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# Plantar Pain, Balance and Foot Functions in Individuals with Diabetes Mellitus

Mehmet DURAY [1], Nilüfer ÇETİŞLİ KORKMAZ [2], Buse KILINÇ [3], Semin Melahat FENKÇİ [4]

[1] Suleyman Demirel University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation
[2] Pamukkale University, Faculty of Physical Therapy and Rehabilitation
[3] University of Health Sciences, Gulhane Institute of Health Sciences
[4] Pamukkale University, Faculty of Medicine, Department of Endocrinology and Metabolism

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**ABSTRACT**

**Aim:** The aim of this study was to investigate the relationship between plantar pain, balance and foot function in Diabetes Mellitus (DM) patients with obese and non-obese. **Material and Methods:** Fifty-four patients were diagnosed as DM were included. Participants were seperated as non-obese (n=27) and obese (n=27). The balance abilities (dynamic and static balance) of participants were examined with the Portable Computerized Kinesthetic Ability Trainer (SportKAT-550). Pain, disability and function status of foot were assessed according to Foot Function Index (FFI) and Manchester Foot Pain and Disability Index (MFPDI). **Results:** FFI-Disability and MFPDI scores of the Non-Obese Group were significantly better than Obese Group. While there were no significant correlation between BMI and MFPDI, FFI-Activity Limitation and FFI-Disability scores in both groups ($p>0.05$), there was medium and positive significant correlation just between BMI and FFI-Pain in Non-Obese Group ($p<0.05$). FFI-Pain scores showed a positive and medium/high relationship with MFPDI, FFI-Activity Limitation and FFI-Disability scores in both groups ($p<0.05$). **Conclusion:** The increased BMI in obese individuals with DM is possible reason of increased plantar pain, which seems to be the primary cause of dysfunction of the foot. BMI has a direct negative effect on sufficiency and disability and an indirect effect on activity limitation and reduced participation rate in individuals with DM.
**Keywords:** Balance, Body Mass Index, Diabetes Mellitus, Function, Plantar Pain.

# Diabetes Mellitus Tanılı Bireylerde Plantar Ağrı, Denge ve Ayak Fonksiyonu

**ÖZ**

**Amaç:** Bu çalışmanın amacı obez ve obez olmayan Diabetes Mellitus (DM) hastalarında plantar ağrı, denge ve ayak fonksiyonu arasındaki ilişkiyi araştırmaktır. **Gereç ve Yöntem:** Elli dört DM'li hasta çalışmaya dahil edildi. Katılımcılar obez olmayan (n=27) ve obez olanlar (n=27) olarak ayrıldı. Katılımcıların denge yetenekleri (dinamik ve statik denge) Portatif Bilgisayarlı Kinestetik Denge Cihazı (SportKAT-550) ile değerlendirildi. Ayağın ağrı, yetersizlik ve fonksiyon durumu Ayak Fonksiyon İndeksi (AFİ) ve Manchester Ayak Ağrısı ve Dizabilite İndeksi (MAADİ) ile değerlendirildi. **Bulgular:** Obez Olmayan Grubun AFİ-Engellilik ve MFPDI skorları Obez Gruba göre anlamlı derecede daha iyiydi. BKİ ile MAADİ, AFİ-Aktivite Kısıtlılığı ve AFİ-Yetersizlik skorları arasında her iki grupta anlamlı bir korelasyon yok iken ($p>0.05$), obez olmayan grupta sadece AFİ-Ağrı ile BMI arasında orta ve pozitif anlamlı korelasyon vardı. AFİ-Ağrı skorları her iki grupta da MAADİ, AFİ-Aktivite Kısıtlılığı ve AFİ-Yetersizlik skorları ile pozitif ve orta/yüksek ilişki gösterdi ($p<0.05$). **Sonuç:** DM'si olan obez bireylerde artan BMI, ayağın disfonksiyonunun birincil nedeni olarak görünen artmış plantar ağrının olası nedenidir. BKİ'nin DM'li bireylerde yeterlilik ve yeti yitimi üzerinde doğrudan, aktivite kısıtlılığı ve katılım oranındaki azalma üzerinde dolaylı bir etkisi vardır.
**Anahtar Kelimeler:** Denge, Beden Kitle Indeksi, Diabetes Mellitus, Fonksiyon, Plantar Ağrı.

***Sorumlu Yazar / Corresponding Author:*** Buse Kılınç, University of Health Sciences, Gulhane Institute of Health Sciences, Ankara, Turkey, Phone: 0090 537 684 4415
***E-mail:*** busekilincfet@gmail.com

