Research Paper

Influence of Photobiomodulation Therapy on Altered Plantar Pressure Distribution and Ankle Biomechanics in Individuals With Diabetic Foot Syndrome

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ABSTRACT

Objectives: Diabetic foot syndrome is becoming increasingly common in India with a prevalence ranging from 24.9% to 49%. Diabetic foot syndrome patients have an increased likelihood of developing ulcers in their feet. Accordingly, this study evaluates the influence of photobiomodulation on altered plantar pressure distribution and ankle biomechanics in individuals with diabetic foot syndrome.

Methods: A total of 20 diabetic foot syndrome patients with an absence of 10 g monofilament in one out of six sites at the plantar surface of feet, a biothesiometer for vibration perception threshold of >20 V, and diminished or absent ankle reflexes were included. The evaluation of ankle biomechanics was performed by SIMI motion analysis. In addition, the plantar pressure distribution was measured by the WinTrack pressure platform at baseline and the end of 10 sessions. They were treated with scanning mode on the foot plantar surface and probe laser at the popliteal fossa region for three sessions per week, for ten sessions.

Results: Plantar pressure parameters were significantly improved (P<0.01) and ankle biomechanics (P<0.01) after the intervention, respectively, except for no significant difference in the total contact area and ankle midstance kinematics.

Discussion: Photobiomodulation therapy can be an effective treatment for improving foot plantar pressure redistribution and ankle biomechanics in individuals with diabetic foot syndrome.

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Highlights

- This is the first study to evaluate ankle kinematics and foot plantar pressures in diabetic peripheral neuropathy.
- Photobiomodulation therapy was applied at the dorsal and plantar aspect of the feet and popliteal fossa.
- Foot kinematics and plantar pressure distribution improved significantly after application of the photobiomodulation therapy.

Plain Language Summary

Individuals with diabetic peripheral neuropathy will have sensory and motor-related issues due to hyperglycemia. Non-invasive therapies, like low-level laser therapy, showed significant results in treating symptoms of diabetic foot syndrome. A total of 10 sessions of irradiation of photobiomodulation therapy showed a significant reduction in ankle biomechanics and plantar pressure distribution.

Introduction

The triad of neurological, vascular, and biomechanical impairments associated with the development of type 2 diabetes mellitus is known as diabetic foot syndrome (DFS) [1, 2]. It is commonly associated with functional impairment of limbs and poor quality of life. Reduced sensations, pain, muscle weakness, spasms, loss of balance, and proprioception are the main symptoms often presented due to damage or injury to the vasa nervorum, axons, and atrophy of the axons [3]. The prevalence of DFS is approximately 24.6% to 49% in India [4, 5].

Altered sensory and motor nerve functions in diabetic peripheral neuropathy (DPN) can affect altered biomechanics in ankle kinematics, gait kinetics and plantar pressure distribution [6]. Plantar pressures are the pressure field that acts between the foot and the support surface during everyday locomotor activities. The literature indicates that elevated plantar pressures and aberrant lower limb biomechanics, which may contribute to the development of diabetic foot ulceration, have a strong association with DPN [7].

The use of non-invasive medical treatments has reported symptomatic relief of DPN. Among the conventional electrotherapy modalities, because photobiomodulation therapy (PBMT) can generate a biostimulation effect on the nervous system's cells, it has been used to treat nerve injuries and other disorders connected to nerves [8]. Since PBMT stimulates nerve regeneration to enhance neural function and vascularity, it has been utilized to treat peripheral nerve damage and other diabetes problems at different wavelengths [9].

Even though PBMT is effective in reducing pain, improving nerve physiology and conduction, and regeneration, there is a dearth of literature on the influence of PBMT on plantar pressure parameters and ankle biomechanics in diabetic foot individuals in the Indian scenario. Accordingly, this study assesses how plantar pressure distribution and ankle biomechanics in DFS are affected by PBMT.

