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The influence of isometric resisted ankle strength on dynamic foot plantar pressure in diabetes and non-diabetes participants

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ABSTRACT

Introduction: Patients with diabetes are more likely to fall due to increased plantar pressure and decreased strength in the lower extremities.

Objectives: To determine the influence of isometric ankle strength on dynamic foot plantar pressure in diabetes and non-diabetes participants.

Methods: Twenty diabetes patients and twenty non-diabetes participants with age 28-54 years, height 150-182 cm, weight 48-90 kg, and BMI 25-54 kg/m^2 participated in the study. The diabetes level was determined based on fasting plasma glucose levels. The resisted isometric muscle strength of the foot during dorsiflexion, plantar flexion, inversion, and eversion was measured using an electronic handheld dynamometer. The plantar pressure distribution during dynamic conditions was determined by using a 48.7×44.7 cm pressure platform. The outcome measures between diabetes and non-diabetes groups were statistically compared by student t-test. The correlation coefficient was determined by the Pearson correlation coefficient test. A p-value of less than 0.05 was considered significant.

Result: The significant differences were found between diabetes and non-diabetes participants for the dorsiflexion (p=.048), plantarflexion (p=.031), inversion (p=.011), eversion (p=.024), peak pressure (p=.024), pressure per square inch (p=.012), pressure time integral (p=.014), and peak pressure gradient (p=.009). Significant relationships between resisted isometric ankle joint strength and foot plantar pressure for diabetes patients and non-diabetes participants were found.

Conclusion: The present study's findings reflect the higher frequency of plantar pressure distribution and higher muscle weakness in diabetes patients than in non-diabetes participants. These findings suggested that pressure data could help us to customize therapy strategies for patients with diabetes and prescribe a proper exercise intervention's short-and long-term effects on gait biomechanics.

Keywords: gait, plantar pressure, isometric, strength, diabetes, healthy

INTRODUCTION

The foot is one of the most fascinating components of human body. It is a bottom part of the lower extremity that bears body weight and enables motion. The arrangement of muscles, bones, and joints enables motion by absorbing and distributing pressure on the foot while the individual is in a movable position. Walking is a heterogeneous biomechanical mechanism that includes different gait cycle phases. The stance phase of the gait cycle is characterized by an increase in plantar pressure as a result of mechanical loading on the ground. Plantar pressure is well recognized as a reliable biomechanical parameter for studying and diagnosing a wide range of foot diseases [1]. Numerous musculoskeletal abnormalities in the lower extremity have been associated to anatomical and physiological foot disorders. Measurements of plantar pressure while standing, walking, or doing other activities provide more information for evaluating diseases or anomalies [2]. The researchers [3] also emphasized the importance of examining foot mechanics during walking, they stated that alterations in normal foot mechanics could negatively affect the functioning of the ankle, knee, hip, and even the back.

Previous research has determined the differences and associations between plantar pressure in various populations. Researchers have revealed that diabetes imbalances plantar pressure distribution between the forefoot and heel while walking. It was discovered that type 2 diabetes patients had higher plantar pressure at the fifth metatarsal head and hallux and lower heel pressure than healthy controls [4]. It was discovered that prediabetics and diabetics have higher peak plantar pressure than healthy controls [5]. Biomechanical variables may increase the plantar pressure associated with diabetes. Examples include weight growth, restricted joint mobility, plantar tissue thickness, motor/sensory neuropathy, muscular strength, and foot structure/deformity [6].

People with diabetes often have greater posture and gait limitations, and their chances of falling are high. These limitations usually comprised leg muscle atrophy, plantar fat pad, hammer toe, and limited joint movements [7]. It was found a progressive muscular weakening in long-term diabetes patients under active isokinetic settings, and the rate was directly proportional to the severity of diabetic neuropathy [8]. In type 1 diabetes, muscle atrophy starts in the foot and proceeds through the lower legs, causing muscular imbalance and weakness of the intrinsic muscles and relatively strong long toe flexor, extensor, and ankle muscles [9]. Foot abnormalities cause increases in planter pressure, foot ulcers, and lower limb amputations. Ankle joint muscle strength affects gait pattern, and there is an association between muscle weakness and other movement abnormalities in diabetes patients [10].