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## INTRODUCTION

About 425 million people are suffering from Diabetes Mellitus (DM) worldwide. The alterations secondary to DM, such as mitochondrial dysfunction and inadequate blood supply, may cause motor dysfunction (Nomura Kawae, Kataoka, & Ikeda, 2018). So, muscle strength and functionality are significantly decreased in patients with DM (Colberg et al., 2016). Because the amount of intramuscular non-contractile tissue increases, skeletal muscle mass and function are also decreased. This can lead to impaired balance and increased use of assistive devices, such as canes and walkers (Kera et al., 2018). The American Diabetes Association suggests that patients with DM should perform balance and flexibility exercises to prevent falls and improve functionality (Colberg et al., 2016). Reportedly, patients with DM have variable muscle force distribution, showing variability in all phases of walking (Gomes, Ackermann, Ferreira, Orselli, & Sacco, 2017). Besides, the distribution of pressures in the plantar area of the foot also varies among patients with DM (Matos, Mendes, Silva, & Sousa, 2018). High pressure in the plantar area of the foot is a common complication associated with DM (Matos et al., 2018). Both high pressure in the plantar area and the impairment of the structure of the foot cause plantar pain, which is a common complaint that can lead to disability. Prevalence of plantar pain increases up to 17-24% in individuals over 18 years of age, especially in middle aged patients (40-60 years) (Menz, Munteanu, Zammit, & Landorf, 2010; Rosenbaum, DiPreta, & Misener, 2014). Plantar pain risk factors are divided into intrinsic and extrinsic (environmental) factors. Intrinsic factors are individual characteristics such as increased body mass index (BMI), limited range of motion, step length, increased connective tissue thickness, like plantar fascia, and decreased calf muscle strength. The presence of intrinsic risk factors increases the possibility of injuries (Chatterton, Muller, & Roddy, 2015). One of main intrinsic factors is increased BMI indicating obesity. A comorbidity of DM and attracting more attention than DM, obesity is another important cause of plantar pain (Menz et al., 2010). Obese individuals are more probably to have increased foot pain than individuals have normal BMI (Tanamas et al., 2012). With increased weight, plantar pressure increases and plantar tissues remain under extreme load, causing pain (Menz et al., 2010). Obesity has powerfully association with not only foot pain but also disability (Tanamas et al., 2012). Because obesity causes biomechanical deformations in foot structure and increased plantar pressure, disability levels are higher in obese individuals (Tanamas et al., 2012). However, it seems that plantar pain and disability are related with each other in both obese and diabetic patients (Matos et al., 2018; Menz et al., 2010; Rosenbaum et al., 2014; Tanamas et al., 2012). Common foot structure and function disorders have been reported in individuals with plantar pain. Pain and related dysfunctions may lead to activity limitations, restrictions of participation to life, and increase risk of falls (Chatterton et al., 2015). Especially, diabetic foot lesions are a major cause of disability. Microangiopathic and macroangiopathic vascular diseases and neuropathy are the main causes of diabetic food lesions. Both the Achilles tendon and plantar fascia augment forefoot pressures and this is a risk for diabetic ulcerations. Metabolic disorders such as DM are known to change the mechanic properties and structure of tendons. Increased production contributes to increased plantar facial thickness. Advanced glycation end-products destroy the plantar fascia, which in turn increases the risk of plantar fasciitis (Giacomozzi, D'ambrogi, Uccioli, & Macellari, 2005). Another risk of plantar fasciitis is obesity. This study aimed to demonstrate the effect of weight and metabolic destruction in patients with DM. In general, the effects of DM and BMI on plantar pain have been studied before, separately. Although, to the best of our knowledge, no study has investigated the effects of obesity on plantar pain in DM patients in the literature, especially from the perspective of disability and activity limitation. Therefore, it is important to specify the changes on plantar pain and balance and to identify the secondary problems related with plantar pain in patients with DM who are vulnerable to dysfunction and pain. The aim of our study was to investigate the relationship between plantar pain, balance and foot function in Diabetes Mellitus (DM) patients with different BMI.

## MATERIALS AND METHODS

### Participants

This was designed as a cross-sectional and comparative study. The study was recorded to ClinicalTrials.gov (NCT04444375). Fifty four patients (33 females, 21 males) admitted to the Endocrinology and Metabolism Clinic and were diagnosed as DM were included (Figure 1). Inclusion criteria were no change in BMI by more than 10% for at least 3 months and having plantar pain and volunteering to participate in the study. DM patients who had musculoskeletal surgery for foot, diagnosis of diabetic neuropathy and had orthopedic, neurological and cardiovascular diseases, and hearing problems and vision that may cause balance disorder were excluded. As a result of the power analysis, we calculated that 90% power could be obtained with 95% confidence when at least 42 people were enrolled (at least 21 people for each group).

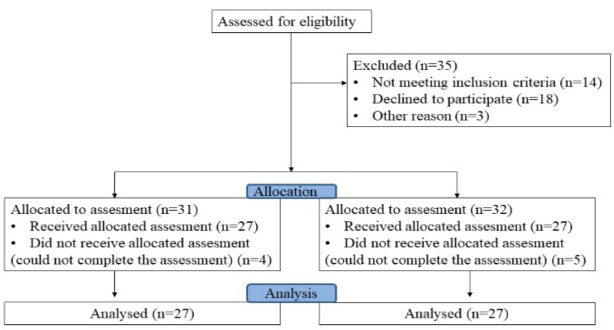


**Figure 1. A total of 54 patients with DM were analyzed, as described in the Consolidated Standards of Reporting Trials flowchart**

