

Performance of the lower limb musculoskeletal system in patients with different degree of diabetic ulcer risk

Snježana Novaković Bursać (✉ snjezana.nb@ms.zotovicbl.org)

Institute for physical medicine and rehabilitation „Dr Miroslav Zotović“ <https://orcid.org/0000-0001-7499-8537>

Goran Talić

Institute for Physical Medicine and Rehabilitation "Dr Miroslav Zotović"

Nataša Tomić

Institute for Physical Medicine and Rehabilitation "Dr Miroslav Zotović"

Slavica Jandrić

Univerzitet u Banjoj Luci Medicinski Fakultet

Research

Keywords: diabetes, diabetic foot ulcer, muscle strength, muscle weakness, range of motion

Posted Date: August 13th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-55950/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background

The objective of the study was to determine the correlation between the biomechanical parameters: ankle and foot muscle strength, range of motion (ROM) at ankle joint (AJ), subtalar joint (SJ) and first metatarsophalangeal joint (I MTP) in patients with different diabetic ulcer risk assessed by IWGDF 2019 Guidance risk stratification system.

Method

A cross-sectional study included 100 diabetic patients. The patients were classified into 4 risk categories of development of diabetic foot ulcer (DFU) applying IWGDF Guidelines 2019 stratification risk system. The function of ten foot and ankle muscles was evaluated by manual muscle testing and application of the Michigan Diabetic Neuropathy Score (MDNS) system. The range of motion ROM at the ankle, subtalar and first metatarsophalangeal joint was measured with a goniometer. The risk assessment was done applying IWGDF Guidelines 2019 stratification risk system. To test the statistical significance the ANOVA test was applied.

Results

Average muscle strength in specified categories was category 0:9.2; category 1:13.9; category 2:13.3; category 3:15.2. Average ROM at AJ in specified categories was: category 0:49.3°; category 1:48.8°; category 2:45.5°; category 3:44.6°. Average ROM at SJ in specified categories was: category 0:37.8°; category 1:31.3°; category 2:35°; category 3:28.7°. Average ROM at I MTP in specified categories was: category 0:78.6°; category 1:74.4°; category 2:65.5°; category 3:57.9°.

Conclusion

The risk for DFU significantly correlates with foot muscle strength and ROM at SJ, and I MTP, but does not with ROM at AJ.

1. Background

Diabetic foot ulcer (DFU), as one of the most severe diabetic complications of the lower extremities, will be developed in up to 34% of persons with diabetes during their lifetime [1]. Amputation, as the most serious complication of diabetes in the lower extremities, takes place every 20 seconds somewhere in the world [2]. Although the data on the burden of diabetes mellitus are very obvious, this complication is underestimated in scientific and clinical practice compared to other diabetes complications [3].

DFU is usually developed as a result of several risk factors present in people with diabetes, with diabetic peripheral neuropathy (DPN) and peripheral arterial disease (PAD) usually playing a central role in this process [4]. DFU development is related to an abnormal pattern of plantar pressure distribution caused by

alterations in the foot rollover process due to loss of foot-ankle muscular strength, range of motion (ROM), and nervous function, as their integrity is needed to enable proper load absorption on the plantar surface [5-9]. The ROM at joints is altered in diabetes [10] and can result in abnormally high intrinsic plantar pressures and lead to plantar ulceration, but only as a contributor to other risk factors [11]. There is evidence that elevated hyperglycaemia accelerates the loss in muscle size and strength, especially in the distal muscles of the lower leg [13]. Weakness evaluated by manual testing has been reported to be an independent risk factor for the development of foot ulcers, probably because muscle weakness at the ankle and knee in DPN leads to the abnormal application of pressure at the sole during gait due to alterations of the biomechanics of the feet [13,14].

Considering the above facts about the DFU burden, the health care profession's noble quote is worth stating: "prevention is better than the treatment of the disease," the earlier the intervention, the better the outcome. [15]. Unfortunately, prevention does not receive top priority when it comes to diabetes. Two cornerstones of the preventative foot care are 1) to implement knowledge in daily foot care, and b) to improve treatment adherence [16]. According to the recommendations outlined in the Guidelines on the prevention and management of diabetic foot disease published by the International Working Group on the Diabetic Foot (IWGDF), identifying patients who are at risk for ulceration is the first step in prevention [4]. For the purpose of at-risk patient identification, the IWGDF has established a stratification system that also directs care interventions. Key risk factors include loss of protective sensation (LOPS), PAD, and foot deformity, history of foot ulceration, and any level of lower extremity amputations [17].

Relationship between the performances of the musculoskeletal system of the lower limb and the assessed DFU risk in diabetic patients has not yet been explored, however, it was assumed that the overall DFU risk is positively correlated with the decline of the lower extremity muscle performance. If there is a positive relationship between these two variables, it might be possible to establish an additional set of preventative measures to decrease the complications of DM of the lower extremities by using an active rehabilitative approach with the goal of muscle strengthening and increasing the mobility at the joint.

1.1 Objective

The objective of the study was to determine the correlation between the biomechanical parameters: ankle and foot muscle strength, ROM at ankle, subtalar and first metatarsophalangeal joint in patients with different diabetic ulcer risk assessed by IWGDF 2019 Guidance risk stratification system.

2. Methods

2.1. Design and subjects

Patients with both types of diabetes mellitus who are registered with primary health care physicians during 2014 were the subject of this cross-sectional study. The sample of 100 patients who entered the study consecutively consisted of patients from ten primary health care clinics who were seen for their

insulin needs or for their oral hypoglycemic medication management. The survey included medical records review, interview for the sake of detailed with the medical history , as well as measurement and testing of the patients. Medical records were the source of personal data, data on the type of DM, duration and management of the disease up to date, and HbA1c values not older than six months. [18,19]. The clinical examinations were performed routinely by the same examiner.

