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Original Article

Pressure distribution under the contralateral limb in Charcot arthropathy with different walking speeds

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ABSTRACT

Background: The total contact cast has been recognized as the "gold standard" for treatment of Charcot neuro-osteoarthropathy (CN). However, removable cast walkers (RCWs) became an alternative option especially after resolution of the acute stage. RCWs with an elevated sole construction often induce leg length discrepancy (LLD) that could significantly affects plantar pressure (PP) distribution in diabetic patients with neuropathy.
Aim: To study the additional effect of walking speed on PP abnormalities induced by LLD.
Method: The study included 16 patients with diabetes (59 ± 8.8 years; 8 men and 8 women), with unilateral CN offloaded by RCW. In-shoe PP distribution was measured using F-scan (Tekscan Inc.), whilst patients walked at their normal speed (53 ± 4 steps/min), versus short slow steps (24 ± 3/min) under the two walking conditions: (1) neglected LLD, and (2) corrected LLD.
Results: The greatest reduction in PP was seen during reduction of walking speed, with corrected LLD, followed by corrected LLD with normal walking speed, followed by neglected LLD with slowing of walking speed. The highest PP was found when the patient remain on their normal walking speed and LLD was neglected.
Conclusion: The contralateral foot of CN offloaded with RCW, is subjected to high pressure loads beneath the hallux, 1st, 2nd, 3rd, and 5th metatarsal heads. As such, care should be taken not only to avoid minor LLD, but to also advise the patient to practice short slow steps while walking, so that pressure overload on contralateral limb and its possible contribution to the development of bilateral Charcot, could be minimized.

1. Introduction

Pressure overload is likely to be one of the precipitating factors that can lead to Charcot joints. That is why offloading remains the mainstays of therapy, and is the most important management in the acute stages [1]. Armstrong and Lavery found that the peak plantar pressures were significantly higher in the patients who had acute neuro-osteoarthropathy (CN), and those who had neuropathic ulceration compared to those who had neuropathy without ulceration [2].

The total contact cast has been recognized as the "gold standard" for treatment of Charcot neuro-osteoarthropathy (CN) [3–6]. However, removable cast walkers (RCWs) were found to be the most effective of the removable devices [7], they became an alternative option especially after resolution of the acute stage [8–10]. Armstrong et al. showed that bilateral Charcot is estimated to be approximately 9% [11]. Another study reported that approximately 8 out of 140 patients with unilateral CN (5.7%), who were offloaded with RCWs, developed CN in the contralateral foot within one year post follow up period [12].

RCWs with an elevated sole construction often induce leg length discrepancy (LLD). Nahas et al. [13] reported that minor LLD could significantly affects plantar pressure distribution in diabetic patients with neuropathy. The short leg of patients with neuropathic diabetic foot, was subjected to higher pressure load beneath the total foot, midfoot and 2nd, 3rd, 4th and 5th metatarsal heads; inevitably exposing the shorter foot to risk. Therefore, care should be taken to avoid minor LLD induced by offloading devices [13]. White et al. [14] and O'Toole et al. [15], also found that the shorter limb sustained higher loading patterns.

The walking speed can also affect the pressure applied to the feet [16,17]. Segal et al. [18] and Warren et al. [19], found that walking speed is positively associated with peak plantar pressure in people with diabetes. The peak plantar pressures are considerably reduced during a shuffling gait with short steps [16,17] Brand attributed that to the

Abbreviations: CN, Charcot neuro-osteoarthropathy; LLD, leg length discrepancy; NLLD, nullified leg length discrepancy; RCWs, removable cast walkers

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Fig. 1. Neglected leg length discrepancy.

Fig. 2. Nullified leg length discrepancy.

Table 1
Pressure time integral using patient selected and short-step gait strategies.