Plantar pressure is used to assess numerous dynamic and static situations related to various health disorders, disabilities, and illnesses. Many researchers investigated the muscular strength of the lower extremities. However, there was no investigation to determine the influence of isometric muscle strength of the ankle joint on plantar pressure distribution. Therefore, in the present study, we examined the dynamic foot plantar pressure and ankle joints' muscle strength in diabetes and non-diabetes participants using resisted isometric dynamometry, which has a high degree of reliability in determining maximal strength in non-diabetes and diabetes participants [11].

METHODS

Participants

All diabetes and non-diabetes participants gave informed consent for the study. The study protocol was approved by the deanship of scientific research, Imam Abdulrahman bin Faisal University, Dammam, Saudi Arabia. This study was conducted according to the declaration of Helsinki principles. 20 diabetes patients (all male) aged 39.25±9.12 years, height 164±8.87 cm, body mass 63.70±10.27 kg, BMI 38.63±5.79 kg/m^2 with a diabetes duration >4 years and 20 non-diabetes participants (all male) age 42.45±8.24 years, height 167.95±9.90 cm, weight 69.9±12.67 kg, and BMI 41.54±6.69 kg/m^2 participated in the study. Participants having a history of lower limb asymmetric weakness, severe lung or heart diseases, musculoskeletal diseases, or other endocrine or neurological abnormalities, or those unable to walk were excluded.

Assessment of Anthropometric Characteristics

Anthropometric characteristics were measured using a stadiometer for standing height, bioelectrical impedance device for weight, BMI, and body compositions, and blood glucose monitor was used to determine blood glucose level [2]. The diabetes level was determined based on fasting plasma glucose levels.

Assessment of Resisted Isometric Strength

The resisted isometric muscle strength of the foot during dorsiflexion, plantar flexion, inversion, and eversion was measured using an electronic handheld dynamometer (Model 01163, Lafayette, IN, USA). The participants were given explicit instructions to carry out each movement while a dynamometer applied a resistive force in the opposite direction of the motion that was sought i.e., plantarflexion, dorsiflexion, inversion, and eversion. Participants were asked to carry out three trials for each intended movement with an interval of 60 seconds. The handheld dynamometer device (kg) recorded the mean peak force. The average was recorded for each movement. This dynamometer measures muscle strength with an accuracy of 0.1 kg from 0 to 199.9 kg. The manual muscle test's reliability has been documented previously (interclass correlation coefficient>0.8) [12].

Assessment of Peak Plantar Pressure

A 48.7×44.7 cm pressure platform (Tekscan MobilMat 3140) was used to test the plantar pressure distribution during dynamic condition. Participants were asked to walk on the Tekscan MobilMat three times barefoot at a self-selected gait speed. The research was conducted by averaging the outcomes of three distinct trials. The acquisition frequency was 100 Hz for all participants. Tekscan MobilMat foot pressure had a good validity and reliability scores of 0.99 and 0.69, respectively [11, 13].

Procedure

All test instructions were imparted to all participants upon arrival at the physical therapy lab in the morning session. Patients already have been diagnosed with type 2 diabetes, they were selected for data collection. Diabetes patients' blood glucose levels were assessed prior to the test using a blood glucose kit (OMRON GHM-111). A skilled physical therapist extracted a drop of blood from the fingertip using a lancing device. Blood was dropped onto the test strip's edge, and the device's screen revealed blood glucose measurements. A stadiometer was used to measure height. The participants' health level and body composition were determined by the bioelectric impedance device (ioi-353, Jawon Medical, South Korea). All the participants were instructed to warm up for 10 minutes before isometric muscle strength measurement was taken for the ankle joint. The participants were asked to lay supine on a treatment bed with both legs fully extended. The resisted isometric muscular strength was determined in dorsiflexion, plantarflexion, eversion, and inversion movement with the help of the handheld dynamometer (MICROFET Manual Muscle Testing). Participants resisted movement in each direction while the researcher applied force with the handheld dynamometer. Three tests were done for each movement, and the average was used for statistical analysis. To determine the plantar pressure, each participant performed three trials of self-selected walking speed on the Tekscan foot pressure MobilMat. The plantar pressure MobilMat was calibrated for each participant. We used the step calibration technique to get things ready for the test. All participants acquired data at a rate of 100 Hz. The sensitivity of the mat was assessed for each participant to ensure the amount of pressure. Each participant placed on the mat did not exceed the sensitivity of the mat. For walking movement, data were recorded for 40 seconds (1,200 frames) on one trail. All trails of plantar pressure measurements were exported from the software and recorded into an Excel spreadsheet. The averages of three trails were calculated for all variables and used for further analysis.