2.2.Diabetc foot risk assessment

Using the data obtained from comprehensive examinations and the history taking, the patients were classified into risk categories applying IWGDF Guidelines 2019 stratification risk system as follows: the risk category 0 - patients with normal findings; the risk category 1 (low risk) -patients with LOPS or PAD; the risk category 2 (moderate risk) - patients with LOPS + PAD, or LOPS + foot deformity or PAD + foot deformity; the risk category 3 (high risk) - patients who had LOPS or PAD, and one or more of the following: history of a foot ulcer, lower-extremity amputation, and end-stage renal disease [17].

LOPS was assessed as follows: vibration testing using a 128-Hz tuning fork, tests of pinprick sensation on the dorsum of foot, tactile sensation test using cotton wool on the dorsum of foot, and Achilles ankle reflex assessment [20,21]. Vibratory sensation was tested over the tip of the great toe bilaterally. Abnormal vibratory sensation was defined as a situation when the patient loses vibratory sensation while the examiner still perceives it with a 128-Hz tuning fork on the tip of the toe. A disposable pin was applied just proximal to the toenail on the dorsal surface of the hallux, with just enough pressure to deform the skin. The inability to perceive pinprick over either hallux was considered to be an abnormal test result. Ankle reflexes were tested using the tendon hammer, with the patient kneeling on a chair. Absence of ankle reflex either at rest or upon the reinforcement, was regarded as an abnormal result [22]. Inability to perceive the cotton wool touch on the dorsal surface of the foot was regarded as an abnormal test result. One or more abnormal tests would suggest LOPS, while at least two regular tests (and no abnormal test) would rule out LOPS [20].

Vascular examination included palpation of the posterior tibial and dorsalis pedis pulses bilaterally, which was characterized as either “present” or “absent” [22-24]. The presence of two or less of the four pedal pulses indicated PAD [23]. In patients with amputations, the result on the one leg counted twice.

2.3.Foot strenght assessment

Foot and ankle muscle function were evaluated with manual muscle testing (MMT) on the dominant leg. The same scoring system, which is used in the MDNS, was applied [18,25,26]. MMT indicates the ability of the tested muscle to produce an active movement against the examiner’s resistance. MMT was done on a dominant leg. Score 0 was for normal muscle strength, 1 for mild, 2 for severe muscle weakness, and 3 for complete loss of muscle strength. As described, the muscle score (MS) was obtained for each set of muscles that were examined. The minimum score was 0 (normal strength in 10 muscles) and the

maximum score was 30 (complete loss of strength in 10 muscles). Higher scores indicated increased muscle weakness [25,27]. In described testing positions, the manual clinical assessment [28] was performed for the following muscles: triceps surae, tibialis anterior, interosseus, lumbrical, flexor hallucis brevis, extensor digitorum brevis, extensor digitorum longus, flexor digitorum brevis, extensors hallucis longus, and extensor hallucis brevis [8].

2.4. Range of motion measurement

The joint mobility at the ankle joint (AJ), subtalar joint (SJ), and first metatarsophalangeal joint (I MTP) was determined using a goniometer on the dominant lower limb [29,30]. ROM at the AJ was measured with the patient in a supine position. The passive maximum range of talar flexion and extension were measured and the sum of the two values was recorded as ROM at the AJ [29]. The ROM at SJ was measured with the patient in a prone position. The maximum range of calcaneal inversion and eversion were measured and added up to indicate the ROM at the SJ. The range of passive extension to plantar flexion at the I MTP was measured with the patient supine and the ROM at the I MTP was recorded as the sum of those two values [29,30].

2.5. Foot deformities assessment

The presence of deformities such as hammer toes, claw toes, prominent metatarsal heads, and high medial arch were assessed using a foot deformity score. Hammer toes were defined as “a hyperextended metatarsophalangeal joint with a flexion deformity of the proximal interphalangeal joint and hyperextension of the distal interphalangeal joint”. Claw toes were defined as “hyperextension of the metatarsophalangeal joints and flexion of the proximal and distal interphalangeal joints”. Prominent metatarsal heads were defined as “any palpable plantar prominences of the metatarsal site of the foot”. Lastly, high medial arch was defined as “an abnormally high medial longitudinal arch”. A point was given for each deformity present to whatever degree, with a maximum score of 6 (3 for one leg) because subject could only score for one of the toe deformities. In patients with amputations, the result on the one leg counted twice [25,27]. Patient was defined as having a deformity if he/she had a score of 2 or more.

2.6. Statistical analyses

The statistical analyses were done using the software package "IBM SPSS Statistics". For a statistical analysis continuous data were presented as means and standard deviations. To test the statistical significance between variables, the one-way ANOVA test were applied. The cut off for the significance of the results was $p < 0.05$.

3. Results

In the sample of the 100 patients, there were more women (53%) than men (47%). The average age of the group was 61.91 years, SD \pm 10.74, and the average diabetes duration was 12.25 years, SD \pm 8.60. Based on the IWGDF Guidelines 2019 stratification risk system, patients were classified into one of the risk categories. The largest number (51%) of patients were classified into risk category 0. 16% of patients were classified into risk category 1, 21% into risk category 2, and 12% of patients were classified into risk category 3.