Pressure time integral (kPa s)	LLD, normal gait Median (range)	LLD, short slow steps Median (range)	p Value
Hallux	42.7 (0–179.6)	26.4 (13.1–97.4)	$p < 0.05$
1st MTH	94.7 (59.3–135.8)	59.3 (53.3–128)	$p < 0.05$
2nd MTH	119.2(73.3–160.8)	83 (56.7–91.5)	$p < 0.03$
3rd MTH	111.1(85.3–144.8)	83.2 (51–89.5)	$p < 0.03$
4th MTH	97.3 (58.7–139.8)	91.7 (39.7–109.6)	$p = 0.11$
5th MTH	82.2 (67.6–697)	71.3 (24.4–343.6)	$p < 0.05$
Mid-foot	83.1 (61.3–133.3)	44.8 (35.6–108.1)	$p < 0.05$
Heel	318 (189.8–374.6)	188.4 (110.8–407.7)	$p = 0.11$
2nd toe	93.2 (0–182.5)	36.3 (16.6–163.9)	$p = 0.17$
3rd toe	88 (0–188.9)	54.6 (11.5–216.8)	$p = 0.75$
4th and 5th toes	68.3 (1.3–1045.2)	32.5 (15.8–600.9)	$p = 0.11$

LLD: leg length discrepancy, MTHs: metatarsal head.

increase in the period of foot being flat, and the area of weight bearing during the shuffling gait with short steps [16,17]. Walking and running speed were significantly associated with high plantar pressure, at the heel and metatarsal heads regions with the increase of velocity [20].

The aim of this work was to study the additional effect of walking speed on plantar pressure abnormalities induced by LLD.

2. Subjects and method

The study included 16 people with diabetes (8 men and 8 women), attending Mansoura diabetic foot clinic in Egypt, with unilateral chronic CN offloaded by RCWs. This took place in between May 2013 and January 2014. Two people with forefoot, 11 with midfoot rocker bottom deformities, 2 cases involving the rearfoot, and 1 involving the ankle were included. They were classified according to Brodsky anatomic classification [21] with Trepman et al. modifications [22]. Their diagnosis was on clinical bases, and was supported by radiological images. They have been offloaded by total contact cast till resolution of the acute stage, then were shifted to RCW. They used the RCW for a duration ranging from 8 to 29 months. All removable casts had the same sole design (i.e rocker bottom, outsole thickness). At the time of inclusion the contralateral foot was free from ulcers, amputations or deformities. In-shoe plantar pressure distribution was measured using tethered F-scan (Tekscan Inc.), a computerized insole sensor system with 960 pressure-sensing areas, distributed as 4 sensors/cm^2. The F-Scan insoles, were measured for each individual's shoe of the contralateral foot of Charcot according to manufacturer's guidelines. Insole calibration was performed once for each subject. As per manufacturer's guidelines, subjects were asked to walk a minimum of 20 steps to allow adjustment of the insole to the shoe conditions. The same insole was then used for each individual's walking trials. Plantar pressure data was collected over 10 m (double way 5 m length room area with a hard surface). Standardized instructions were given to each patient by the same educator. The pressure time integral under all metatarsals, hallux, lesser toes, midfoot and heel were compared, while patients walked at their normal walking speed (53 ± 4 steps/min), and the short slow steps (24 ± 3 steps/min) while looking straight ahead after training the patients over a 20 min period, to maintain this cadence and become comfortable with the procedure. Results were gathered under two walking conditions; 1 — LLD was neglected (patient own shoe) (Fig. 1), 2 — LLD was nullified by increasing the height of the outsole of the contralateral foot to the same degree of the RCW (Fig. 2). Pressure time integral was used as it express the dynamic plantar loading in the diabetic foot [23]. The study design was approved by the Institutional research board of the faculty of medicine, no. R/15.09.24, statements of consent to participate and publish from the participants are available.

2.1. Sample size calculation

Sample size was calculated using an online calculator [24], assuming confidence of 80% and probability of 11%, which is the average peak plantar pressure reduction found with Rosenbaum et al. [25] The sample size was calculated to be 14 cases.