Materials and Methods

A total of 97 participants were screened and 20 DFS subjects were recruited based on the inclusion and exclusion criteria. A comprehensive diabetic foot evaluation was performed which included history, sensory, motor, biomechanics, neuropathy components were evaluated. DPN was assessed as per International Diabetes Federation (IDF) 2021 guidelines. The inclusion criteria were 1) Inability to feel or perceive monofilament 10 g at least one out of 6 sites at the plantar surface of feet; 2) Using a biothesiometer, unable to perceive the vibration perception test <20 V at plantar surface region; and 3) Absence of ankle reflexes using a reflex hammer. Exclusion criteria were neuropathies other than diabetes origin. Any orthopedic, vision-related issues, central nervous system, or other disability that may affect gait and posture. Resting limb pain, peripheral vascular disease, current pain, injury, severe ulceration, ulcer history, or toe amputation [9].

Following a detailed baseline comprehensive diabetic foot evaluation, all subjects were irradiated with two separate low-level Laser therapy equipment. The scanning mode laser wavelength of 632.8 nm with a dosage of 3.1 J/cm^2 (Tech Laser SS-1000, Technomed, India, 2018), and the probe laser, a wavelength of 660 nm and

850 nm with a dosage of 3.4 J/cm^2 and power density of 50-150 mW/cm^2 (Thor Laser LX2.3, Thor Photomedicine LTD, UK). The scanning mode with a duration of 9-min covering the entire plantar and dorsum region of the foot and the Thor laser probe was used with the contact method over the popliteal fossa for 5 min for a total of 10 sessions (Figure 1). All subjects were reassessed with detailed diabetic foot evaluation at the end of the 10 sessions. Plantar pressure parameters were measured on the WinTrack pressure plate (Medicapteurs France SAS, Balma, France). Average plantar pressure (APP), maximum plantar pressure (MPP), the forefoot-hind foot ratio (FHR) and total contact area (TCA) measurements were taken, and the data were analyzed with WinTrack software, version 12 (Medicapteurs France SAS, Balma, France). For gait analysis, the 3D SIMI motion analysis system, version 2018 measured ankle biomechanics parameters, like angular velocity and acceleration. Initially, three trials were conducted for participants to walk at an average pace on the pressure plate platform. The data were analyzed using the SPSS software, version 21. To investigate the group's pre-test and post-test changes, descriptive statistics and paired t-tests were used with the significance level set at P<0.05.

Results

A total of 20 subjects participated in this study. The demographic characteristics of the subjects are provided in Table 1. The mean age was 60.2±11.8 years in addition to the history of type 2 diabetes mellitus with a mean duration of 14.12±4.47 years and a mean body mass index of 25.9±4.6 kg/m^2.

Pre-test and post-test study means values of the plantar pressure parameters in the intervention group

According to Table 2, the Mean±SD for APP at baseline were 163.6±28.1 and at the tenth session was 136.1±24.4 with a mean change of 27.5±18.8 (t=3.39, P<0.01). Meanwhile, MPP at baseline was 370.3±54.1 and at the tenth session was 316.73±56.9, with a mean change of a mean change of 53.6±25.2 (t=8.22, P<0.01). FHR at the baseline was 1.43±0.4 and at the tenth session was 1.05±0.3, with a mean change of 0.37±0.3, (t=4.35, P<0.01). And, the TCA at baseline was 84.1±19.1 and at the end of the tenth session was 84.33±21.7, with a mean change of 0.26±1.7 (t=0.08, P=0.91).

Pre-test and post-test study means values of the ankle biomechanics in the intervention group

According to Table 3, the Mean±SD for the parameters of ankle biomechanics, peak angular velocity at heel strike phase baseline was 43.2±8.9 and at the tenth session was 65.2±5.3, with a mean change of 22.1±11.2 (t=-3.5, P<0.01). At the midstance phase, the value was 33.9±7.7 and at the tenth session, it was 33.7±7.8 with a mean change of 0.16±8.1 (t=-2.1, P=0.98). In addition, at the toe-off phase, the value was 219.8±25.9 and at the tenth session was 254.3±32.8, with the mean change of 34.4±26.7 (t=-6.7, P<0.01).