Table 1 - Mean and standard deviation and p-values of demographics

	0 (n=51)	1 (n=16)	2 (n=21)	3 (n=12)	p
Age (years)	60.5 \pm 11,4	66.6 \pm 8.8	62.3 \pm 9.9	61.1 \pm 9.0	0.2649 ¹
Males (%)	39.2	50	52.4	66.6	
Body mass index (kg/m ²)	27.7 \pm 4.1	27.5 \pm 4.2	26.8 \pm 3.9	28.1 \pm 5.7	0.8316 ¹
Diabetes duration (years)	10.1 \pm 7.1	14.5 \pm 7.5	11.8 \pm 8.5	19.3 \pm 10.8	*0.0045 ¹

¹ p values for the ANOVA tests, * Statistically significant difference

3.1. Ankle and foot muscle strenght

The average muscle strength in the patients who were classified into risk category 0 was 9.2, 13.9 for those in the risk category 1, 13.3 in the risk category 2, and 15.2 in the risk category 3, all of which are shown in Figure 1. The strength of ankle and foot muscles significantly declines with risk progression (F=9.37551, p=.0000).

3.2. ROM at ankle joint

The average ROM at AJ in the group of patients classified into risk category 0 was 49.3°, risk category 1 was 48.8°, risk category 2 was 45.5° and the risk category 3 was 44.6°, as shown in Figure 2. The average ROM at AJ in the groups of patients classified into different risk categories is not significantly different (F=.98757, p= .4020).

3.3. ROM at subtalar joint

The average ROM at SJ in the group of patients classified into risk category 0 was 37.8°, risk category 1 was 31.3°, risk category 2 was 35°, and the risk category 3 was 28.7°. The average ROM at SJ

significantly declines with risk progression ($F=5.53021$, $p=.0015$), as shown in Figure 3.

3.4. ROM at I MTP

The average ROM at I MTP in the group of patients classified into risk category 0 was 78.6° , risk category 1 was 74.4° , risk category 2 was 65.5° and those classified into risk category 3 was 57.9° . The average ROM at I MTP significantly declines with risk progression ($F=4.61539$, $p=.0046$) as shown at Figure 4.

4. Discussion

One hundred patients in the study group were classified into one of the risk categories based on the comprehensive foot examination and history taking. The majority of patients were classified into risk category 0 (51%) and the lowest number of patients were classified into risk category 3 (12%). So far, there are no published studies on distribution of patients into risk categories for development of diabetic ulcers applying IWGDF Guidelines 2019 stratification risk system, making any type of comparison not possible. The average age and body mass index are not statistically significant in patients classified into different risk categories, but diabetes duration differ significantly.

The average foot and ankle muscle strength in groups of patients classified into different risk categories significantly declines with risk progression. This indicates a positive correlation between muscle strength loss in the foot and the lower limb, and other DM complications of the lower extremities. Ferreira et al. have found that the hallux strengths decreased as risk of development of DFU increased [31], but there are no published studies on the overall risk for developing DM complications at lower extremities and ankle and foot muscle strength so far. The effects of the certain determining clinical elements for the risk categorization are explained. Risk category 0 determines the absence of positive clinical findings, so it is to be expected that patients classified into this category have greater muscle strength compared to those patients classified in the other risk categories with some complications. The presence of LOPS, PAD, and foot deformity is the determining factors for classifying patients into risk categories 1 and 2. The presence of the LOPS is due to the presence of a certain degree of DPN and many studies proved a strong association between DPN and the loss of muscle strength [32-35]. The muscle atrophy in diabetic patients is most pronounced in distal parts of the lower leg indicating a length-dependent neuropathic process [10]. The presence of PAD is also one of the determining factors for classifying patients into risk category 1 and 2. Regensteiner found the correlation between the PAD with chronic changes in affected muscle morphology and its function. Muscles in the region affected by PAD has demonstrated denervation and a reduction in the cross-sectional area of type II muscle fibers. In patients with PAD there is also a decrease in oxidative enzyme activities, more pronounced with increasing disease severity [36]. McDermott also confirmed that the PAD affects muscle strength, especially the distal lower extremity muscles [37]. Certain number of authors believe that there is a relationship between intrinsic foot muscle weakness caused by motor neuropathy and the development of foot deformities such as pes cavus, claw toe deformity, hammer toe deformity, and hallux valgus, however, this relationship has not been

sufficiently explored, especially regarding the muscle weakness level that affects the development of the deformities [38,39]. Patients classified into risk category 3 had ulcer or amputation in the history and the lowest muscular strength compared to patients classified into lower risk categories. Ulcers are most commonly of the neuropathic or neuro-ischemic origin [40] which means that the loss of muscle strength in patients classified in this risk category is primarily influenced by a neuropathic [14,32,34] and/or ischemic process [36]. The average ulcer healing time is 8 weeks [23] to 78 days [41], and in many cases the ulcer does not heal and pass into chronic wounds, which affects the mobility, loss of muscle fibers, and consequently loss of muscle strength. As 80% of the cases of amputations are preceded by an ulcer, the period of inactivity in patients with an amputation can be very prolonged and affects accelerated muscle loss, strength reduction, and functional capacity [42].