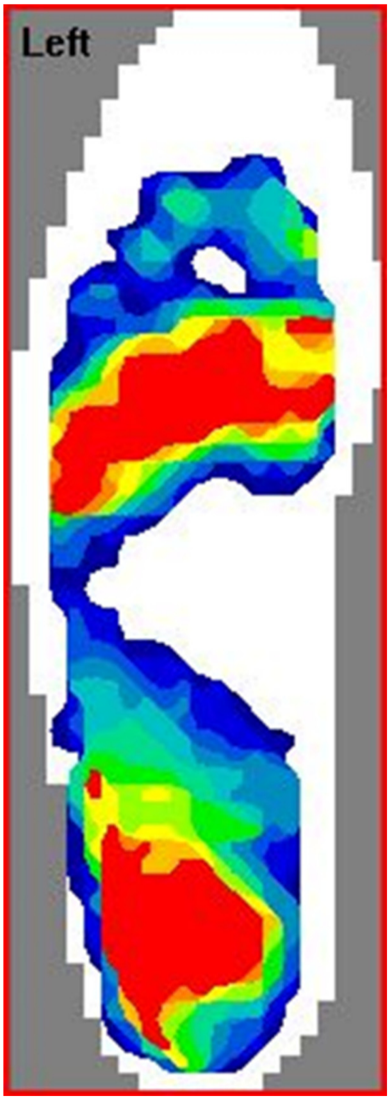

Fig. 3. Plantar pressure for neglected leg length discrepancy with normal gait.

2.2. Statistical analysis

Plantar pressure data were collected using 2 step protocol using Wilcoxon’s matched pairs signed-rank test with exclusion of the 1st and the last stances

“Statistical significance was defined at the 5% ($p \leq 0.05$) level.”

3. Results

Sixteen patients with diabetes (59 ± 8.8 years; 8 males), their mean body mass indices were (32 ± 2), mean duration of diabetes was 17.1 ± 6.9 years., mean duration of Charcot 20.4 ± 12.1 months.

When LLD was neglected, pressure time integral was significantly increased beneath hallux, 1st, 2nd, 3rd, 5th metatarsal heads and midfoot during normal gait versus short slow steps {42.7(0–179.6), 94.7(59.3–135.8), 119.2(73.3–160.8), 111.1(85.3–144.8), 82.2(67.6–697), 83.1(61.3–133.3) KPa s, respectively} versus {26.4(13.1–97.4), 59.3(53.3–128), 83(56.7–91.5), 83.2(51–89.5) 71.3(24.4–343.6), 44.8(35.6–108.1) kPa s, respectively} (Table 1, Figs. 3 and 4)

When LLD was corrected pressure time integral was significantly increased beneath hallux, 1st, 2nd, 3rd and 5th metatarsal heads, during patient’s normal gait versus short slow steps {91(40.5–147.2), 72(40.6–182.6), 104 (59.6–187.4), 96(61–141), 66.5(41.5–227.9)

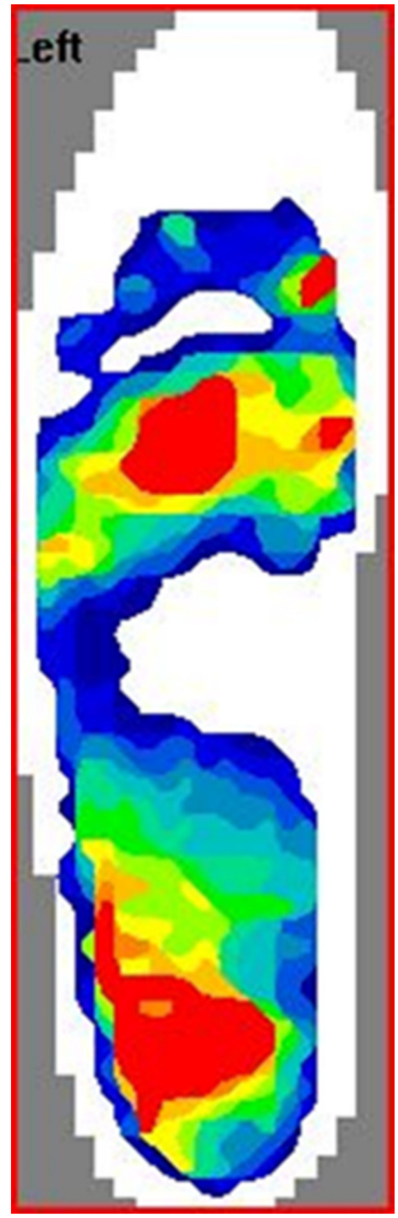

Fig. 4. Plantar pressure for neglected leg length discrepancy with short slow steps.

