIF (2020) = 7.893

Effect of Tibial Length Discrepancy on the Pelvic List During Human Gait

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ABSTRACT

Introduction: Tibial length discrepancy (TLD) is an anatomical leg length discrepancy in which tibia length differs in the same individual. Current literature has not documented the TLD as the source of discrepancy for studying the biomechanics of walking. Instead of TLD studies have considered the total leg length discrepancy for studying the biomechanics of walking.

Objective: The objective of the study was to investigate the motion of the pelvis in the frontal plane during walking with various degrees of TLD.

Settings and Design: Musculoskeletal modelling

Material and Methods: The study used the Stanford-based software (Opensim) in which several levels of TLD were manipulated to a generic musculoskeletal model of gait and subsequently the simulations were carried out using the inverse kinematics tool. A data set of the pelvic lists during a complete gait cycle was generated which was exported to the database for statistical operations.

Statistical Analysis Used: Mann Whitney's U test for independent samples was used to test the difference between the groups with Tibial Length Discrepancy less than 2% (n=8) and TLD more than 2% (n=8).

Results: The Pelvic list was significant (p<.000) between the two groups regarding variables namely RHS, LTO, LHS, RTO, RHS1, LTO1, and LHS1. Furthermore, there was an increase in the pelvic list in the anticlockwise direction (negative side) for all the variables with the increase in the level of TLD.

Conclusions: With the increment in TLD the pelvis listed towards the shorter side of the leg persistently in the gait cycle.

The pelvis listed significantly in the group with TLD more than two per cent as compared to the group with TLD less than two per cent for all the selected variables namely right heel strike left toe-off, left heel strike, right heel strike, right heel strike1, left toe-off1 and left heel strike1.

Key Words: Biomechanics, Gait Analysis, Musculoskeletal Modeling, OpenSim, Pelvis Kinematics, Tibial Length Discrepancy

INTRODUCTION

Tibial length discrepancy (TLD) is a type of anatomical leg length discrepancy in which the length of the tibia differs from the tibia of another leg.[1] The difference in tibial length amounts to a discrepancy in the effective length of the whole leg which is generally called leg length discrepancy(LLD). Leg length discrepancy is common and can affect up to 70% of the population with varying degrees of discrepancy.[2,3] There is enough evidence that LLD can develop deviant patterns during gait which are known to be the underlying causes of various musculoskeletal problems.[4,5,6]

Leg length discrepancy has been extensively studied during gait with a focus to understand the pathomechanics of the condition. The majority of the studies have investigated the condition by inducing a heel lift or an insole to acutely simulate leg length discrepancy(LLD) with lower limb kinematics and kinetics being the most sought out.[7-15] However very little attention has been put to understand the kinematics of the pelvis.

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ISSN: 2231-2196 (Print) **ISSN:** 0975-5241 (Online)

Received: 13.01.2021 **Revised:** 15.02.2021 **Accepted:** 27.03.2021 **Published:** 10.08.2021

The pelvic list has been reported to be a common strategy in subjects with LLD. During static standing, it was found that LLD caused significant pelvic obliquity.[16] However during walking the dynamics of pelvis kinematics get increasingly complex with the literature providing contradictory findings. Furthermore, the studies that have looked at the pelvis motion of LLD have shown no regard to whether the discrepancy lies in tibial length or femoral length.[17,18] Thus a comprehensive understanding of the pelvic list is needed to clearly understand how TLD affects the biomechanics of a person during gait.

We took an alternative approach in this study by adopting musculoskeletal modelling using a Stanford-based software program (OpenSim). The musculoskeletal modelling provides the flexibility of manipulating the length of the bones and thus enables us to study the effect of TLD on the kinematics of the human body during gait, whilst also controlling for the individual differences.