The mean ROM value at AJ in the study group is not statistically significant, but it is worth noting that the average value of the ROM at AJ drops from the lower to the higher risk category. The average value of ROM at SJ in patients classified into risk category 0 is 37.8°, and in patients classified into risk category 3 is 28.75°. It has been proven that there is a statistically significant difference in the mean values of the ROM at SJ between risk categories. The average value of ROM at the I MTP joint in patients classified into risk category 0 is 78.6°, and in patients classified into risk category 3 is the smallest, and it is 57.92°. This study has proved a strong relationship between the average values of ROM at I MTP joint in patients classified into different risk categories. There are no studies that explored the relationship between the values of ROM in different risk categories for development of DM complications at lower extremities. The limited joint mobility (LJM) at AJ and I MTP joint have been identified as a causing factor of local pressure increase and ulcer formation in patients with DPN [43]. LJM and reduction of the elasticity of the ankle in diabetic patients develop due to three mechanisms: (1) collagen glycosylation based on the hyperglycemic state; (2) shortening of triceps fibers, and (3) qualitative changes in connective tissue because of increasing in fibrous versus contractile tissue [44]. Lower ROM in patients classified into category 2 compared to the patients classified into the risk category 1 can be explained by the presence of additional qualitative changes in muscle tissue and formation of connective tissue due to ischemia in patients with PAD [36]. The lowest ROM in patients classified into category 3 characterized by history of ulcer or amputation can be explained by adaptive changes in the tissues resulting from the long-term inactivity of patients during the ulcer healing process, and more intensive tissue changes caused by hyperglycemia which primarily led to the onset of ulceration or amputation in these patients.

The main goals of physical therapy interventions in DM patients are to prevent complications, to reduce the effects of immobilization, to maintain functional capacity, and to minimize the onset of complications. Presently, in the majority of cases, physical therapies are applied when DFU and amputation have already occurred and only occasionally are used as preventative procedures [5-7]. This research highlights the significance of the continued surveillance and screening, along with some elements of biomechanical assessment of the feet in a primary care setting, intending to identify factors that can be influenced by active measures to reduce the incidence of diabetic complications on the lower extremities [45].

The limitation of this study is the fact that overall physical activity and fitness were not individually assessed as both parameters have impact on muscle strength. Assessment of the muscle strength is done using MMT which is more or less a subjective evaluation method. This weak spot in measurement objectivization is alleviated by utilization of a qualitative system used in MDNS which offers four grades of strength and measuring by the same examiner. The range of motion measurement is also performed by an examiner; however, the human error was minimized through high-quality preparation, including drawing lines from joint center using prongs. The use of subjective measure in the assessment of musculoskeletal system performance is justified when it is used meticulously and by a single examiner. Although many studies have shown a correlation between diabetes and some functions of the musculoskeletal system [25,27,29,30], there are no studies that evaluated the total risk for DFU development and performance, which presents another limitation in the area of methodology and the results themselves.

5. Conclusion

The risk for diabetic foot ulcer significantly correlates with decreased ankle and foot muscle strength, as well as decreased range of motion at the subtalar joint and first metatarsophalangeal joint, but it does not correlate with the range of motion at the ankle. It is a huge scientific and professional challenge to explore if an active approach through targeted physical therapy and rehabilitation procedures enhances the performance of the lower limb musculoskeletal system and thus slows down - or even stops progression of DM complications and reduces the risk of amputations. In conclusion, the simplicity and low cost of the assessment of the lower limb musculoskeletal performance could be an additional screening tool for of risk of developing DFU, mainly because its results could be the basis for another active preventative approach.

Abbreviations

DM - Diabetes mellitus

DFU - diabetic foot ulceration

DPN- diabetic peripheral neuropathy

PAD - peripheral arterial disease

LOPS - loss of protective sensation

ROM – the range of motion

IWGDF - International Working Group on the Diabetic Foot

MMT - manual muscle testing

MS - muscle score

AJ - ankle joint

SJ - subtalar joint

MDNS - Michigan Diabetic Neuropathy Score

I MTP - first metatarsophalangeal joint

LJM - limited joint mobility

Declarations

Ethics approval and consent to participate

Ethics were approved by the Primary Health Centre Banja Luka Ethics Review Committee (01-3802-1)

Written informed consent was obtained from all participants.

Availability of data and material

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

Competing interests:

None

Funding

The authors received no financial support for the research, authorship, and publication of this article.

Authors' contributions

SNB and SJ made the conception and design of the study. SNB performed data acquisition and statistical analysis and drafted the manuscript. SJ and NT revised the manuscript. GT contributed to the study design and coordination and revised the manuscript. Co-authors agreed with the finalized submission. All authors read and approved the final manuscript.

Acknowledgments

The authors would like to thank and acknowledge all the study participants who gave up their time to take part in this study. Thank you also to the colleagues from the Primary Health Centre Banja Luka and the Institute for physical medicine and rehabilitation „Dr Miroslav Zotović “Banja Luka for their assistance in carrying out the study.