Table 2
Pressure time integral with nullified leg length discrepancy using patient selected and short-step gait strategies.

Pressure time integral (kPa s)	NLLD, normal gait	NLLD, short steps	p Value
	Median (range)	Median (range)	
Hallux	91 (40.5–147.2)	47.3 (36–110)	$p < 0.05$
1st MTH	72 (40.6–182.6)	59.8 (15.6–156.6)	$p < 0.05$
2nd MTH	104 (59.6–187.4)	77.2 (27.2–147.3)	$p < 0.05$
3rd MTH	96 (61–141)	72.9 (32.6–130.8)	$p < 0.05$
4th MTH	80.5 (55.6–182)	62.7 (38.9–97.3)	$p = 0.5$
5th MTH	66.5 (41.5–227.9)	58.7 (26.4–67.6)	$p < 0.05$
Midfoot	75.5 (33.5–178.9)	73.8 (34.7–83.9)	$p = 0.09$
Heel	258.4 (133.3–354.9)	218.8 (148.4–333.6)	$p = 0.39$
2nd toe	48.4 (7.3–174.7)	43.3 (17.2–66)	$p = 0.7$
3rd toe	69.8 (0–169)	57.6 (19.6–150.7)	$p = 0.8$
4th and 5th toes	104.2 (0–185)	29 (0.1–171.2)	$p = 0.5$

NLLD: nullified leg length discrepancy, MTH: metatarsal head.

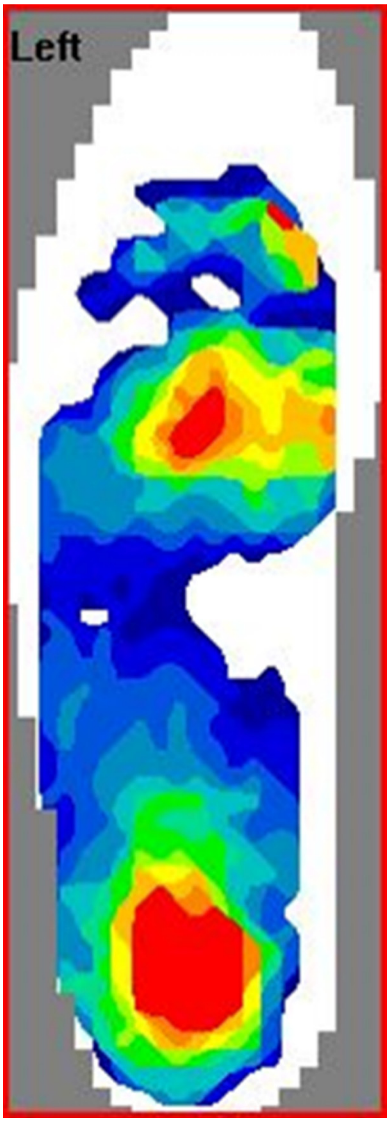

Fig. 5. Plantar pressure for nullified leg length discrepancy with normal gait.