**Procedure**

Demographic characteristics including age, BMI, and medical history (disease duration, comorbidities, medication et al.) and balance, foot function, and disability status were assessed in Obese and Non-Obese Groups, according to BMI scores. The cut-off score was accepted as 30. Participants under 30 BMI score were grouped in the Non-Obese Group, while those with over 30 BMI score were included in the Obese Group. The Portable Computerized Kinesthetic Ability Trainer (SportKAT-550) (SportKAT, LLC 1497 Poinsettia Avenue Vista, CA 92081) was used to assess the dynamic and static balance of DM patients. Foot function, foot pain and disability were examined with the Foot Function Index (FFI) and the Manchester Foot Pain and Disability Index (MFPDI). The SportKAT-550 provides objective data that reflects the amount of weight put on the feet and postural sway. The patients were placed on a power platform and their ability to control the gravity center of the body, with small foot and ankle movements, was measured. The cross on the monitor screen represents the center of the movable platform and participants try to keep the cross mark in the center during the test for about 30 seconds. The pressure of the movable platform can be varied to modify the difficulty of the test. The patients were tested at a Postural Stability Index value of 10. As the time finishes, the device calculates a balance index score between 0 and 6000. The total score indicates balance performance (Figure 2) (Hansen, Dieckmann, Jensen, & Jakobsen, 2000). FFI consists of 23 items and evaluates activity limitation, disability and pain. The subscales of pain and limitation consist of 9 items each and subscale of activity limitation includes 5 items. In FFI, patients' pain levels are evaluated by visual analogue scale in 5 different situations. FFI- Pain severity is evaluated in 9 different categories in terms of different times of the day (morning and evening), maximum degree reached, standing and walking, use of insoles, and use of shoes. Higher scores indicate greater pain, disability, and activity limitation (Külünkoğlu, Firat, Yildiz, & Alkan, 2018). MFPDI was developed by Garrow et al. is used to assess foot pain and related disabilities in the last month. It is a well-established self-report scale. The index consists of 4 subscales including 9 questions for inadequacy, 5 for pain, 3 for concern, and 2 for difficulty. Each item is scored between 0-2. The total score is calculated by summing the scores from all items (Garrow et al., 2000). All assessments applied once.

**Figure 2. Balance test with SportKAT 550**

**Statistical analysis**

The statistical package SPSS 21.00 for Windows (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The Mann–Whitney U test was used for intergroup comparisons and the Spearman Correlation Analysis was used to detect the correlations between dependent variables. Level of significance was set at $p<0.05$.

**Ethical considerations**

Approval was obtained from the Ethics and Human Research Committee of Pamukkale University Hospital (60116787-020/71494). Written informed consent was obtained from all patients. The research was performed in accordance with the principles of the Declaration of Helsinki.

**RESULTS**

Mean age was 57.00±8.61 years in the Obese Group and 59.30±9.45 years in the Non-Obese Group (z=-0.859, p=0.391). Mean BMI was 26.53±2.32 kg/m$^2$ in the Non-Obese Group and 34.23±4.93 kg/m$^2$ in the Obese Group (z=-6.012, p<0.001). No differences were found between groups in terms of sex (p=0.163), marital status (p=1.00), insulin use (p=1.00), education status (p=0.483), or occupation (p=0.296) (Table 1).

Table 2 shows the comparisons of balance, FFI, and MFPDI scores between the groups. There were no differences between the groups in terms of static or dynamic balance scores. The Obese Group showed significantly higher FFI-Disability and MFPDI scores (p=0.002 and p=0.047, respectively), although FFI-Pain (p=0.090) and FFI-Activity Limitation (p=0.12) scores were similar between the groups. To understand the cause of insufficiency and difficulty in routine activities, the correlations between BMI, FFI's alt parameters and MFPDI were investigated in both groups, separately. Accordingly, BMI scores had a significant correlation only with FFI-Pain (p=0.002). BMI was not correlated with FFI-Activity Limitation, FFI-Disability, or MFPDI scores in the Non-obese group (p=0.661, p=0.257 and p=0.205, respectively). FFI-Pain scores were positively correlated with FFI-Activity Limitation, FFI-Disability and MFPDI scores in the Non-Obese Group (p<0.001, p=0.001 and p<0.001, respectively). FFI-Pain scores were positively correlated with FFI-Disability, FFI-Activity Limitation, and MFPDI scores in the Obese Group (p<0.001, p<0.001, and p=0.006, respectively). MFPDI scores were correlated with all FFI subscale scores in the Non-Obese Group (p<0.001). Besides, MFPDI scores were correlated with FFI-Activity Limitation, FFI-Disability and FFI-Pain in the Obese Group (p<0.001, p=0.014 and p=0.006, respectively) (Table 3). The data showed that the number of postural sways had no significant correlation with BMI in both groups. There were no statistically significant correlations in FFI-Disability, FFI-Pain, FFI-Activity Limitation, or MFPDI scores with dynamic and static postural sway measurements in the Non-Obese Group. Similarly, despite the insufficiency and difficulty, the number of postural sways was correlated only with FFP-

Pain and FFI-Disability scores in the Obese Group, except during the static single leg standing test (Table 4).