References

1. Armstrong DG, Boulton AJM, Bus SA. Diabetic foot ulcers and their recurrence. *N Engl J Med*. 2017;376(24):2367-2375, [https://doi: 10.1056/NEJMra1615439](https://doi:10.1056/NEJMra1615439).
2. International Diabetes Federation. *The Diabetic Foot*. Brussels, Belgium: 2020. Available at: <https://idf.org/our-activities/care-prevention/diabetic-foot.html>
3. Bus, SA, van Netten, JJ, Monteiro-Soares, M, Lipsky, BA, Schaper, NC. Diabetic foot disease: "The Times They are A Changin' ". *Diabetes Metab Res Rev*. 2020; 36(S1):e3249, [https://doi: 10.1002/dmrr.3249](https://doi:10.1002/dmrr.3249).
4. Schaper, NC, van Netten, JJ, Apelqvist, J, Bus, SA, Hinchliffe, RJ, Lipsky, BA, IWGDF Editorial Board. Practical Guidelines on the prevention and management of diabetic foot disease (IWGDF 2019 update). *Diabetes Metab Res Rev*. 2020 Mar;36 Suppl 1:e3266, [https://doi: 10.1002/dmrr.3266](https://doi:10.1002/dmrr.3266).
5. Nagawa MHB, Shawky AF, Basant H. Gait Analysis in Patients with Diabetic Peripheral Neuropathy. *Med J Cairo Univ*. 2010; 78(2): 827-834.
6. Sawacha Z, Spolaor F, Guarneri G, Contessa P, Carraro E, Venturin A, Avogaro A, Cobelli C. Abnormal muscle activation during gait in diabetes patients with and without neuropathy. *Gait Posture*. 2012;35(1):101-5, <https://doi:10.1016/j.gaitpost.2011.08.016>.
7. Sartor CD, Hasue RH, Cacciari LP, Butugan MK, Watari R, Pássaro AC, et al. Effects of strengthening, stretching and functional training on foot function in patients with diabetic neuropathy: results of a randomized controlled trial. *BMC Musculoskelet Disord* 2014, 15:137, <https://doi:10.1186/1471-2474-15-137>.
8. Sartor CD, Watari R, Pássaro AC, Picon AP, Hasue RH et Sacco ICN. Effects of a combined strengthening, stretching and functional training program versus usual-care on gait biomechanics and foot function for diabetic neuropathy: a randomized controlled trial. *BMC Musculoskeletal Disorders* 2012, 13:36 Available at: <http://www.biomedcentral.com/1471-2474/13/36>
9. Sacco IC, Hamamoto AN, Gomes AA, Onodera AN, Hirata RP, Hennig EM Role of ankle mobility in foot rollover during gait in individuals with diabetic neuropathy. *Clin Biomech*. 2009;24(8):687-92, <https://doi:10.1016/j.clinbiomech.2009.05.003>
10. Alam U, Riley DR, Jugdey RS, Azmi S, Rajbhandari S, D'Août K, Malik RA. Diabetic Neuropathy and Gait: A Review. *Diabetes Ther*. 2017 Dec;8(6):1253-1264, <https://doi:10.1007/s13300-017-0295-y>.
11. Fernando DJ, Masson EA, Veves A, Boulton AJ. Relationship of limited joint mobility to abnormal foot pressures and diabetic foot ulceration. *Diabetes Care*. 1991;14(1):8-11, <https://doi:10.2337/diacare.14.1.8>.
12. Alam U, Riley DR, Jugdey RS, Azmi S, Rajbhandari S, D'Août K, Malik RA. Diabetic Neuropathy and Gait: A Review. *Diabetes Ther*. 2017 Dec;8(6):1253-1264, <https://doi:10.1007/s13300-017-0295-y>.
13. Andreassen CS, Jakobsen J, Andersen H. Muscle weakness: a progressive late complication in diabetic distal symmetric polyneuropathy. *Diabetes*. 2006 Mar;55(3):806-12.

14. Andersen H. Motor dysfunction in diabetes. *Diabetes Metab Res Rev.* 2012 Feb;28 Suppl 1:89-92, <https://doi:10.1002/dmrr.2257>.
15. Iraj B, Khorvash F, Ebneshahidi A, Askari G. Prevention of diabetic foot ulcer. *Int J Prev Med.* 2013;4(3):373- PMID: PMC3634178
16. Bus SA, van Netten. A shift in priority in diabetic foot care and research: 75% of foot ulcers are preventable. *Diabetes Metab Res Rev.* 2016 Jan;32 Suppl 1:195-200, <https://doi:10.1002/dmrr.2738>.
17. Bus, S, Lavery, L, Monteiro-Soares, M, et al. Guidelines on the prevention of foot ulcers in persons with diabetes (IWGDF 2019 update). *Diabetes Metab Res Rev.* 2020 Mar;36 Suppl 1:e3269, <https://doi:10.1002/dmrr.3269>.
18. Boyko EJ, Ahroni JH, Stensel V, Forsberg RC, Davignon DR, Smith DG; A prospective study of risk factors for diabetic foot ulcer. The Seattle Diabetic Foot Study. *Diabetes Care.* 1999;22(7):1036-42, <https://doi:10.2337/diacare.22.7.1036>.
19. Tapp RJ, Shaw JE, de Courten MP, et al. Foot complications in type 2 diabetes: an Australian population-based study. *Diabet Med.* 2003; 20:105–13; PMID: 12581261.
20. American Diabetes Association. Standards of Medical Care in Diabetes 2015. Position statement. *Diabetes Care* 2015; 38(1), <https://doi:10.2337/diacare.27.2007.s63>.
21. Singh N, Armstrong DG, Lipsky BA. Preventing foot ulcers in patients with diabetes. *JAMA* 2005; 293:217–28, <https://doi:10.1001/jama.293.2.217>.
22. Boulton AJ, Armstrong DG, Albert SF, Frykberg RG, Hellman R, Kirkman MS, et al. American Diabetes Association; American Association of Clinical Endocrinologists. Comprehensive foot examination and risk assessment: a report of the task force of the foot care interest group of the American Diabetes Association, with endorsement by the American Association of Clinical Endocrinologists. *Diabetes Care.* 2008;31(8):1679-85, <https://doi:10.2337/dc08-9021>.
23. Abbott CA, Carrington AL, Ashe H et al. The North-West Diabetes Foot Care Study: incidence of, and risk factors for, new diabetic foot ulceration in a community-based patient cohort. *Diabet Med.* 2002 May;19(5):377-84, <https://doi:10.1046/j.1464-5491.2002.00698.x>.
24. Mayfield JA, Reiber GE, Sanders LJ, Janisse D, Pogach LM, American Diabetes Association. Preventive foot care in diabetes. *Diabetes Care.* 2004; 27(1): S63-4, <https://doi:10.2337/diacare.26.2007.s78>.
25. van Schie CHM, Vermigli C, Carrington AL, Boulton A. Muscle weakness and foot deformities in diabetes: relationship to neuropathy and foot ulceration in caucasian diabetic men. *Diabetes Care.* 2004; 27: 1668-73, <https://doi:10.2337/diacare.27.7.1668>;
26. Feldman EL, Stevens MJ, Thomas PK, Brown MB, Canal N, Greene DA. A practical two-step quantitative clinical and electrophysiological assessment for the diagnosis and staging of diabetic neuropathy. *Diabetes Care.* 1994;17(11):1281-9, <https://doi:10.2337/diacare.17.11.1281>.
27. Bokan V. Muscle weakness and other late complications of diabetic polyneuropathy. *Acta Clin Croat.* 2011;50(3):351-5.