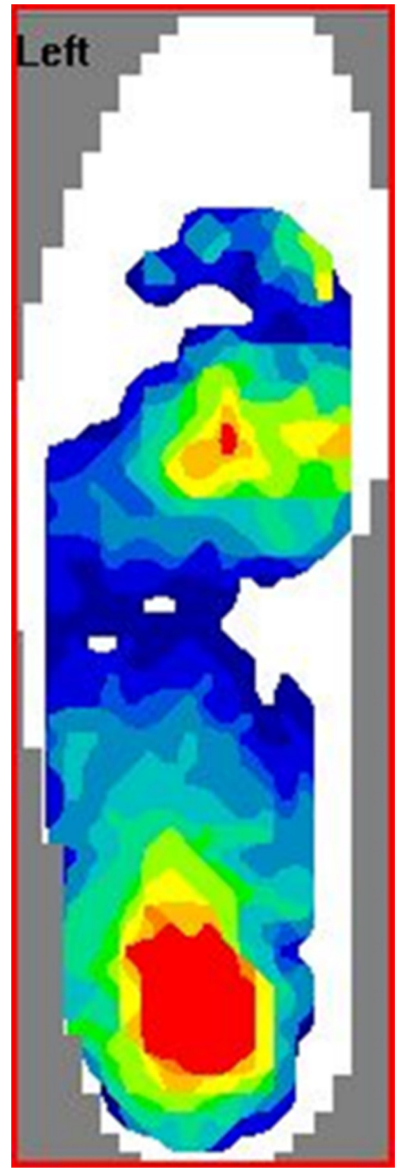

Fig. 6. Plantar pressure for nullified leg length discrepancy with short slow steps.

kPa s, respectively}versus {(47.3(36–110), 59.8(15.6–156.6), 77.2(27.2–147.3), 72.9(32.6–130.8), 58.7 (26.4–67.6) kPa s, respectively} (Table 2, Figs. 5 and 6)

The pressure time integral beneath the lesser toes, 4th metatarsal head and the heel in both conditions, and midfoot in case of NLLD were higher with the patient normal gait versus their short, slow steps; but the results were statistically insignificant.

4. Discussion

The results of this study showed that reducing walking speed significantly decrease plantar pressure beneath the contralateral foot of Charcot neuro-osteoarthropathy patients. The effect exist even after correction of LLD but become more manifest when LLD was neglected. Prior data on leg length inequality and its impact on foot pressure, was limited. Nahas et al. [13] previously studied the effects of simulated minor LLD on foot pressure. They tested diabetic patients with neuropathy under three different conditions: no LLD, 20 mm long leg, and 20 mm short leg. These three conditions were compared in a randomized, single-blinded crossover design, and concluded that the short legs of patients with neuropathic diabetic foot would be subjected to a higher pressure load, inevitably exposing the short foot to risk.

Previous studies also indicated that the reduction of walking speed in normal people, leads to a decrease in the peak pressure on most of the areas of the plantar surface of the foot [26]. During weight-bearing activities, such as standing and walking, the plantar surface of the foot is exposed to ground reaction forces. During standing, this force equals that of the body weight, with each foot bearing ~50% of body weight distributed over the plantar surface with higher pressure at the heel, rather than at the forefoot [27]. During walking, the stress applied to the feet is much higher than when standing [28]. At a self-selected walking speed, these vertical peaks are approximately 1.2 times body weight, which increase with fast walking to 1.5 times body weight [29].

Winter and Sienko [30] have also shown that at a walking speed of nearly 0.5 m/s, the vertical force will be equal to body weight, rather than higher. Rosenbaum et al. [25], also demonstrated that when walking speed is reduced from 1.19 m/s (normal) to 0.83 m/s (slow), peak plantar pressure is reduced at the hallux (11%), at the medial forefoot (9%–11%), and at the heel (5%–18%). Highest peak pressure normally occurs over the medial metatarsophalangeal region, and over the big toe [31] that could be deleterious in patients with diabetes due to loss of protective sensation.

