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**ARTICLE**

# Heel lift improves walking ability of persons with traumatic cauda equina syndrome—a pilot experimental study

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## Abstract

**Study design** Non-randomized within-subject experimental study.

**Objective** To determine whether the addition of the 1 cm heel lift to the footwear improves the walking ability of the persons with Cauda Equina Syndrome (CES).

**Setting** Department of Physical Medicine and Rehabilitation, Christian Medical College, India.

**Methods** Fourteen people with bilateral plantar flexor weakness following traumatic CES (mean age 43.7 years) were recruited for the study. Their walking speed, stride length, cadence, and time taken to complete Timed Up and Go (TUG) were measured using footwear with back straps. Then, the 1 cm heel lift was attached to the sole of the footwear. After sufficient practice, all the parameters were reassessed to find out the effectiveness of the heel lift.

**Results** With the 1 cm heel lift, the participants walked 0.13 m/s (95% CI, 0.08–0.17) faster than their regular footwear. They were able to complete the TUG test 2.6 s (95% CI, 1.4–3.7) earlier than before. There was an increase of 5.2 in. in stride length (95% CI, 2.9–9) and an eight steps increase in cadence (95% CI, 4.9–11.3) observed after the heel lift.

**Conclusions** This pilot study has demonstrated that addition of 1 cm heel may be effective in improving the walking performance of persons with Cauda Equina Syndrome. Future studies should investigate the kinetic and kinematic changes of this modification using a randomized controlled trial study design.

## Introduction

Cauda Equina Syndrome (CES) is an incomplete injury to a number of nerve roots at the lower end of the spinal cord. Though it is considered as a peripheral nerve injury, the possibility of full reinnervation is limited as the distance between the injury and the point of innervation is longer, and axonal regeneration is blocked by glial collagen scarring [1, 2].

Sacral roots are the most commonly involved, which lead to lower motor weakness of the bilateral gastrocnemius, hamstring, and gluteal muscles. Though the ability to walk independently is not lost, their gait is hampered by excessive ankle dorsiflexion and knee flexion during stance phase, and reduced ankle push off at early pre-swing phase [3–5].

Lack of eccentric contraction of ankle plantar flexor causes ground reaction force vector (GRFV) to pass behind the knee, thus creating a knee flexion moment with excess tibial motion over talus during mid to late stance. To prevent knee buckling, increased quadriceps contraction is needed, which may lead to stiff-knee gait [6] and reduced gait speed [7]. Excessive dorsiflexion allows the load to transfer through the heel, causing calcaneal gait pattern, which is one of the hallmarks of CES [8].

Gastrocnemius muscles are important for support and forward progression of the body during the gait cycle [9]. Gastrocnemius muscle weakness is an important reason for imbalance, due to the inability to counter dorsiflexor moment while standing [10]. The study by Lencioni et al. [11] and Rossor et al. [12] identified that plantar flexor weakness is a major cause for the imbalance in patients with Charcot-Marrie-Tooth disease similarly to CES.

Restraining excessive tibial movement over the talus will enable the center of pressure to move forward along the

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long axis of the foot and reduce excessive knee flexion. This can be achieved by providing ankle-foot orthoses (AFOs) with an anterior stop set at 5° plantar flexion [13, 14]. The presence of 5° plantar flexion reduces the excessive knee flexion by change of the relative position of the knee center to the vertical component of the ground reactive force. Though the biomechanical advantages are identified for the use of AFOs for people with plantar flexor weakness, the availability, usability, and cosmetic appearance of the appliance limits its application.

In this paper, we described the use of a low heel lift as an alternative solution to improve walking ability of persons with CES. The low heel lift is found to alter the kinetics and kinematics of lower extremity in a positive way for people with neuromuscular conditions [15–17].

Thus, this study was initiated to identify the effectiveness of the 1 cm heel raise on walking performance of people with bilateral plantar flexor weakness following CES.

## Methods

A non-randomized within-subject experimental study was conducted in the Department of Physical Medicine & Rehabilitation, Christian Medical College, India. The trial was prospectively registered through Clinical Trial Registry (ID: CTRI/2019/01/017193).