28. Lacote M, Chevalier AM, Miranda A, Bleton JP, Stevenin P. Clinical evaluation of muscle function. Edinburgh, London, Melbourn and New York: Churchill Livingstone, 1987.
29. Zimny S, Schatz H, Pfohl M. The role of limited joint mobility in diabetic patients with an at-risk foot. *Diabetes Care*. 2004; 27: 942-46, <https://doi:10.2337/diacare.27.4.942>.
30. Fernando DJ, Masson EA, Veves A, Boulton AJ. Relationship of limited joint mobility to abnormal foot pressures and diabetic foot ulceration. *Diabetes Care*. 1991;14(1):8-11, <https://doi:10.2337/diacare.14.1.8>.
31. Ferreira, J.S.S.P., Panighel, J.P., Silva, É.Q. et al. Foot function and strength of patients with diabetes grouped by ulcer risk classification (IWGDF). *Diabetol Metab Syndr* 11, 89 (2019), <https://doi.org/10.1186/s13098-019-0487-x>
32. Andersen H, Gjerstad MD, Jakobsen J. Atrophy of foot muscles: a measure of diabetic neuropathy. *Diabetes Care*. 2004;27(10):2382-5, <https://doi:10.2337/diacare.27.10.2382>.
33. Andersen H, Nielsen S, Mogensen CE, Jakobsen J. Muscle strength in type 2 diabetes. *Diabetes*. 2004;53(6):1543-8, <https://doi:10.2337/diabetes.53.6.1543>.
34. 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:10.2337/diabetes.55.03.06.db05-1237>.
35. Andreassen CS, Jakobsen J, Ringgaard S, Ejksjaer 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 Jun;52(6):1182-91, <https://doi:10.1007/s00125-009-1320-0>.
36. Regensteiner JG, Wolfel EE, Brass EP, Carry MR, Ringel SP, Hargarten ME, Stamm ER, Hiatt WR. Chronic changes in skeletal muscle histology and function in peripheral arterial disease. *Circulation*. 1993 Feb;87(2):413-21, <https://doi:10.1161/01.cir.87.2.413>.
37. McDermott MM, Tian L, Ferrucci L, Liu K, Guralnik JM, Liao Y, Pearce WH, Criqui MH. Associations between lower extremity ischemia, upper and lower extremity strength, and functional impairment with peripheral arterial disease. *J Am Geriatr Soc*. 2008 Apr;56(4):724-9, <https://doi:10.1111/j.1532-5415.2008.01633.x>.
38. Soysa A, Hiller C, Refshaug K, Burns J. Importance and challenges of measuring intrinsic foot muscle strength. *J Foot Ankle Res*. 2012;5(1):29. Published 2012 Nov 26, <https://doi:10.1186/1757-1146-5-29>.
39. Bus SA, Yang QX, Wang JH, Smith MB, Wunderlich R, Cavanagh PR. Intrinsic muscle atrophy and toe deformity in the diabetic neuropathic foot: a magnetic resonance imaging study. *Diabetes Care*. 2002 Aug;25(8):1444-50, <https://doi:10.2337/diacare.25.8.1444>.
40. Bakker K, Apelqvist J, Schaper NC; International Working Group on Diabetic Foot Editorial Board. Practical guidelines on the management and prevention of the diabetic foot 2011. *Diabetes Metab Res Rev*. 2012;28(1):225-31, <https://doi:10.1002/dmrr.2253>.
41. Jeffcoate WJ, Chipchase SY, Ince P, Game FL. Assessing the outcome of the management of diabetic foot ulcers using ulcer-related and person-related measures. *Diabetes Care* 2006;29(8):1784-7,

<https://doi:10.2337/dc06-0306>.

42. International Working Group on the Diabetic Foot. International Consensus on the Diabetic Foot: Practical Guidelines on the Management and the Prevention of the Diabetic Foot [CD-ROM]. Amsterdam, the Netherlands: International Working Group on the Diabetic Foot, 2005.
43. Frykberg RG, Zgonis T, Armstrong DG, Driver VR, Giurini JM, Kravitz SR et al. Diabetic foot disorders. A clinical practice guideline (2006 revision). *J Foot Ankle Srg.* 2006;45(5):1-66, [https://doi:10.1016/S1067-2516\(07\)60001-5](https://doi:10.1016/S1067-2516(07)60001-5).
44. Rao S, Saltzman C, Yack HJ. Ankle ROM and stiffness measured at rest and during gait in individuals with and without diabetic sensory neuropathy. *Gait Posture.* 2006;24(3):295-301, <https://doi:10.1016/j.gaitpost.2005.10.004>.
45. Formosa C, Gatt A, Chockalingam N. The importance of clinical biomechanical assessment of foot deformity and joint mobility in people living with type-2 diabetes within a primary care setting. *Primary Care Diabetes.* 2013;7(1):45-50, <https://doi:10.1900/RDS.2016.13.158>.