Statistical Analysis

All the data analysis were performed using the IBM statistical package for the social sciences (Armonk, NY, USA) v26.0 for Windows. Data from the right and left foot were processed separately for each participant.

Table 1. Comparison of resisted isometric ankle joint strength & foot plantar pressure (N/cm²) in diabetes & non-diabetes participants

		Mean±SD	95% CI lower & upper	t	Significance
Dorsiflexion	Diabetes	31.98±4.44	29.43-37.53	-1.96	.048
	Non-diabetes	35.26±6.04	32.44-38.09		
Plantarflexion	Diabetes	42.78±6.38	40.05-47.99	-2.23	.031
	Non-diabetes	48.52±9.56	42.39-54.17		
Inversion	Diabetes	29.50±5.42	27.03-33.97	-3.17	.011
	Non-diabetes	36.23±7.78	26.59-33.87		
Eversion	Diabetes	29.21±5.73	28.52-33.89	-2.35	.024
	Non-diabetes	34.94±9.29	26.59-35.28		
Peak pressure	Diabetes	65.90±16.79	63.07-71.73	2.36	.024
	Non-diabetes	61.00±12.79	59.08-68.92		
Pressure per square inch	Diabetes	47.15±16.21	39.56-49.44	2.75	.012
	Non-diabetes	43.50±15.57	37.57-58.74		
Pressure time integral	Diabetes	14.83±2.30	13.75-15.90	2.56	.014
	Non-diabetes	13.36±3.53	11.70-15.01		
Peak pressure gradient	Diabetes	49.65±17.04	41.68-57.62	-3.29	.009
	Non-diabetes	42.70±11.72	37.21-48.19		

Table 2. Relationship between resisted isometric ankle joint strength & foot plantar pressure (N/cm²) for diabetes patients

		Peak pressure	Pressurep per square inch	Pressure time integral	Peak pressure gradient
Dorsi flexion strength	Pearson correlation	-.312	-.348	.119	-.195
	Significance (2-tailed)	.018	.013	.018	.041
Plantar flexion strength	Pearson correlation	.018	.444	.431	.157
	Significance (2-tailed)	.040	.051	.050	.048
Inversion strength	Pearson correlation	-.166	-.007	-.076	-.168
	Significance (2-tailed)	.048	.028	.048	.047
Eversion strength	Pearson correlation	-.202	-.117	-.007	-.222
	Significance (2-tailed)	.029	.021	.013	.032

For this study, we used the data of the dominant foot only. Results were expressed as mean, standard deviation (SD), and 95% confidence interval (CI). The outcomes measured between diabetes and non-diabetes groups were compared by student t-test where data were normally distributed (Shapiro-Wilk test p>0.05). The correlation coefficient (r) was determined by the Pearson correlation coefficient test. The statistical significance of the t-test and correlation and coefficient (two-tail) were determined. A probability less than 0.05 indicate statistical significance.

RESULT

Table 1 shows significant differences between resisted isometric ankle joint strength at each movement and foot plantar pressure in diabetes and non-diabetes participants. The dorsiflexion (p=.048), plantarflexion (p=.031), inversion (p=.011), eversion (p=.024), peak pressure (p=.024), pressure per square Inch (p=.012), pressure time integral (p=.014), and peak pressure gradient (p=.009) were significant at 0.05 level of significance between diabetes and non-diabetes participants.

Table 2 shows significant relationships between resisted isometric ankle joint strength and foot plantar pressure for diabetes patients. Dorsi flexion isometric strength showed a negative relationship with peak pressure (r=-.312, p=.018), pressure per square inch (r=-.348, p=.013), and peak pressure gradient (r=-.195, p=.041). Whereas the pressure time integral showed a positive relationship (r=.199, p=.018). Plantar flexion isometric strength showed a positive relationship with peak pressure (r=.018, p=.040), pressure per square inch (r=-.444, p=.051), pressure time integral (r=.431, p=050), and peak pressure gradient (r=-.157, p=.048).