**Table 1. Baseline characteristics of the groups.**

| | | Non-obese Group n (%) | Obese Group n (%) | $\chi^2$ | p |
|---|---|---|---|---|---|
| **Gender** | Female | 14 (51.85) | 19 (70.37) | 1.948 | 0.163 |
| | Male | 13 (48.15) | 8 (29.63) | | |
| **Marital status** | Married | 23 (85.19) | 23 (85.19) | 0.000 | 1.000 |
| | Widow | 3 (11.11) | 3 (11.11) | | |
| | Single | 1 (3.70) | 1 (3.70) | | |
| **Insulin use** | Yes | 11 (40.74) | 11 (40.74) | 0.000 | 1.000 |
| | No | 16 (59.26) | 16 (59.26) | | |
| **Education status** | Primary School | 13 (48.15) | 15 (55.56) | 3.467 | 0.483 |
| | Secondary School | 3 (11.11) | 2 (7.41) | | |
| | High School | 9 (33.33) | 6 (22.22) | | |
| | University | 2 (7.41) | 4 (14.81) | | |
| **Occupation** | Housewife | 11 (40.74) | 12 (44.44) | 2.435 | 0.296 |
| | Retired | 10 (37.03) | 13 (48.15) | | |
| | Working | 6 (22.22) | 2 (7.41) | | |

$\chi^2$: chi squared test

**Table 2. Comparison of balance, FFI and MFPDI scores of non-obese and obese diabetes mellitus patients.**

| | | | | Non-Obese group (n=27) | Obese group (n=27) | z | p |
|---|---|---|---|---|---|---|---|
| **The Number of Postural** | **Static Balance** | **Eyes open** | **Double Leg** | 712.93±602.21 | 679.78±406.56 | -0.277 | 0.782 |
| | | | **R Single Leg** | 1250.88±1065.46 | 1261.35±693.66 | -1.007 | 0.314 |
| | | | **L Single Leg** | 979.12±696.69 | 1130.15±728.08 | -1.016 | 0.310 |
| | | **Eyes closed** | **Double Leg** | 1266.04±697.77 | 1488.24±795.76 | -0.999 | 0.318 |
| | | | **R Single Leg** | 1579.60±942.70 | 1565.95±759.67 | -0.640 | 0.522 |
| | | | **L Single Leg** | 1657.83±932.14 | 1881.68±1265.49 | -0.220 | 0.826 |
| | **Dynamic Balance** | **Clockwise** | | 2023.96±459.33 | 2139.67±542.09 | -0.554 | 0.580 |
| | | **Counter clockwise** | | 1894.04±352.394 | 2150.52±593.03 | -1.254 | 0.132 |
| **Mean Score** | **FFI** | **Pain** | | 36.44±31.75 | 54.88±40.59 | -1.697 | 0.090 |
| | | **Disability** | | 34.25±41.06 | 68.0±37.90 | -3.118 | **0.002**** |
| | | **Activity limitation** | | 9.25±13.14 | 11.29±10.31 | -1.555 | 0.120 |
| | **MFPDI** | | | 10.92±7.98 | 15.33±8.38 | -1.984 | **0.047*** |

**FFI:** Foot Function Index, **MFPDI:** Manchester Foot Pain and Disability Index, **R:** Right, **L:** Left, **z:** Mann-Whitney U test, *p<0.05, **p<0.001

**Table 3. Correlation between BMI, FFI and MFPDI scores of patients with diabetes mellitus.**

| | **BMI** | | **FFI-P** | | **FFI-D** | | **FFI-A** | | **MFPDI** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Non-obese group** | **rho** | **p** | **rho** | **p** | **rho** | **p** | **rho** | **p** | **rho** | **p** |
| **BMI** | 1.0 | | 0.567 | **0.002**** | 0.226 | 0.257 | 0.088 | 0.661 | 0.252 | 0.205 |
| **FFI-P** | 0.567 | **0.002**** | 1.0 | | 0.615 | **0.001**** | 0.637 | **0.000**** | 0.698 | **0.000**** |
| **FFI-D** | 0.226 | 0.257 | 0.615 | **0.001**** | 1.000 | | 0.776 | **0.000**** | 0.630 | **0.000**** |
| **FFI-A** | 0.088 | 0.661 | 0.637 | **0.000**** | 0.776 | **0.000**** | 1.0 | | 0.708 | **0.000**** |
| **MFPDI** | 0.252 | 0.205 | 0.698 | **0.000**** | 0.630 | **0.000**** | 0.708 | **0.000**** | 1.0 | |
| **Obese group** | | | | | | | | | | |
| **BMI** | 1.0 | | 0.161 | 0.424 | 0.212 | 0.308 | 0.132 | 0.512 | 0.246 | 0.215 |
| **FFI-P** | 0.161 | 0.424 | 1.0 | | 0.686 | **0.000**** | 0.638 | **0.000**** | 0.513 | **0.006**** |
| **FFI-D** | 0.212 | 0.308 | 0.686 | **0.000**** | 1.0 | | 0.584 | **0.002**** | 0.486 | **0.014*** |
| **FFI-A** | 0.132 | 0.512 | 0.638 | **0.000**** | 0.584 | **0.002**** | 1.0 | | 0.712 | **0.000**** |
| **MFPDI** | 0.246 | 0.215 | 0.513 | **0.006*** | 0.486 | **0.014*** | 0.712 | **0.000**** | 1.0 | |

**BMI:** Body Mass Index, **FFI-P:** Foot Function Index-Pain Subscale, **FFI-D:** Foot Function Index-Disability Subscale, **FFI-A:** Foot Function Index-Activity Limitation Subscale, **MFPDI:** Manchester Foot Pain and Disability Index, **rho:**Spearman Correlation test, *p<0.05, **p≤0.005.