MATERIAL AND METHODS

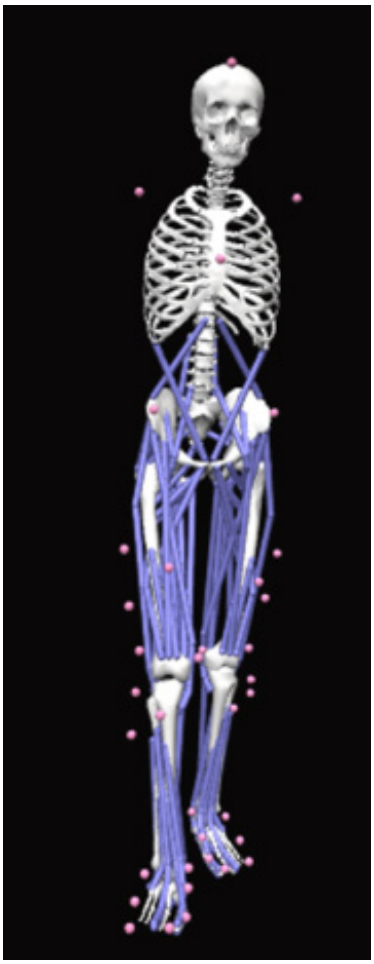

Figure 1: View of the 2392 Gait Model in OpenSim

The simulations were carried out in Opensim (version 4.1) software program. The tibia length was manipulated in the 2392 model with 0.25 percentage increments to produce a total of 16 levels of TLD (Fig.1). The "inverse kinematic" tool was used to generate the plot for the pelvic list for the selected levels of TLD during a gait simulation.

Statistical Analysis

The Mann-Whitney's U for independent samples was used to test the difference between the two groups (n=16) of data which were produced by splitting the data set at the median. The value $p<0.05$ was taken for testing the hypothesis. All the statistical operations were performed in IBM SPSS.

RESULTS

Figure-2 displays that the pelvic list pattern through the gait cycle remains similar however, with increments in TLD there is a persistent listing towards the shorter side (negative side). The figure is complemented by a depiction of the pelvis at various gait events during normal gait (without TLD) showing a subtle list at right heel strike (+) and left heel strike (-). Figure-3 shows as the level of TLD increases the pelvic lists towards the negative side (left side) for all the selected variables (Table 1).

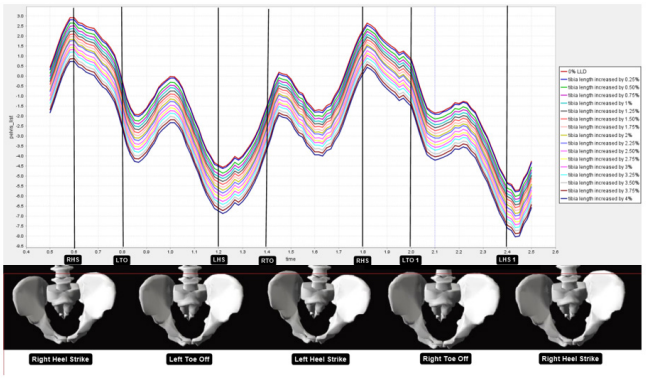

Figure 2: Pelvic List Plotted against Time for various Levels of Tibial Length Discrepancy during a Gait Cycle Note: RHS stands for right heel strike; LTO stands for left toe-off; LHS stands for left heel strike; RTO stands for right toe-off. The pelvic list occurs about the x-axis (anterior-posterior axis) of the pelvis with listing to the right being positive (+) and listing to the left being negative (-).

Table 1: Data Set of Pelvic List at Various Levels of Tibial Length Discrepancy for Various Gait Events

S. no	Gait Events → Level of LLD (%) ↓	Right Heel Strike	Left Toe Off	Left Heel Strike	Right Toe Off	Right Heel Strike	Left Toe Off	Left Heel Strike
1	0	2.92	-0.27	-4.46	-1.5	2.3	0.85	-5.33
2	0.25	2.82	-0.36	-4.53	-1.57	2.2	0.76	-5.39
3	0.50	2.65	-0.57	-4.75	-1.75	2.03	0.55	-5.6
4	0.75	2.51	-0.72	-4.89	-1.9	1.89	0.4	-5.76
5	1	2.38	-0.87	-5.03	-2.04	1.75	0.25	-5.9
6	1.25	2.24	-1.02	-5.17	-2.17	1.62	0.1	-6.03
7	1.50	2.11	-1.16	-5.31	-2.31	1.48	-0.04	-6.18
8	1.75	1.97	-1.31	-5.46	-2.43	1.35	-0.19	-6.32
9	2	1.83	-1.45	-5.6	-2.56	1.21	-0.33	-6.45
10	2.25	1.76	-1.55	-5.74	-2.66	1.14	-0.43	-6.59
11	2.50	1.56	-1.76	-5.89	-2.86	0.93	-0.64	-6.76
12	2.75	1.43	-1.89	-6.03	-2.98	0.81	-0.77	-6.9
13	3	1.34	-2.02	-6.18	-3.1	0.71	-0.89	-7.04
14	3.25	1.2	-2.16	-6.32	-3.23	0.57	-1.04	-7.18
15	3.50	1.01	-2.35	-6.47	-3.41	0.38	-1.23	-7.32
16	3.75	0.87	-2.5	-6.61	-3.55	0.25	-1.38	-7.46
17	4	0.73	-2.66	-6.76	-3.69	0.1	-1.53	-7.61