Inversion-resisted isometric ankle joint strength showed a negative relationship with peak pressure (r=-.166, p=.048), pressure per square inch (r=-.007, p=.028), pressure time integral (r=-.076, p=.048), and peak pressure gradient (r=-.168, p=.047). Eversion resisted isometric ankle joint strength also showed weak negative relationship peak pressure (r=-.202, p=.029), pressure per square inch (r=-.117, p=.021), pressure time integral (r=-.007, p=013), and peak pressure gradient (r=-.222, p=.032) for diabetes patients.

Table 3 shows significant relationships between resisted isometric ankle joint strength and foot plantar pressure for non-diabetes participants. Dorsi flexion isometric strength showed a positive relationship with peak pressure (r=.366, p=.012), pressure per square inch (r=.061, p=.047), and peak pressure gradient (r=.106, p=.048). Whereas the pressure time integral showed a negative relationship (r=-.271, p=.048). Plantar flexion isometric strength showed a positive relationship with peak pressure (r=.323, p=.045) and peak pressure gradient (r=.035, p=.048), whereas a negative relationship for pressure per square inch (r=-.203, p=.031), pressure time integral (r=-.094, p=.049).

Inversion-resisted isometric ankle joint strength showed a positive relationship with peak pressure (r=.113, p = .036), pressure per square inch (r=.017, p=.044), and pressure time integral (r=.120, p=014). Whereas peak pressure gradient has a negative relationship (r=-.183, p=.040). Eversion-resisted isometric ankle joint strength also showed weak negative relationship pressure per square inch (r=-.089, p=.010), pressure time integral (r=-.032, p=.048), and peak pressure gradient (r=-.244, p=.030). In contrast, peak pressure has a positive relationship (r=-.127, p=.045) in diabetes patients.

Table 3. Relationship between resisted isometric ankle joint strength & foot plantar pressure (N/cm²) for non-diabetes participant

		Peak pressure	Pressurep per square inch	Pressure time integral	Peak pressure gradient
Dorsi flexion strength	Pearson correlation	.366	.061	-.271	.106
	Significance (2-tailed)	.012	.047	.048	.048
Plantar flexion strength	Pearson correlation	.323	-.203	-.094	.035
	Significance (2-tailed)	.045	.031	.049	.048
Inversion strength	Pearson correlation	.113	.017	.120	-.183
	Significance (2-tailed)	.036	.044	.014	.040
Eversion strength	Pearson correlation	.127	-.089	-.032	-.244
	Significance (2-tailed)	.045	.010	.048	.030

DISCUSSION

This study aimed to investigate the influence of isometric muscle strength of the ankle joint on plantar pressure distribution in diabetes patients and non-diabetes participants. Our findings have recognized that statistically non-significant differences and associations existed for dynamic foot pressure and resisted isometric ankle joint strength between diabetes patients and non-diabetes participants. We found that non-diabetes participants have higher resisted isometric ankle joint strength during dorsiflexion, plantar flexion, inversion, and eversion than diabetes. Diabetes patients had increased peak pressure, pressure per square inch, pressure time integral, and peak pressure gradient in the plantar pressure distribution. Diabetes and non-diabetes participants have statistically significant differences. Diabetes patients with plantar flexion had a positive relationship between resisted isometric ankle joint strength and foot plantar pressure. Resisted isometric muscular ankle joint strength and foot planter pressure during dorsiflexion, inversion, and eversion in diabetes are negatively correlated. Foot planter pressure correlated positively with resisted isometric ankle joint strength during dorsiflexion, plantar flexion, and inversion in non-diabetes. In non-diabetes, pressure per square inch, pressure time integral, and peak pressure gradient are negatively correlated during eversion movement.

This study's findings were supported with previous research on muscle strength and diabetes. Diabetes patients are more likely to develop foot ulcers and amputations [7]. Manual muscle strength testing showed slight to moderate muscle weakness in diabetes patients [14]. Andersen et al. found ankle joint muscle weakness in diabetes patients. Diabetics had 21% poor plantar flexion and dorsiflexion strength [15]. According to current investigation, association between ankle joint strength and foot plantar pressure in diabetes individuals has been found. Type 2 diabetes patients showed significant muscular weakness [16]. Walking style affects lower extremity strength. A study has found a correlation between muscular weakness and gait impairment in diabetes patients [10]. It was found that diabetic patients have lower maximal contraction strength of plantar and dorsal flexion muscles [17]. It was shown weak intrinsic foot muscles in diabetic patients [18]. The researchers [17] found that diabetic patients' plantar pressure lowers calf muscular strength by 30%-50%.