Figures

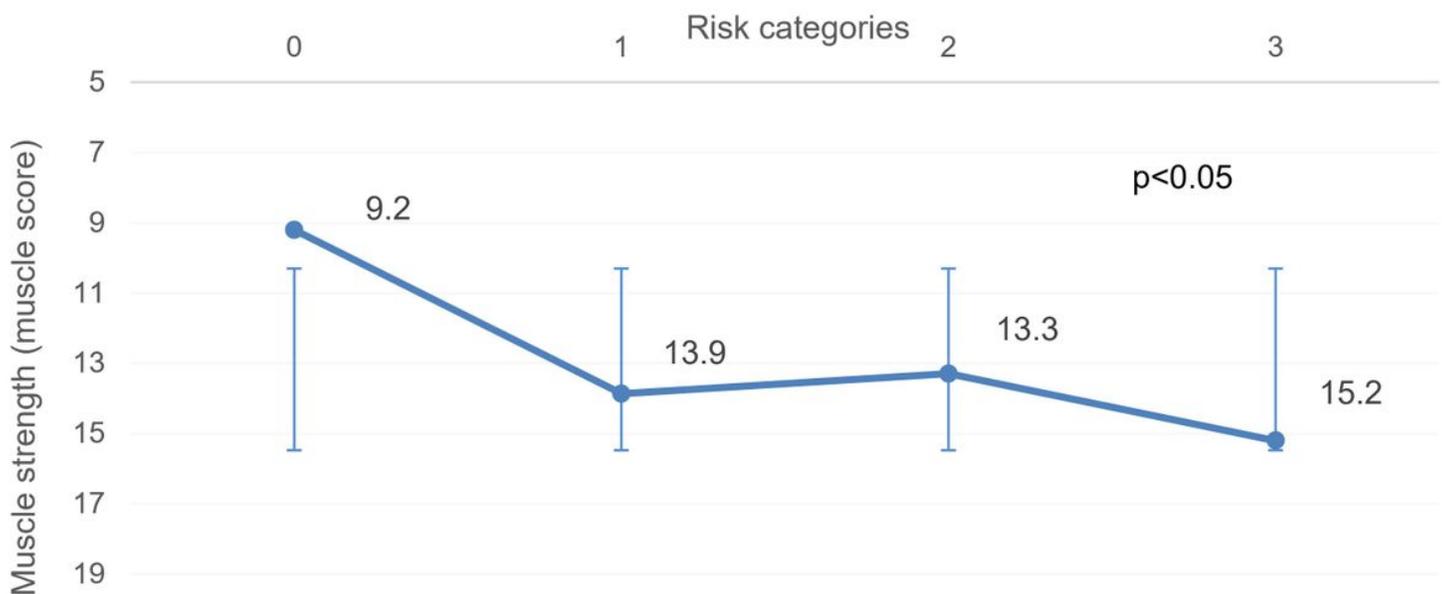


Figure 1

Muscle strength and risk for diabetic foot ulceration Score 0 was for normal muscle strength, 1 for mild, 2 for severe muscle weakness and 3 for complete muscle loss of strength. Minimum score was 0 (normal strength in 10 muscles) and maximum score was 30. Muscle strength in groups of patients classified into different diabetic foot ulcer risk categories significantly declines with risk progression; $p < 0.05$. Points represent the average muscle strength in the groups of diabetic patients classified into certain risk category followed by straight lines that represent their SDs.