The results were compared with the plantar pressure, while the

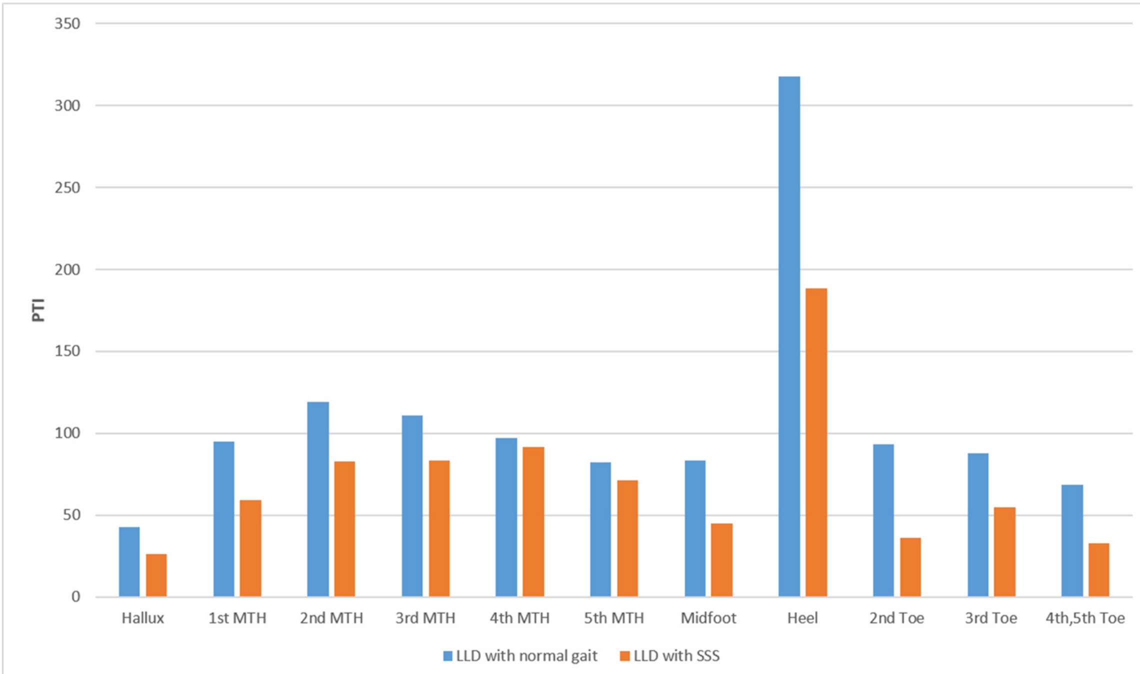

Fig. 7. Comparing the median pressure time integral in neglected leg length discrepancy with normal gait versus short slow steps.