In peak angular acceleration at the heel strike phase, the baseline was 1306±232.9 and at the tenth session was 1593.3±284.2 with a mean change of 76.8±10.2 (t=-6.7, P<0.01). In addition, at the midstance phase, the value was 1241.4±151.4 and at the tenth session, it was 1182.5±368.2, with a mean change of 58.8±301.2 (t=-2.05, P=0.46). The toe-off phase was 512.1±68.3 and at the tenth session was 588.9±78.5 with a mean change of 76.8±10.2 (t=-4.7, P<0.01).

Discussion

Plantar pressure distribution and ankle biomechanics are drastically altered in individuals with DFS due to sensory and motor nerve deficits. These modifications may be critical risk factors for developing a diabetic foot ulcer in the future [10]. The loss of protective sensation, abnormal muscle activity, and plantar tissue stiffness due to diabetic neuropathy can be a potential variable associated with DFS that can impact reduced ankle biomechanics compared with healthy individuals [11].

The purpose of this research was to determine the effect of PBMT among individuals with DFS. Dynamic pressure foot scanning was used to determine APP, MPP, FHR and TCA. Foot plantar pressure scanning is dependable, precise, and simple to replicate [12]. Ankle biomechanics parameters were measured using 3D motion gait analysis, and various variables, like peak ankle angular velocity and peak angular acceleration at heel strike, midstance, and toe-off of stance phase were evaluated [13].

Accordingly, at the post-intervention comparison, plantar pressure parameters and ankle biomechanics were significantly improved compared to baseline after the PBMT. This may be due to increased electrophysiological changes in peripheral nerves, especially the peroneal nerve. No difference was seen in the TCA and midstance

Table 1. Mean±SD of the analyzed variables at baseline (n=20)

Variables	Mean±SD
Age (y)	60.2±11.8
Weight (kg)	74.8±16.46
BMI (kg/m^2)	25.95±4.63
Duration of diabetes (y)	14.12±4.47
HbA1c (%)	7.4±0.9
VPT (volts)	31.6±6.7

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Abbreviations: BMI: Body mass index; HbA1c: Glycated hemoglobin; VPT: Vibration perception threshold.

kinematics. Regarding the influence of PBMT on plantar pressure parameters, the study found that APP decreased by about 16.5%, MPP decreased by about 14.3% and FHR reduced by about 25.8% compared to the baseline.

An evaluation of plantar pressures in offloading or pressure redistribution treatment is helpful because it provides a perspective on the pressure reduction level required to heal and prevent foot ulcers [14]. Increased FHR is a high predictor of ulcers in DFS. In the average population, FHR is less than one; that is, the hind foot takes higher loading than the forefoot during gait [15]. In DFS, due to loss of protective sensation and muscle function alteration, there is an increase in forwarding translation of loading, thus increasing FHR by more than one [16]. As per the literature, both forefoot and rearfoot MPP is increased, the FHR ratio was significantly higher in severe neuropathy, and an FHR ratio greater than one can predict ulcer development in the foot region [17].

Another study observed significant variations in joint angle, joint velocity, and acceleration during the heel strike, midstance, and toe-off phases of gait walking in people with DPN compared to people without DPN [7]. Recent advances in motion analysis technology, such as improved multi-segment foot models, 2D/3D movement analysis, or motion detection system studies that support connections between peripheral neuropathy and a decline in gait excursions of the ankle complex and subsegments of the foot are emerging [18, 19]. Also, ankle angular velocity at heel strike and toe-off was increased by about 51.1% and 15.7%, and ankle angular acceleration at heel strike and toe-off was increased by about 21.9% and 14.9%, respectively.