Note: Values are rounded to two digits after decimal

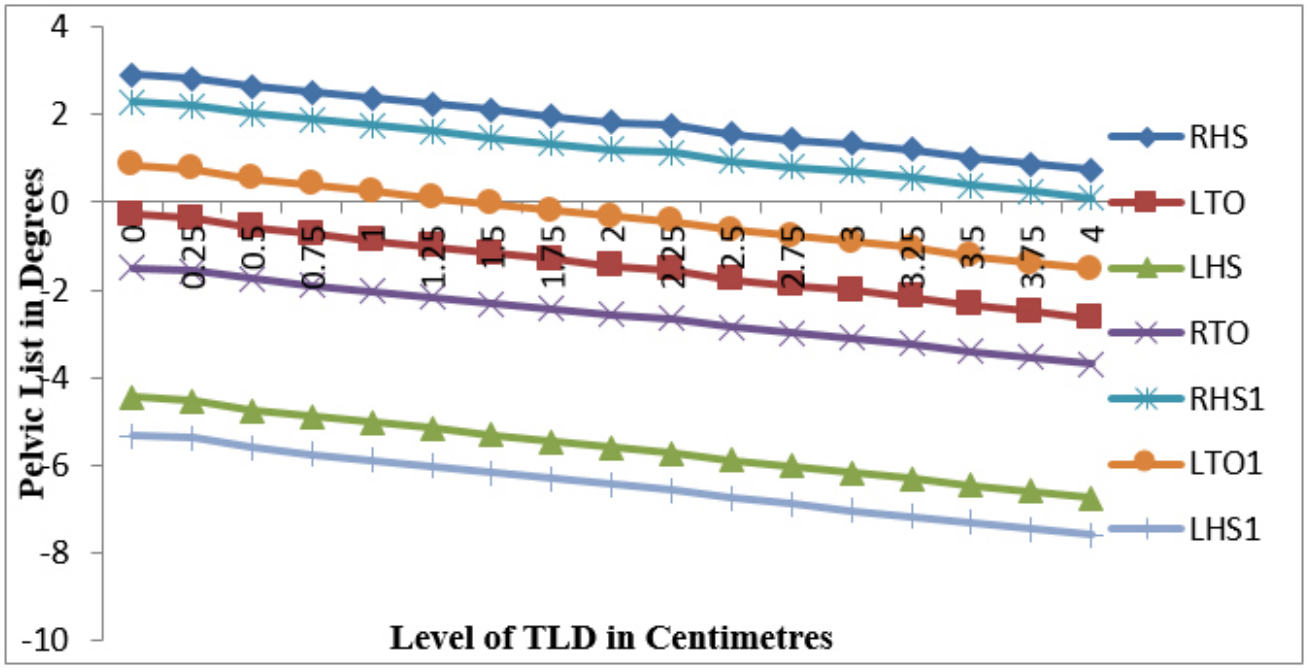

Figure 3: Pelvic List (y-axis) Plotted against Level of FLD (x-axis) for various Gait Events.

Table 2: Descriptive Statistics of Pelvis List During Various Events of Gait

Gait Events	RHS		LTO		LHS		RTO		RHS1		LTO1		LHS1	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mean	2.45	1.24	-0.79	-2.11	-4.95	-6.25	-1.96	-3.19	1.83	0.61	0.36	-0.99	-5.81	-7.11
Median	2.45	1.27	-0.8	-2.09	-4.96	-6.25	-1.97	-3.17	1.82	0.64	0.33	-0.97	-5.83	-7.11
SD	0.34	0.35	0.37	0.38	0.36	0.36	0.34	0.35	0.34	0.35	0.37	0.38	0.36	0.35
Range	0.95	1.03	1.04	1.11	1	1.02	0.93	1.03	0.95	1.04	1.04	1.1	0.99	1.02
Min.	1.97	0.73	-1.31	-2.66	-5.46	-6.76	-2.43	-3.69	1.35	0.1	-0.19	-1.53	-6.32	-7.61
Max	2.92	1.76	-0.27	-1.55	-4.46	-5.74	-1.5	-2.66	2.3	1.14	0.85	-0.43	-5.33	-6.59