### Participants

Fourteen patients with plantar flexor manual muscle testing (MMT) scores of <3 following traumatic CES were recruited for the study. Participants were included if they were able to walk independently (Walking Index Score for Spinal Cord Injury Version II level- 20). They also should have normal knee extensor and dorsiflexor strength along with <3 MMT score in plantar flexor, knee flexor, and hip extensor muscles. Patients were excluded if they had more than 2 years post injury ($n = 1$), calcaneal ulcers or neuropathic ankle joint ($n = 1$), severe dorsiflexor tightness and any premorbid or congenital lower limb deformities. The Institutional Review Board of Christian Medical College approved the study, and informed consent was obtained from all participants prior to their participation.

### Procedure

After the recruitment, all the participants were requested to use footwear with back straps for all the measurements (Fig. 1). The advantage of this footwear is that the straps around the ankle and the two dorsal straps provide better support & comfort for walking. They do not require conscious gripping as we do for slip-on model footwear. It is a
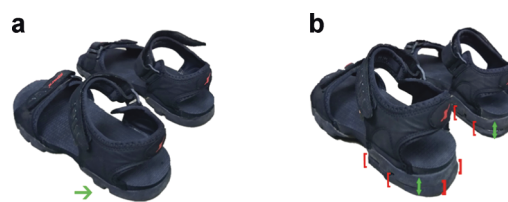
Fig. 1 Shows the sample of back strap footwear and heel lift used in this study. a Back strap footwear without heel lift. b Back strap footwear with 1 cm heel lift.

routine in our institution to suggest this model of footwear for all the patients with lower extremity muscle weakness to initiate gait training.

Their current functional mobility was measured using the Timed Up and Go (TUG) test. Participants were instructed to stand up from an armrest chair, walk around a cone that was located 3 m away from the chair, and return to sit down on the chair at a maximum and safe speed. The test recorded the time taken to complete the task and get back to the armrest chair [18]. The participants performed three trials and the average finding over the three trials was used for data analysis.

The walking speed was measured using the 10 Meter Walk Test (10MWT). The time taken to complete a 10 m flat corridor at their preferred walking speed was recorded [19]. The stride length was measured along with 10MWT by applying ink to the bottom of the footwear and using their resultant foot impressions.

Cadence was measured using a pedometer when they were made to walk on the 30 m corridor.

Once the baseline measurements recorded, their footwear was modified by attaching 1 cm heel lifts at the bottom. Subsequently, they were asked to walk with the modified footwear to get accustomed to the heel lift. All the mobility and gait parameters were repeated after 24 h of usage of the modified footwear.

### Statistical analysis

Group mean and standard deviations were calculated for descriptive data. Comparison of pre-and post-footwear modification measurements was analyzed using a paired 't' test. An alpha level of 0.05 (95% confidence interval) was adopted, and the analysis was performed using SPSS software version 23.0.

## Results

The study sample comprised fourteen adults ($n = 14$) with CES (12 male and 2 female) with an average age of 43.7 ($\pm9.5$) years (range of 30–58 years). The average time since injury was 11.7 ($\pm7.5$) months, and ranged from 2 month to