Increased motor and sensory nerve conduction velocity and voluntary muscle activity recruitment were found after applying PBMT transcutaneously. Increased sensation of the plantar region may increase the sense of awareness of the foot, thus reducing plantar pressure

Table 2. Mean±SD, mean difference and level of significance of plantar pressure parameters

Parameters	Mean±SD			P
	Baseline	Post-intervention	Mean	
APP (KPa)	163.6±28.1	136.1±24.4	27.5±18.8	<0.01*
MPP (KPa)	370.3±54.1	316.73±56.9	53.6±25.2	<0.01*
FHR	1.43±0.4	1.05±0.3	0.37±0.3	<0.01*
TCA (cm^2)	84.1±19.1	84.33±21.7	- 0.26±1.7	0.91

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Abbreviations: APP: Average plantar pressure; MPP: Maximum plantar pressure; FHR: Forefoot hindfoot ratio; TCA: Total contact area; KPa: Kilo Pascals.

*P<0.05.

Table 3. Mean±SD, mean difference, and level of significance of variables of ankle biomechanics

Peak Ankle joint velocity (°/s)		Mean±SD			P
		Baseline	Post-intervention	Mean Difference	
Heel strike		43.2±8.9	65.2±5.3	22.1±11.2	<0.01*
Midstance		33.9±7.7	33.7±7.8	0.16±8.1	0.937
Toe-off		219.8±25.9	254.3±32.8	34.4±26.7	<0.01*
Peak ankle joint acceleration (°/s²)	Heel strike	1306±232.9	1593.3±284.2	287.3±51.2	<0.01*
	Midstance	1241.4±151.4	1182.5±368.2	58.8±301.2	0.462
	Toe-off	512.1±68.3	588.9±78.5	76.8±10.2	<0.01*

*P<0.05.

distribution. The possible mechanism explained is: a) Increased nerve metabolism, b) Prevents motor cell degeneration, c) Stimulates Schwann cell proliferation, d) Facilitates and increases myelination, and e) Regeneration of axons [20].

Other possible cellular mechanisms for tissue regeneration by PBMT involve the following items: 1) Elevated calcium in the cell cytoplasm; 2) Accelerated division of cells and development; 3) Interactions with cytochromes resulting in cell stimulation; 4) Protein and cytokine formation and activation; 5) Adenosine triphosphate production; and 6) Vasodilation and skin microcirculation in the blood [21, 22]. An improvement in plantar pressure parameters following PBMT can be comprehended as improving the peripheral neural function of both the sensory and motor nerves in the lower limb resulting in a significant reduction in pain level [23]. All of these implications can be clinically and operationally indicated during walking to reset plantar pressure parameters and improve ankle kinematics [24].

DFS is usually a typical scenario that starts as injury or damage to peripheral nerves. The research findings highlight that PBMT's bio-stimulation effect improves the nervous system [25]. This study used the total dosage of 3.1 J/cm² and 3.4 J/cm². It has been documented that the sensory nerve and motor nerve velocity and latency in subjects with carpal tunnel syndrome with an intensity of 2.7 to 3.6 J/cm² have increased significantly [26].

Conclusion

PBMT can effectively reduce foot plantar pressures and improve ankle biomechanics in individuals with diabetic foot syndrome. This therapy should be implemented in

Figure 1. Application of laser probe at the popliteal fossa

routine foot care management as preventive therapy that can reduce the risk of development of foot ulcers in type 2 diabetes mellitus patients.

Study limitations

This study had limitations due to a small number of participants and a short treatment period, with no control or placebo to compare the results for better interpretation. Further studies with a significant number of participants using distinctive laser wavelengths and the same application method are required.

Ethical Considerations

Compliance with ethical guidelines

This research approved by Kasturba Medical College and Hospitals Institutional of Manipal Academy of Higher Education (MAHE) Ethics Committee (Code: IEC-169/2019). Each participant provided informed written consent.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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Appendix

Abbreviations	
DFS	Diabetic foot syndrome
APP	Average plantar pressure
FHR	Forefoot hindfoot ratio
KPa	Kilo pascals
MPP	Maximum plantar pressure
PBMT	Photobiomodulation therapy
DPN	Diabetic peripheral neuropathy
TCA	Total contact area
VPT	Vibration perception threshold

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