**Table 4. Correlation between postural sway, and BMI, FFI and MFPDI scores of patients with diabetes mellitus.**

| | | | | BMI | | FFI-P | | FFI-D | | FFI-A | | MFPDI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Non-Obese Group** | | | | **rho** | **p** | **rho** | **p** | **rho** | **p** | **rho** | **p** | **rho** | **p** |
| **The Number of Postural Sway** | **Static Balance** | **Eyes open** | **Double** | 0.184 | 0.358 | -0.184 | 0.359 | 0.020 | 0.921 | -0.056 | 0.782 | -0.058 | 0.775 |
| | | | **R Single** | 0.071 | 0.729 | -0.199 | 0.331 | -0.233 | 0.253 | -0.258 | 0.203 | -0.017 | 0.934 |
| | | | **L Single** | 0.008 | 0.669 | -0.038 | 0.852 | 0.138 | 0.502 | 0.010 | 0.960 | 0.201 | 0.326 |
| | | **Eyes closed** | **Double** | 0.276 | 0.172 | -0.099 | 0.630 | 0.031 | 0.879 | -0.137 | 0.503 | 0.076 | 0.713 |
| | | | **R Single** | 0.287 | 0.164 | 0.083 | 0.693 | 0.170 | 0.416 | 0.064 | 0.762 | 0.136 | 0.517 |
| | | | **L Single** | -0.095 | 0.658 | 0.118 | 0.582 | 0.243 | 0.252 | 0.114 | 0.596 | 0.028 | 0.897 |
| | **Dynamic Balance** | **Clockwise** | | -0.126 | 0.532 | 0.031 | 0.877 | 0.014 | 0.946 | -0.061 | 0.763 | 0.053 | 0.793 |
| | | **Counter clockwise** | | -0.202 | 0.311 | 0.202 | 0.312 | 0.289 | 0.144 | 0.175 | 0.382 | 0.092 | 0.649 |
| **Obese Group** | | | | | | | | | | | | | |
| **The Number of Postural Sway** | **Static Balance** | **Eyes open** | **Double** | 0.171 | 0.394 | 0.141 | 0.483 | 0.013 | 0.953 | -0.047 | 0.814 | 0.187 | 0.351 |
| | | | **R Single** | -0.172 | 0.400 | 0.385 | 0.052 | 0.191 | 0.372 | -0.054 | 0.794 | -0.122 | 0.554 |
| | | | **L Single** | 0.080 | 0.699 | 0.345 | 0.084 | 0.425 | **0.038*** | 0.082 | 0.689 | -0.079 | 0.702 |
| | | **Eyes closed** | **Double** | 0.156 | 0.457 | -0.157 | 0.454 | 0.046 | 0.833 | -0.153 | 0.465 | 0.059 | 0.780 |
| | | | **R Single** | 0.282 | 0.243 | 0.521 | **0.022*** | 0.337 | 0.158 | 0.051 | 0.836 | 0.093 | 0.704 |
| | | | **L Single** | 0.053 | 0.830 | 0.276 | 0.253 | 0.087 | 0.724 | -0.107 | 0.662 | 0.036 | 0.884 |
| | **Dynamic Balance** | **Clockwise** | | -0.067 | 0.742 | 0.151 | 0.451 | 0.280 | 0.175 | -0.135 | 0.501 | 0.053 | 0.792 |
| | | **Counter clockwise** | | 0.045 | 0.825 | 0.355 | 0.069 | 0.306 | 0.138 | 0.162 | 0.402 | 0.247 | 0.214 |

**BMI:** Body Mass Index, **FFI-P:** Foot Function Index-Pain Subscale, **FFI-D:** Foot Function Index-Disability Subscale, **FFI-A:** Foot Function Index-Activity Limitation Subscale, **MFPDI:** Manchester Foot Pain and Disability Index. **R:** Right, **L:** Left, **rho:** Spearman Correlation test, *p<0.05.