Note: A is the group with TLD less than 2 % and B is the group with TLD of more than 2%

Table 3: Effect of TLD level on Various Gait Variables and their P-values

Variable	TLD less than 2%	TLD more than 2%	p-value
Right Heel Strike	2.45	1.27	0.000*
Left Toe Off	-0.8	-2.09	0.000*
Left Heel Strike	-4.96	-6.25	0.000*
Right Toe Off	-1.97	-3.17	0.000*
Right Heel Strike 1	1.82	0.64	0.000*
Left Toe Off 1	0.33	-0.97	0.000*
Left Heel Strike 1	-5.83	-7.11	0.000*

Significant difference at p<0.05; * means p-value is significant

Pelvic list in the group with TLD less than 2% (Mdn=2.45) was significantly different than the group with TLD more than 2% (Mdn=1.27) for the variable RHS, U=.000, z=-3.361, p<.000. In regard to the variable LTO the group with TLD less than 2% (Mdn=-0.8) was significantly different than the group with TLD of more than 2%(Mdn=-2.09), U=.000, z=-3.361, p<.000. For the variable LHS the group with TLD less than 2% (Mdn=-4.96) was also significantly different than the group with TLD of more than 2% (Mdn=-6.25), U=.000, z=-3.361, p<.000. The variable RTO was significantly different for the two groups of TLD less than 2% (Mdn=-1.97) and TLD more than 2%(-3.17), U=.000, z=-3.361, p<.000. For the variable RHS1 the test showed a significant difference between TLD less than 2% (Mdn=1.82) and TLD more than 2%(Mdn=-0.97), U=.000, z=-3.361, p<.000.Regarding the variable LTO1, the group with TLD less than 2% (Mdn=0.33) was significantly different than the group with TLD of more than 2% (Mdn=-2.44), U=.000, z=-3.361, p<.000 (Table 2 and 3). Finally, the variable LHS1 was also significantly different for the groups TLD less than 2% (Mdn=-5.83) and TLD more than 2% (Mdn=-7.11), U=.000, z=-3.361, p<.000.

DISCUSSION

In this study, we manipulated TLD through various levels to a generic model of gait and performed the inverse kinematics in Opensim intending to understand how TLD affects the motion of the pelvis in the frontal plane during a gait cycle. We observed that with the increment in TLD the pelvis listed towards the shorter side of the leg persistently throughout the gait cycle.

We also found that the pelvis listed significantly in the group with TLD more than 2% when compared to the group with TLD less than 2%. Our finding was supported by various studies that reported increased pelvic obliquity in their subjects with LLD during walking. [11,13]

LLD is almost always concomitant with lumbar bending towards the shorter side in the frontal plane [6,19] it is intuitive to think that this is due to the pelvic drop on the shorter side, causing the lumbar to adjust to the unlevel pelvis.

Furthermore, the pelvic list or drop on the shorter side could be the reason why there is decreased hip adduction and consequently decreased hip adduction moment on the longer side.[10,20] It is intriguing since this compensatory strategy (decreased hip adduction) prevents the femoral head from exposing itself through stance which could potentially contribute to early osteoarthritis.[21] Therefore, it opens up a new avenue of research in which how decreased hip adduction is coordinated by our neuromuscular system should be sought.

CONCLUSIONS

1. With the increment in TLD the pelvis listed towards the shorter side of the leg persistently in the gait cycle
2. The pelvis listed significantly in the group with TLD more than two per cent as compared to the group with TLD less than two per cent for all the selected variables namely right heel strike left toe-off, left heel strike, right heel strike, right heel strike1, left toe-off1 and left heel strike1.

ACKNOWLEDGEMENT

The authors would like to thank the OpenSim developers for making the software open source, thus enabling countless studies which would otherwise not be possible including this one.

Conflict of interest: Nil

Source of Funding: Nil

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