**Table 1** Shows the pre- and post-heel lift values of all the parameters along with demographical data.

| S:no | Age (years) | Gender | Time since injury (months) | Mode of injury | LEMS | Stride length (inches) | | Cadence (steps/min) | | 10 MWT (m/sec) | | TUG test (sec) | |
|------|-------------|--------|----------------------------|----------------|------|------|------|------|------|------|------|------|------|
| | | | | | | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 1 | 36 | F | 8 | RTA | 44 | 14 | 21 | 86 | 95 | 0.33 | 0.59 | 17.1 | 14.8 |
| 2 | 30 | M | 14 | Fall | 42 | 12 | 16 | 109 | 112 | 0.63 | 0.83 | 18.4 | 11.9 |
| 3 | 41 | M | 20 | Fall | 42 | 34 | 40 | 108 | 112 | 0.86 | 1.00 | 8.8 | 6.4 |
| 4 | 58 | M | 7 | RTA | 40 | 35 | 39 | 73 | 97 | 0.58 | 0.72 | 17.6 | 17.1 |
| 5 | 55 | M | 21 | Fall | 42 | 28 | 35 | 108 | 115 | 0.55 | 0.74 | 18.2 | 16.3 |
| 6 | 40 | M | 20 | Fall | 42 | 31 | 41 | 112 | 121 | 0.57 | 0.65 | 11.6 | 10.0 |
| 7 | 40 | M | 2 | Fall | 44 | 32 | 34 | 16 | 17 | 0.75 | 0.81 | 23.0 | 16.2 |
| 8 | 42 | M | 6 | RTA | 42 | 42 | 44 | 96 | 108 | 0.81 | 0.87 | 14.7 | 11.9 |
| 9 | 45 | M | 18 | RTA | 44 | 53 | 75 | 93 | 98 | 0.43 | 0.64 | 19.0 | 15.8 |
| 10 | 55 | F | 5 | Fall | 44 | 38 | 44 | 84 | 92 | 0.66 | 0.83 | 14.8 | 12.3 |
| 11 | 33 | M | 6 | RTA | 44 | 34 | 39 | 114 | 126 | 0.52 | 0.54 | 13.2 | 12.6 |
| 12 | 30 | M | 24 | Fall | 42 | 33 | 37 | 90 | 96 | 0.70 | 0.77 | 13.7 | 13.1 |
| 13 | 50 | M | 3 | Fall | 40 | 36 | 40 | 102 | 110 | 0.65 | 0.75 | 13.3 | 12.5 |
| 14 | 57 | M | 12 | Fall | 42 | 40 | 42 | 90 | 96 | 0.59 | 0.71 | 17.0 | 14.0 |

*LEMS* lower extremity muscle score, *10MWT* 10 meter walk test, *TUG* timed up and go test.
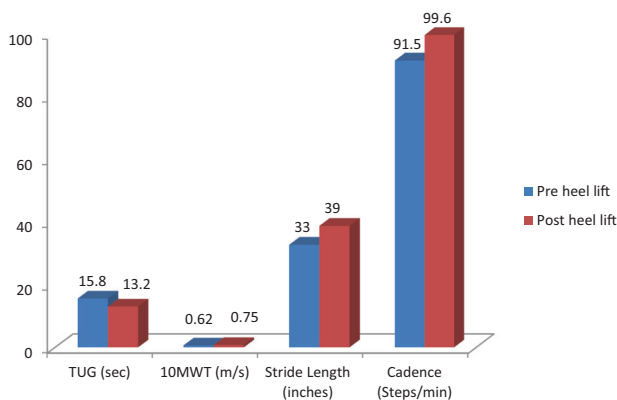


**Fig. 2** Shows comparison of pre- and post-heel lift values.

## Discussion

The present study investigated the impact of the 1 cm heel lift in improving walking ability of people with traumatic CES. All the measured gait parameters showed improvement after the heel lift.

Allowing the foot to be in plantar flexion with heel lifts limits the ankle range of motion in dorsiflexion direction, which restrains excessive ankle dorsiflexion, enables the center of pressure to move forward along the foot and reduces increased knee flexion [15]. Systematic review of Rabusin et al. [20] identified that low heel lift decreases maximum ankle dorsiflexion angle. This concept can be utilized for people with plantar flexor weakness where excessive dorsiflexion is a major reason for gait deviation. Heel lifts can also be detrimental if the lift is excessive [21].

Heel lifts position the ankle in more plantar flexion during mid stance to late stance [21]. The study by Johnson et al. [16] identified that walking in heel lifts results in the greatest increase in time to heel off compared with walking in shoes alone. When the heel height increases, the GRFV moves more anterior to the knee and ankle. This shift of GRFV minimizes the over-activity of quadriceps during mid to late stance and thereby avoids stiff-knee gait. The GRFV shift at the ankle helps to minimize the retropulsive movement. Subotnick [22] theorized that increased extension of the knee due to a short gastrocnemius-soleus muscle complex (which is achieved by heel lift in this study) may maintain the heel on the ground longer during the stance phase of gait by allowing continued forward progression of the body over the foot while the heel remains on the ground.

24 months. The common mode of injury was fall (64%) and other by the road traffic accident.