**DISCUSSION**

The major finding of the current study was that patients with DM had foot pain and pain-related disability whether they were obese or not. Also, BMI was related only with foot pain rather than insufficiency, disability, participation, or balance in non-obese individuals with DM. Besides, increased BMI caused a secondary negative effect on sufficiency, activity limitation, and participation. Previous studies suggest that DM related peripheral neuropathy contributes to the development of abnormal degenerative structure in diabetic plantar lesions. Here, diabetic neuropathy was not detected in any of the cases. However, it has been reported that plantar enthesopathy can be seen in the absence of diabetic neuropathy (Ursini et al., 2017). Individuals with DM have loss of protective sensation and decreased muscle strength, especially in lower extremity muscles. In patients with DM, insufficiency of movement in sensorimotor functions may result in a greater decrease in balance and postural control compared to healthy individuals (Lim, Kim, Noh, Yoo, & Moon, 2014). The sensorial flexibility and feedback of the foot in stance might be affected from the pathological stiffening of the ankle–foot complex and this may have a subsequent impact on postural balance in standing (Cheing, Chau, Kwan, Choi, & Zheng, 2013). In addition to balance problems that may occur due to DM, increased BMI may affect balance because of the increased mechanical load on the foot. Studies have investigated the relationship between obesity and nutrition in patients with DM (Ottum & Mistry, 2015; Singh, Barden, Mori, & Beilin, 2001), although the effect of obesity on balance has not been studied much. According to the findings of Frames et al., BMI≥30 is a significant risk factor for balance disorders (Frames et al., 2018). The increased stiffness of plantar soft tissue might make the feet more vulnerable to plantar pressure in stance, which possibly cause difficulties in maintaining balance and standing on different surfaces (Cheing et al., 2013). In our study, the non-obese group generally showed less oscillations in all balance tests, except static balance with eyes opened, double foot position and eyes closed, right single foot position (Table 2). Although increased BMI clearly increases postural oscillations and causes imbalance (Cheing et al., 2013), there was no statistically significant difference between the balance scores of the two groups from SportKAT-550. The duration of foot pain and obesity were not questioned in this study, which might have affected our results. We thought that the DM patients who participated in our study used to manage with obesity and plantar pain, so they found the appropriate balance strategies according to their situation. The other two causes for these findings could be because our study was performed in DM patients just with plantar pain. The presence of DM and plantar pain might have obscured the effects of obesity on balance. The obese group demonstrated a greater deficiency in terms of sufficiency and related disabilities. Difficulty in functional use of the foot may be due to structural degeneration of the foot simultaneously with increased BMI. Increased BMI and DM cause a decrease in the stiffness of plantar fascia during weight-bearing activities and an increase in the thickness of the plantar fascia. The increase in body mass could cause deformation in the mechanical features of the plantar fascia (Duffin, Lam, Kidd, Chan, & Donaghue, 2002; Taş, Bek, Ruhi Onur, & Korkusuz, 2017). So, changes in plantar tissue thickness can deteriorate normal foot mechanics and contribute to insufficiency with high energy demands and significantly higher plantar pressure during walking. Especially, obese people with DM are under risk for plantar pain (Mohammad, Chusid, Trepal, & Battaglia, 2015). This cross-sectional and comparative study showed that obesity caused a significant increase in FFI insufficiency and MFPDI scores. Increased peak plantar pressure are highly associated with risk for future diabetic foot pain and complications (Hazari et al., 2016). As stated in the literature, this survey also highlighted that people have increased difficulty in mobilization and transfer activities such as walking down stairs. However, we found that they did not cause loss of balance or activity limitation despite these difficulties. Even though they experienced difficult periods, they succeeded in continuing their daily life activities. Plantar pain was the main outcome measure in the present study, because it is one of the main reasons that cause DM patients to have insufficiency and difficulty in daily activities. According to intergroup comparisons, even though pain, postural sway, and activity limitation levels were similar, increased BMI affected sufficiency status and related disabilities. To provide homogeneity with regards to BMI, separation of participants into two groups had given us an opportunity to evaluate and interpret the main effects of plantar pain on insufficiency and difficulty in daily life activities using correlation analyses. In agreement with the literature (Mickle & Steele, 2015), the results of this study counter the controversial issue on how and when increased BMI leads to negative functional influences on foot and routine daily activities. The increase in peak plantar pressure due to higher ground reaction force and repetitive microtrauma are the most important etiological factors for the pathogenesis of diabetic foot syndrome (Hazari et al., 2016). This was also observed here and we concluded that increased body composition, especially when BMI is below 30, appears to cause an increase in plantar pain. The results suggest that pre-obesity weight gain causes plantar pain rapidly and sharply by lowering the pain threshold in diabetics, whereas post-obesity weight gain does not have a significant association with the characteristic of severe pain developed before obesity. Besides, FFI-Pain was significantly correlated with MFPDI, FFI-Activity Limitation and FFI-Disability in both groups with DM. These results reflect that even a very small change in the BMI of non-obese DM individuals could cause an increase in plantar pain, leading to functional difficulties. Plantar pain is a difficult symptom to manage and frequently progresses to a chronic condition. In parallel with our findings, Barnes et al. reported no difference between acute and chronic plantar pain with regards to BMI (Barnes, Sullivan, Pappas, Adams, & Burns, 2017). Nevertheless, increased plantar pain associated with any cause increases the level of disability and activity limitation, reducing the rate of participation (Moes, 2019). So, the most important predictive and inhibitory factor for normal foot function following DM appears to be the severity of plantar pain, which we focused on in this study. However, decreasing this prevalence, performing screening, and providing treatment for plantar pain and overweight status in the DM population would require dramatic changes, such as comprehensively implemented population policies. Foot problems including pain and dysfunction and balance problems cause a risk of falling and may affect each other (Awale et al., 2017). A previous study showed that the functional limitations of elders with DM were different from those of healthy elders during different tasks. So, assessment of balance was advised to address foot problems and to maintain foot function, independence, and safety for elder patients with DM (Tsai et al., 2016). However, analgesic and functional interventions such as mobilization and massage to stimulate plantar mechanoreceptors have demonstrated positive effects on postural control and balance (Vaillant et al., 2009). We examined correlation between balance and foot problems between two groups according to BMI and determined that BMI was not correlated with balance. Correlation analysis in homogeneous groups formed for BMI provided an opportunity to examine the correlation between balance, plantar pain, sufficiency, disability, activity limitation, and participation. Our findings proposed that the association between static and dynamic balance and foot symptoms did not differ according to BMI in individuals with DM. DM individuals at high risk of plantar pain, whether obese or not, could be targeted with intensive efforts to prevent, delay, or revert plantar pain. There were some strengths and limitations that should be addressed concerning the current research. The main strengths of this study lie on the comparative and interdisciplinary design, objective measurement methods, and the findings that can guide other studies. Considering the limitations, the number of participants remains relatively small. Secondly, comparisons with an sex and age-matched healthy control group could be included in future studies. Thirdly, our study was planned as a cross-sectional research and conducted only on individuals with DM and plantar pain. The study could have been planned as a prospective research and include radiological measurements and laboratory data such as HbA1c. Finally, although patients with diabetic neuropathy or other comorbidities were excluded, variables such as medications or management of diabetes may not have been well controlled.