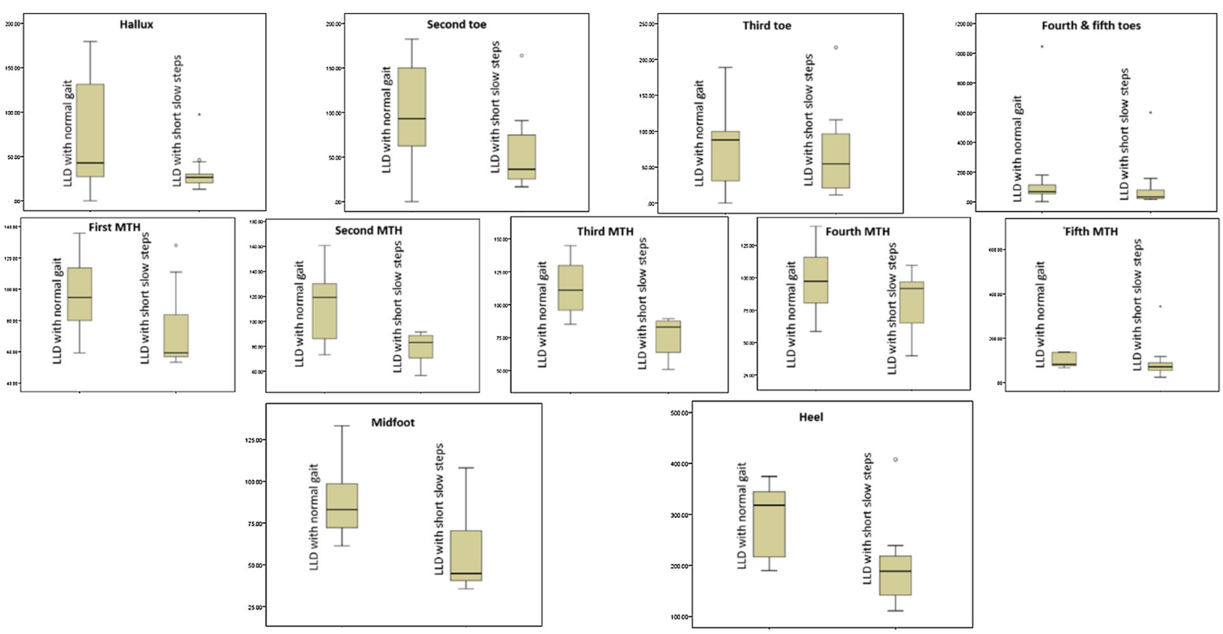

Fig. 8. Boxplots showing the pressure time integrals in neglected leg length discrepancy with normal gait and short slow steps.

patient had normal walking speed in both walking conditions (LLD and NLLD), to see whether the reduction of the walking speed would be reflected on reduction of the plantar pressure; as is the case in people without these medical conditions. Although they are known and work well in normal subjects, but no study in the literature was done to see whether it works well in Charcot patients with RCW or not.

It was found, that the best results were seen in the case of the reduction of walking speed with the nullification of LLD. The next best results were found in NLLD with normal walking speeds, and neglected LLD with slowing of walking speed, respectively. The highest plantar pressure was found in the case of neglected LLD, with normal walking speeds — as shown in Figs. 7–10.

5. Conclusion

The contralateral foot of CN offloaded with RCW, is subjected to high pressure loads beneath the hallux, 1st, 2nd, 3rd, and 5th metatarsal heads. As such, care should be taken not only to avoid minor LLD, but to also advise the patient to practice short slow steps while walking, so that pressure overload on contralateral limb and its possible contribution to the development of bilateral Charcot, could be minimized.

6. Limitation of the study

Small sample size and lack of long term follow up. While 16 subjects is well within the bounds of robustness for repeated measurement

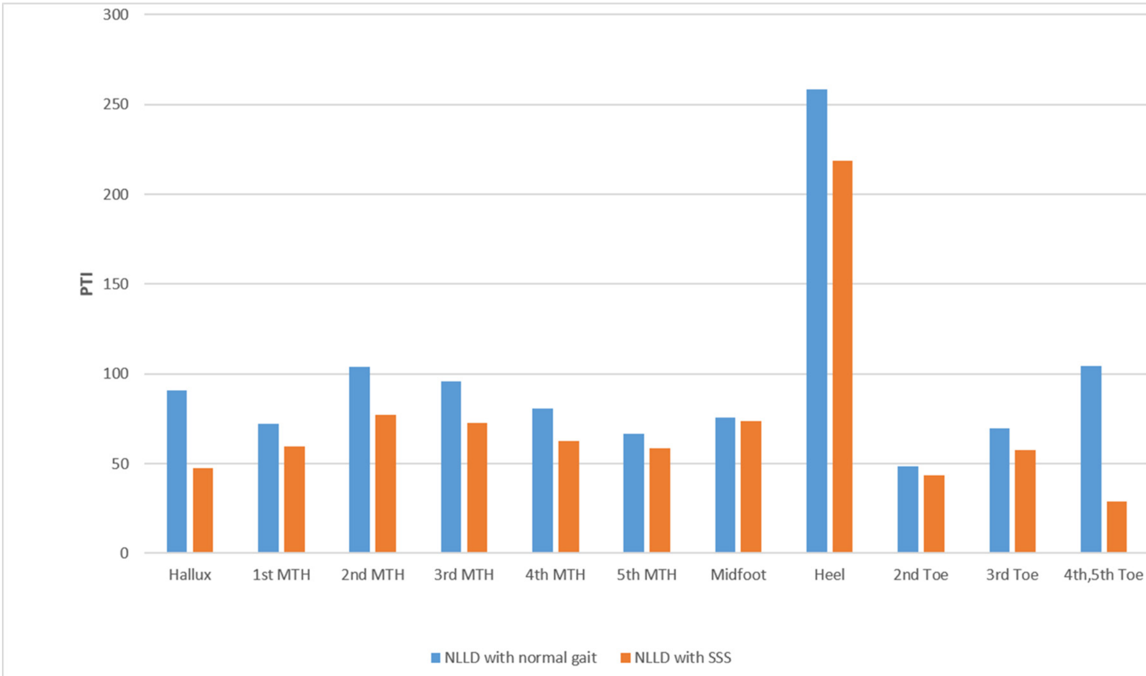

Fig. 9. Comparing the median pressure time integral in nullified leg length discrepancy with normal gait versus short slow steps.