Our findings were supported with the study [19], which demonstrated significant plantar pressure differences between diabetes and non-diabetes. Another study identified significant changes in plantar pressure parameters between diabetes patients and non-diabetes [2]. It was examined plantar pressure dynamics in diabetes. It was discovered that diabetes patients showed higher peak plantar pressure than controls [20]. The authors in [21] also discovered that diabetes patients' plantar tissues increased in different plantar areas than those of the control group. The first metatarsal head had the biggest increase (160%), the first toe had the second greatest increase, and the heel area had non- significant increase [21]. It was found that 35 diabetes patients exhibited higher plantar pressure time integrals than 38 controls [22].

This study's result indicated that an enhanced peak pressure, pressure integral time, and pressure gradient had been found in diabetes patients more than in non-diabetes participants. These findings are similar to the results ofother studies, which demonstrate that diabetes affects foot biomechanics, ankle strength, ankle motions, gait kinematics, and plantar pressure distribution analyses within five years of illness start [23-26]. It was found that diabetes patients had higher plantar pressures than non-neuropathic diabetes in the front and posterior plantar surfaces [27]. A study showed that only 20% of diabetes patients' peak plantar pressure matches the maximum stress entered in the inferior area of the foot [28]. According to previous studies, patients with diabetes and foot abnormalities had a much slower walking speed than non-diabetes age-gender-matched individuals [29]. A careful walking pattern reduces peak plantar pressures during barefoot walking, which can be augmented in a quicker gait by changing temporal gait features like step duration, cadence, or double support time. By changing step duration, cadence, and double support time, a faster gait can reduce peak plantar pressures [29, 30].

In this study, A biomechanical sensor pressure plate was used to determine the influence of resisted isometric ankle joint strength on the plantar pressure distribution during gait of participants with and without diabetes. Peak pressure appears more relevant as a major reference measurement when the big picture is viewed. Muscle strength decreases if the peak pressure of the foot increases. The findings provide a more complete and comprehensive understanding of these relationships. These results may be indicative of the great value of a therapeutic foot-ankle exercise program in improving plantar pressure distribution in a different area of the foot.

There are numerous limitations that must be considered in order to establish the generalizability of this study's findings. The data collection in this study was under controlled conditions, although it differs from normal gait. The loss in muscle strength may be attributable to differences in measurement instrumentation and procedures, specifically the use of an isometric test device as opposed to an isokinetic test device. With this study, it was impossible to consider all potential variables that may be of interest in explaining plantar pressure of different parts of the foot. The primary objective of this research was to establish a correlation between the amount of pressure exerted by the foot's plantar surface and the amount of isometric force generated by the ankle joint.

CONCLUSION

The results of the current study show that people with diabetes are more likely to experience high plantar pressure distribution and have more muscle weakness than people without diabetes. Pressure data may be useful for analyzing the short- and long-term impacts of an exercise intervention on gait biomechanics, as well as for tailoring treatment programs for people with diabetes.

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Ethical statement: The authors stated that the study was conducted in accordance with international criteria for scientific research, and all authors considered the ethical duties entailed by these standards. The Institutional Review Board of IAU approved the study (IRB-UGS-2020-03-139). Informed consent was obtained from every participant. The ethical guidance for this study is based on the Helsinki Declaration, and all data are kept confidential.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