## CONCLUSION

The results of this study report that BMI has a direct negative effect on sufficiency and disability and an indirect effect on activity limitation and reduced participation rate in individuals with DM. Plantar pain shows to be the primary cause of functional limitations of the foot. Therefore, considering plantar pain, researchers and clinicians could plan a more goal-oriented rehabilitation and monitoring programs in managing the difficulties in functional problems of the foot in individuals with DM, especially for various daily activities. Further longitudinal studies with long-term follow-up including a healthy control group and DM patients without pain and normal BMI values are needed to explore the primary effects and contributions to causality of DM and obesity on balance, plantar pain, and foot function. Including radiological-based measurements will also increase objectivity.

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**Conflict of Interest**

No potential conflict of interest relevant to this article was reported

**Author Contributions**

**Plan, design:** MD, NCK; **Material, methods and data collection:** MD, NCK, BK, SMF; **Data analysis and comments:** MD, NCK, BK; **Writing and corrections:** MD, NCK, BK, SMF.

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## REFERENCES

Awale, A., Hagedorn, T. J., Dufour, A. B., Menz, H. B., Casey, V. A., & Hannan, M. T. (2017). Foot function, foot pain, and falls in older adults: the Framingham foot study. *Gerontology,* 63(4), 318-324. https://doi.org/10.1159/000475710.

Barnes, A., Sullivan, J., Pappas, E., Adams, R., & Burns, J. (2017). Clinical and functional characteristics of people with chronic and recent-onset plantar heel pain *The Journal of Injury, Function and Rehabilitation*, 9(11), 1128-1134. https://doi.org/1 0.1016/j.pmrj.2017.04.009.

Chatterton, B. D., Muller, S., & Roddy, E. (2015). Epidemiology of posterior heel pain in the general population: Cross-sectional findings from the clinical assessment study of the foot. *Arthritis Care & Research,* 67(7), 996-1003. https:// doi.org/10.1002/acr.22546.

Cheing, G. L., Chau, R. M., Kwan, R. L., Choi, C. H., & Zheng, Y. P. (2013). Do the biomechanical properties of the ankle–foot complex influence postural control for people with Type 2 diabetes?. *Clinical Biomechanics,* 28(1), 88-92. https://doi.org/10.1016/j.clinbiomech.2012.09.001.

Colberg, S. R., Sigal, R. J., Yardley, J. E., Riddell, M. C., Dunstan, D. W., Dempsey, P. C., ... & Tate, D. F. (2016). Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. *Diabetes Care*, 39(11), 2065-2079. https://doi.org/10.2337/dc16-1728.

Duffin, A. C., Lam, A., Kidd, R., Chan, A. K. F., & Donaghue, K. C. (2002). Ultrasonography of plantar soft tissues thickness in young people with diabetes. *Diabetic Medicine,* 19(12), 1009-1013. https://doi.org/10.10 46/j.1464-5491.2002.00850.x.

Frames, C. W., Soangra, R., Lockhart, T. E., Lach, J., Ha, D. S., Roberto, K. A., & Lieberman, A. (2018). Dynamical properties of postural control in obese community-dwelling older adults. *Sensors*, 18(6), 1692. https://doi.org/10.3390/s18061692.

Garrow, A. P., Papageorgiou, A. C., Silman, A. J., Thomas, E., Jayson, M. I., & Macfarlane, G. J. (2000). Development and validation of a questionnaire to assess disabling foot pain. *Pain,* 85(1-2), 107-113. https://doi.org/10.1016/S0304-3959(99)00263-8.

Giacomozzi, C., D’ambrogi, E., Uccioli, L., & Macellari, V. (2005). Does the thickening of Achilles tendon and plantar fascia contribute to the alteration of diabetic foot loading?. *Clinical Biomechanics*, 20(5), 532-539. https://doi.org/10.1016/j.clinbiomech.2005.01.011.

Gomes, A. A., Ackermann, M., Ferreira, J. P., Orselli, M. I. V., & Sacco, I. C. (2017). Muscle force distribution of the lower limbs during walking in diabetic individuals with and without polyneuropathy. *Journal Of Neuroengineering And Rehabilitation,* 14(1), 1-13. https://doi.org/10.1186/s12984-017-0327-x.

Hansen, M. S., Dieckmann, B., Jensen, K., & Jakobsen, B. W. (2000). The reliability of balance tests performed on the kinesthetic ability trainer (KAT 2000). *Knee Surgery, Sports Traumatology, Arthroscopy*, 8(3), 180-185. https://doi.org/10.1007/s001670050211.

Hazari, A., Maiya, A. G., Shivashankara, K. N., Agouris, I., Monteiro, A., Jadhav, R., ... & Mayya, S. S. (2016). Kinetics and kinematics of diabetic foot in type 2 diabetes mellitus with and without peripheral neuropathy: a systematic review and meta-analysis. *Springerplus,* 5(1), 1-19. https://doi.org/10.1186/s40 064-016-3405-9.