The mean lower extremity muscle score was 42.4 (±1.1), which was ranged between 40 and 44. The mean planar flexor muscle MMT score was 1.7 (±0.5) in the right leg and 1.6 (±0.5) in the left leg. Table 1 shows the individual participants' pre-and post-heel lift values along with demographical values.

The comparison of pre-and post-heel lift values showed a significant difference in all of the parameters (Fig. 2). With the 1 cm heel lift, the participants walked 0.13 m/s (95% CI, 0.08–0.17) faster than their regular footwear. There was an increase of 5.2 in. in stride length (95% CI, 2.9–9) and an eight steps increase in cadence (95% CI, 4.9–11.3) observed after the heel lift. They were able to complete the TUG test 2.6 s (95% CI, 1.4–3.7) earlier than before.

There are two critical factors for propulsive force generation: ankle moment and the position of the center of pressure relative to the body center of mass. The addition of heel lift shifts the line of gravity more anteriorly and creates a propulsive force to walk with greater speed and stability in comparison with no heel lift. A change in speed of 0.13 m/s is considered as a minimally clinically important difference in 10MWT for people with spinal cord injuries [23]. In our study, a mean difference of 0.13 m/s has been achieved after the heel lift, which may be considered as a meaningful change. Further, it is also a direct reflection of propulsive force increment.

Trailing Limb Angle (TLA) is an important biomechanical component, which is crucial for the forward propulsion of the body. TLA is defined as the angle between the lab's vertical axis and the vector from the 5th metatarsal joint to the greater trochanter. Studies have demonstrated the importance of TLA in improving walking speed for individuals with hemiplegia [24–26]. TLA can be increased by increasing hip and knee extension. Here in the study, the addition of the heel lift increased the stride length, which most likely is reflected in an increase in hip and knee extension. We believe that the improvement achieved in the gait parameters may be due to the positive changes occurred in the TLA.

Thus, it appears that the addition of the heel lift significantly influences the TLA. However, these biomechanical changes need validation through kinetic and kinematics values.

It is a well-known fact that the ankle strategy is the first pattern, which controls upright body sway [27]. Individuals tend to shift to the hip strategy in more unstable conditions [28]. Studies have used this principle and identified that as the heel height increases, there would be more upward displacement of the center of body mass [21, 29]. In our study, the authors believe, the hip strategy was employed to increase postural stability. Heel lifts more than 1 cm can give a negative impact on posture and balance performance [21]. In our study, the moment the heel height was increased, the patients felt safe and were comfortable to stand.

Gait deviations following CES tend to be overlooked during acute phase since higher attention is given to the management of bowel and bladder dysfunction. Allowing people to walk with such pattern may increase the risk of developing neuropathic heel ulcers [8]. The combined effect of incontinence and gait deviation can be a major stigma minimizing the chance of community reintegration.

The functional improvements achieved in this study hold clinical relevance. The lack of availability of appropriate appliances to compensate the plantar flexor weakness is a major hurdle in CES. Poor flexibility and weight of the appliance are a few limiting factors of orthoses. Therefore, the concept used in this study is cost effective and feasible even in busy clinical settings. This footwear modification may prove to be a simple and effective solution to help improve the patient's walking performance. The clinically meaningful changes achieved in the gait parameters may increase the chance of community ambulation, and may also have a positive impact on quality of life.

In this study we have adopted clinically feasible assessment of various parameters, which is different from the usually robust laboratory methods like sensors and signal markers. Lack of kinetic and kinematic information on the biomechanical changes imposed by the heel lift is a major limitation of the study. We have understood this limitation as this study was designed to evaluate the impact of the heel lift in an outpatient set up. Furthermore, the time between test and retest of gait parameters used in this study was 24 h, which may not be sufficient for the patients to accustom to the new footwear modification. Lack of a control group with the use of AFOs with 5° plantar flexion and the small sample size limits generalizability of the study results.

To conclude, this pilot study has demonstrated that addition of 1 cm heel may be effective in improving the walking performance of persons with CES. Future studies should investigate the kinetic and kinematic changes of this modification using a randomized controlled trial study design.

## Data availability

The data collected and analyzed during the current study are available from the corresponding author on reasonable request.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** We certify that all applicable institutional and governmental regulations concerning the ethical use of patients were followed during the course of this research. The experimental protocol was approved by the institutional review board.

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