1. Ang CK, Solihin MI, Chan WJ, Ong YY. Study of plantar pressure distribution. In: Hajek P, Han AL, Kristiawan S, Chan WT, Ismail M, Gan BS, Sriravindrarajah R, Hidayat BA, editors. MATEC web of conferences. Solo Baru, Indonesia; 2018. p. 237. https://doi.org/10.1051/matecconf/201823701016
2. Ahsan M, Shanab AA, Nuhmani S. Plantar pressure distribution among diabetes and healthy participants: A cross-sectional study. Int J Prev Med. 2021;9(12):88. https://doi.org/10.4103/ijpvm.IJPVM_257_20 PMid: 34584654 PMCid: PMC8428319
3. Katoh Y, Chao EY, Laughman RK, Schneider E, Morrey BF. Biomechanical analysis of foot function during gait and clinical applications. Clin Orthop Relat Res. 1983;(177):23-33. https://doi.org/10.1097/00003086-198307000-00005
4. Pataky Z, Assal J-P, Conne P, Vuagnat H, Golay A. Plantar pressure distribution in type 2 diabetic patients without peripheral neuropathy and peripheral vascular disease. Diabet Med. 2005;22(6):762-7. https://doi.org/10.1111/j.1464-5491.2005.01520.x PMid:15910629
5. Robinson CC, Balbinot LF, Silva MF, Achaval M, Zaro MA. Plantar pressure distribution patterns of individuals with prediabetes in comparison with healthy individuals and individuals with diabetes. J Diabetes Sci Technol. 2013;7(5):1113-21. https://doi.org/10.1177/193229681300700503 PMid:24124936 PMCid:PMC3876353
6. Young MJ, Cavanagh PR, Thomas G, Johnson MM, Murray H, Boulton AJM. The effect of callus removal on dynamic plantar foot pressures in diabetic patients. Diabet Med. 1992;9(1):55-7. https://doi.org/10.1111/j.1464-5491.1992.tb01714.x PMid:1551311
7. Gershater MA, Apelqvist J. Elderly individuals with diabetes and foot ulcer have a probability for healing despite extensive comorbidity and dependency. Expert Rev Pharmacoecon Outcomes Res. 2021;21(2):277-84. https://doi.org/10.1080/14737167.2020.1773804 PMid: 32448021
8. Andreassen CS, Jakobsen J, Andersen H. Muscle weakness: A progressive late complication in diabetic distal symmetric polyneuropathy. Diabetes. 2006;55(3):806-12. https://doi.org/10.2337/diabetes.55.03.06.db05-1237 PMid:16505247
9. Andreassen CS, Jakobsen J, Ringgaard S, Ejskjaer N, Andersen H. Accelerated atrophy of lower leg and foot muscles-a follow-up study of long-term diabetic polyneuropathy using magnetic resonance imaging (MRI). Diabetologia. 2009;52(6):1182-91. https://doi.org/10.1007/s00125-009-1320-0 PMid:19280173
10. Andersen H. Motor dysfunction in diabetes. Diabetes Metab Res Rev. 2012;28(Suppl 1):89-92. https://doi.org/10.1002/dmrr.2257 PMid:22271730
11. Cousins SD, Morrison SC, Drechsler WI. The reliability of plantar pressure assessment during barefoot level walking in children aged 7-11 years. J Foot Ankle Res. 2012;5(1):8. https://doi.org/10.1186/1757-1146-5-8 PMid:22433255 PMCid:PMC3325900
12. Escolar DM, Henricson EK, Mayhew J, et al. Clinical evaluator reliability for quantitative and manual muscle testing measures of strength in children. Muscle Nerve. 2001;24(6):787-93. https://doi.org/10.1002/mus.1070 PMid: 11360262
13. Brenton-Rule A, Mattock J, Carroll M, et al. Reliability of the TekScan MatScan® system for the measurement of postural stability in older people with rheumatoid arthritis. J Foot Ankle Res. 2012;5:21. https://doi.org/10.1186/1757-1146-5-21 PMid:22889288 PMCid:PMC3431264
14. Andersen H, Jakobsen J. A comparative study of isokinetic dynamometry and manual muscle testing of ankle dorsal and plantar flexors and knee extensors and flexors. Eur Neurol. 1997;37(4):239-42. https://doi.org/10.1159/000117450 PMid:9208265
15. Andersen H, Poulsen PL, Mogensen CE, Jakobsen J. Isokinetic muscle strength in long-term IDDM patients in relation to diabetic complications. Diabetes. 1996;45(4):440-5. https://doi.org/10.2337/diab.45.4.440 PMid:8603765
16. Andersen H, Nielsen S, Mogensen CE, Jakobsen J. Muscle strength in type 2 diabetes. Diabetes. 2004;53(6):1543-8. https://doi.org/10.2337/diabetes.53.6.1543 PMid:15161759
17. Ijzerman TH, Schaper NC, Melai T, Meijer K, Willems PJB, Savelberg HHCM. Lower extremity muscle strength is reduced in people with type 2 diabetes, with and without polyneuropathy, and is associated with impaired mobility and reduced quality of life. Diabetes Res Clin Pract. 2012;95(3):345-51. https://doi.org/10.1016/j.diabres.2011.10.026 PMid:22104262