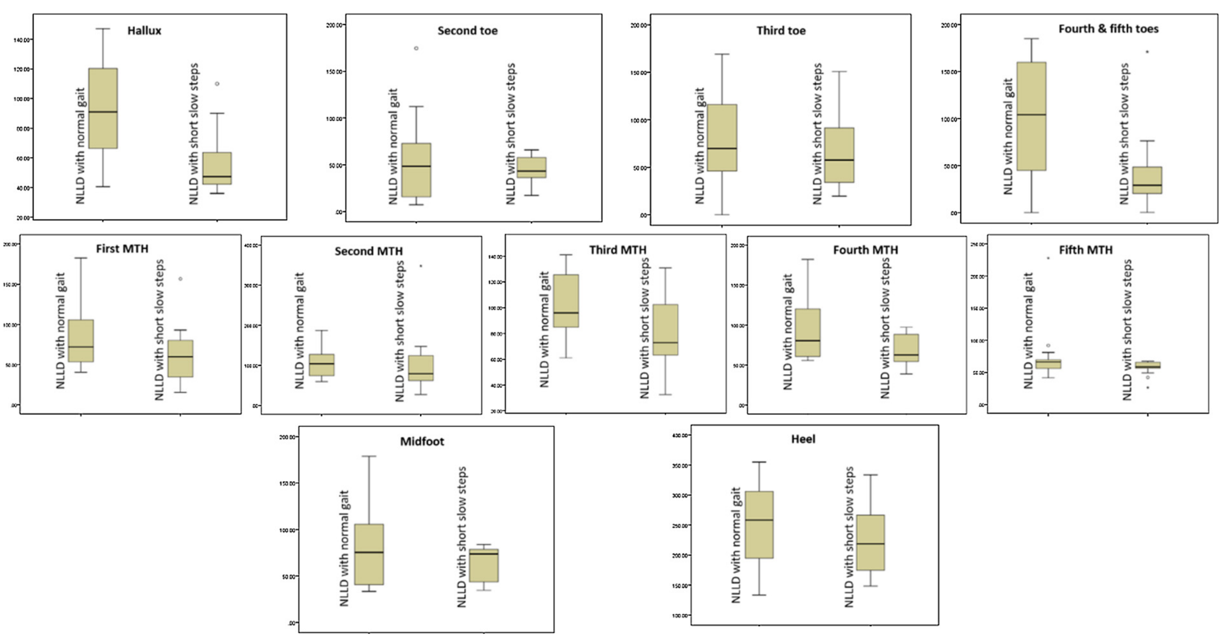

Fig. 10. Boxplots showing the pressure time integrals in nullified leg length discrepancy with normal gait and short slow steps.

design for gait laboratory studies (CITE), we prefer to include more people. This study was not designed to follow subjects for a long period of time. It is entirely possible that people may not be able to follow a short gait strategy over a prolonged time. Further work in this area is necessary. It is believed that advances in wearable, and phone-based accelerometry, might make this type of gait variability analysis and patient feedback easier in the near future.

7. Brief summary

- It was attempted to see the effects of the reduction of walking speed on the plantar pressure of the contralateral foot of Charcot foot patients offloaded with removable cast walkers in 2 scenarios, before and after nullification of leg length discrepancy.
- It was found that the best results were seen in the case of the reduction of walking speed, with nullification of LLD. The next best results were found in NLLD with normal walking speed, and neglected LLD with slowing of walking speed, respectively. The highest plantar pressure was found in the case of neglected LLD with normal walking speed.

Disclosures

The manuscript is original, has not been submitted or published in whole or part elsewhere.

Funding resources

No funding resources.

Declaration of interest

The authors have nothing to declare.

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