Kera, T., Kawai, H., Hirano, H., Kojima, M., Watanabe, Y., Fujiwara, Y., ... & Obuchi, S. (2018). Comparison of body composition and physical and cognitive function between older Japanese adults with no diabetes, prediabetes and diabetes: a cross-sectional study in community-dwelling Japanese older people. *Geriatrics & Gerontology International,* 18(7), 1031-1037. https://doi.org/10.1111/ggi.13301.

Külünkoğlu, B., Firat, N., Yildiz, N. T., & Alkan, A. (2018). Reliability and validity of the Turkish version of the Foot Function Index in patients with foot disorders. *Turkish Journal of Medical Sciences*, 48(3), 476-483. https://doi.org/10.3906/sag-1705-143.

Lim, K. B., Kim, D. J., Noh, J. H., Yoo, J., & Moon, J. W. (2014). Comparison of balance ability between patients with type 2 diabetes and with and without peripheral neuropathy. *Archives of Physical Medicine and Rehabilitation*, 6(3), 209-214. https://doi.org/10.1016/j.pmrj.2013.11.007.

Matos, M., Mendes, R., Silva, A. B., & Sousa, N. (2018). Physical activity and exercise on diabetic foot related outcomes: A systematic review. *Diabetes Research and Clinical Practice,* 139, 81-90. https://doi.org/10.1016/j.diabres.2018.02.020.

Menz, H. B., Munteanu, S. E., Zammit, G. V., & Landorf, K. B. (2010). Foot structure and function in older people with radiographic osteoarthritis of the medial midfoot. *Osteoarthritis and Cartilage*, 18(3), 317-322. https://doi.org/10.1016/j.joca.200 9.11.010.

Mickle, K. J., & Steele, J. R. (2015). Obese older adults suffer foot pain and foot-related functional limitation. *Gait & Posture*, 42(4), 442-447. https://doi.org/10.1016/j.gaitpost.2015.07.013.

Moes, J. (2019). Proper fitting shoes: reducing pain, increasing activity, and improving foot health among adults experiencing homelessness. *Public Health Nursing,* 36(3), 321-329. https://doi.org/10.1111/phn.12604.

Mohammad, R., Chusid, E., Trepal, M., & Battaglia, F. (2015). Severe chronic heel pain in a diabetic patient with plantar fasciitis successfully treated through transcranial direct current stimulation. *Journal of the American Podiatric Medical Association*, 105(2), 173-176. https://doi.org/10.7547/0003-0538-105.2.173.

Nomura, T., Kawae, T., Kataoka, H., & Ikeda, Y. (2018). Assessment of lower extremity muscle mass, muscle strength, and exercise therapy in elderly patients with diabetes mellitus. *Environmental Health and Preventive Medicine,* 23(1), 1-7. https://doi.org/10.1186/s12199-018-0710-7.

Ottum, M. S., & Mistry, A. M. (2015). Advanced glycation end-products: modifiable environmental factors profoundly mediate insulin resistance. *Journal of Clinical Biochemistry and Nutrition,* 57(1), 1-12. https://doi.org/10.3164/jcbn.15-3.

Rosenbaum, A. J., DiPreta, J. A., Misener, D. (2014). Plantar heel pain, *Medical Clinics of North America,* 98(2), 339-352. https://doi.org/10.1016/j.mcn a.2013.10.009. .

Singh, R. B. A. M., Barden, A., Mori, T., & Beilin, L. (2001). Advanced glycation end-products: a review. *Diabetologia,* 44(2), 129-146. https://doi.org/10.1 007/s001250051591.

Tanamas, S. K., Wluka, A. E., Berry, P., Menz, H. B., Strauss, B. J., Davies-Tuck, M., ... & Cicuttini, F. M. (2012). Relationship between obesity and foot pain and its association with fat mass, fat distribution, and muscle mass. *Arthritis Care & Research,* 64(2), 262-268. https://doi.org/10.1002/acr.20663.

Taş, S., Bek, N., Ruhi Onur, M., & Korkusuz, F. (2017). Effects of body mass index on mechanical properties of the plantar fascia and heel pad in asymptomatic participants. *Foot & Ankle International,* 38(7), 779-784. https://doi.org/ 10.1177/1071100717702463.

Tsai, Y. J., Yang, Y. C., Lu, F. H., Lee, P. Y., Lee, I. T., & Lin, S. I. (2016). Functional balance and its determinants in older people with diabetes. *PloS one,* 11(7), e0159339. https://doi.org/10.1371/journal.pone.0159339.

Ursini, F., Arturi, F., Nicolosi, K., Ammendolia, A., D'Angelo, S., Russo, E., ... & Grembiale, R. D. (2017). Plantar fascia enthesopathy is highly prevalent in diabetic patients without peripheral neuropathy and correlates with retinopathy and impaired kidney function. *PLoS One*, 12(3), e0174529. https://doi.org/10.1371/journal.pone.0174529.

Vaillant, J., Rouland, A., Martigné, P., Braujou, R., Nissen, M. J., Caillat-Miousse, J. L., ... & Juvin, R. (2009). Massage and mobilization of the feet and ankles in elderly adults: effect on clinical balance performance. *Manual Therapy,* 14(6), 661-664. https://doi.org/10.1016/j.math.2009.03.004