18. Cavanagh PR, Ulbrecht JS, Caputo GM. New developments in the biomechanics of the diabetic foot. Diabetes Metab Res Rev. 2000;16(Suppl 1):S6-10. https://doi.org/10.1002/1520-7560(200009/10)16:1+<::AID-DMRR130>3.0.CO;2-Z PMid:11054880
19. Syed N, Maiya AG, Hanifa N, Goud S. Plantar pressures in diabetes with no known neuropathy. J Diabetes. 2013;5(3):302-8. https://doi.org/10.1111/1753-0407.12016 PMid:23190733
20. Lung CW, Hsiao-Wecksler ET, Burns S, Lin F, Jan YK. Quantifying dynamic changes in plantar pressure gradient in diabetics with peripheral neuropathy. Front Bioeng Biotechnol. 2016;4:54. https://doi.org/10.3389/fbioe.2016.00054 PMid:27486576 PMCid:PMC4949238
21. Zheng YP, Choi YK, Wong K, Chan S, Mak AF. Biomechanical assessment of plantar foot tissue in diabetic patients using an ultrasound indentation system. Ultrasound Med Biol. 2000;26(3):451-6. https://doi.org/10.1016/S0301-5629(99)00163-5 PMid:10773376
22. Yu X, Yu G-R, Chen Y-X, Liu X-C. The characteristics and clinical significance of plantar pressure distribution in patients with diabetic toe deformity: A dynamic plantar pressure analysis. J Int Med Res. 2011;39(6):2352-9. https://doi.org/10.1177/147323001103900635 PMid:22289554
23. Xu L, Zeng H, Zhao J, et al. Index of plantar pressure alters with prolonged diabetes duration. Diabetes Ther. 2019;10(6):2139-52. https://doi.org/10.1007/s13300-019-00697-w PMid:31595458 PMCid:PMC6848324
24. Kwon OY, Minor SD, Maluf KS, Mueller MJ. Comparison of muscle activity during walking in subjects with and without diabetic neuropathy. Gait Posture. 2003;18(1):105-13. https://doi.org/10.1016/S0966-6362(02)00166-2 PMid:12855306
25. Maluf KS, Mueller MJ, Strube MJ, Engsberg JR, Johnson JE. Tendon achilles lengthening for the treatment of neuropathic ulcers causes a temporary reduction in forefoot pressure associated with changes in plantar flexor power rather than ankle motion during gait. J Biomech. 2004;37(6):897-906. https://doi.org/10.1016/j.jbiomech.2003.10.009 PMid:15111077
26. Bus SA, Maas M, De Lange A, Michels RPJ, Levi M. Elevated plantar pressures in neuropathic diabetic patients with claw/hammer toe deformity. J Biomech. 2005;38(9):1918-25. https://doi.org/10.1016/j.jbiomech.2004.07.034 PMid:16023481
27. Caselli A, Pham H, Giurini JM, Armstrong DG, Veves A. The forefoot-to-rearfoot plantar pressure ratio is increased in severe diabetic neuropathy and can predict foot ulceration. Diabetes Care. 2002;25(6):1066-71. https://doi.org/10.2337/diacare.25.6.1066 PMid:12032116
28. Yavuz M, Erdemir A, Botek G, Hirschman GB, Bardsley L, Davis BL. Peak plantar pressure and shear locations: Relevance to diabetic patients. Diabetes Care. 2007;30(10):2643-5. https://doi.org/10.2337/dc07-0862 PMid:17620447
29. Ko M, Hughes L, Lewis H. Walking speed and peak plantar pressure distribution during barefoot walking in persons with diabetes. Physiother Res Int. 2012;17(1):29-35. https://doi.org/10.1002/pri.509 PMid:21234990
30. Courtemanche R, Teasdale N, Boucher P, Fleury M, Lajoie Y, Bard C. Gait problems in diabetic neuropathic patients. Arch Phys Med Rehabil. 1996;77(9):849-55. https://doi.org/10.1016/S0003-9993(96)90269-5 PMid:8822673