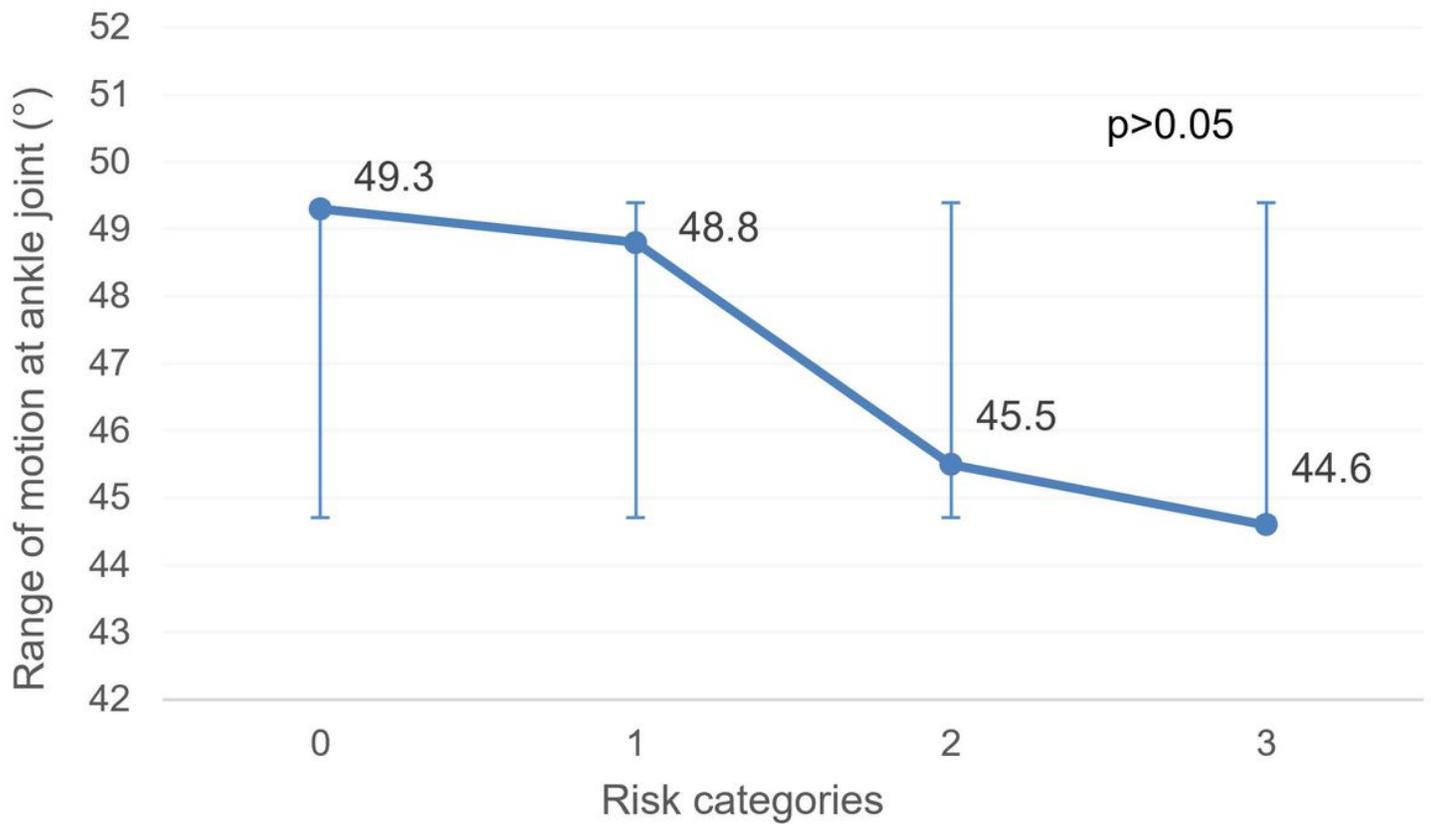


Figure 2

The range of motion at the ankle joint and risk for diabetic foot ulceration The average range of motion (ROM) at ankle joint (AJ) in groups of patients classified into different diabetic foot ulcer risk categories does not significantly differ; $p > 0.05$. Points represent the average ROM at AJ in the groups of diabetic patients classified into certain risk category followed by straight lines that represent their SDs.

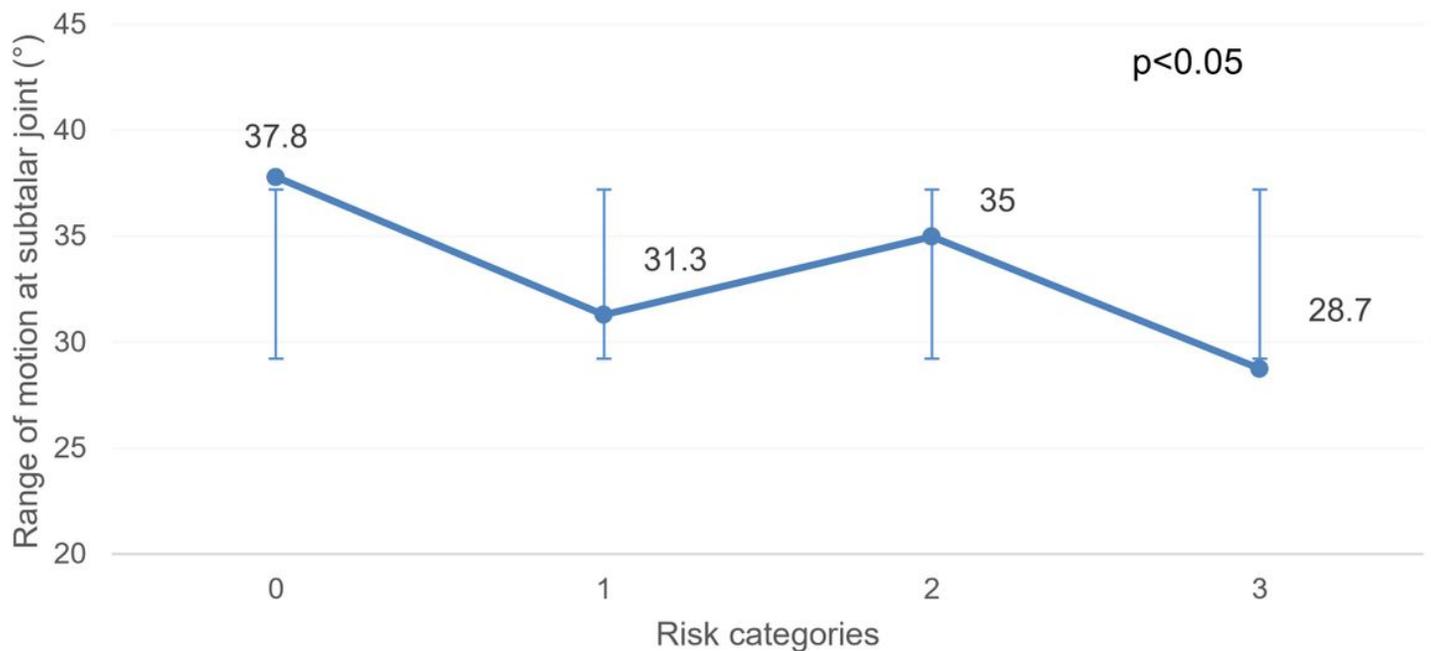


Figure 3

The range of motion at the subtalar joint and risk for diabetic foot ulceration The average range of motion (ROM) at subtalar joint (SJ) in groups of patients classified into different diabetic foot ulcer risk categories significantly declines with risk progression; $p < 0.05$. Points represent the average ROM at SJ in the groups of diabetic patients classified into certain risk category followed by straight lines that represent their SDs.

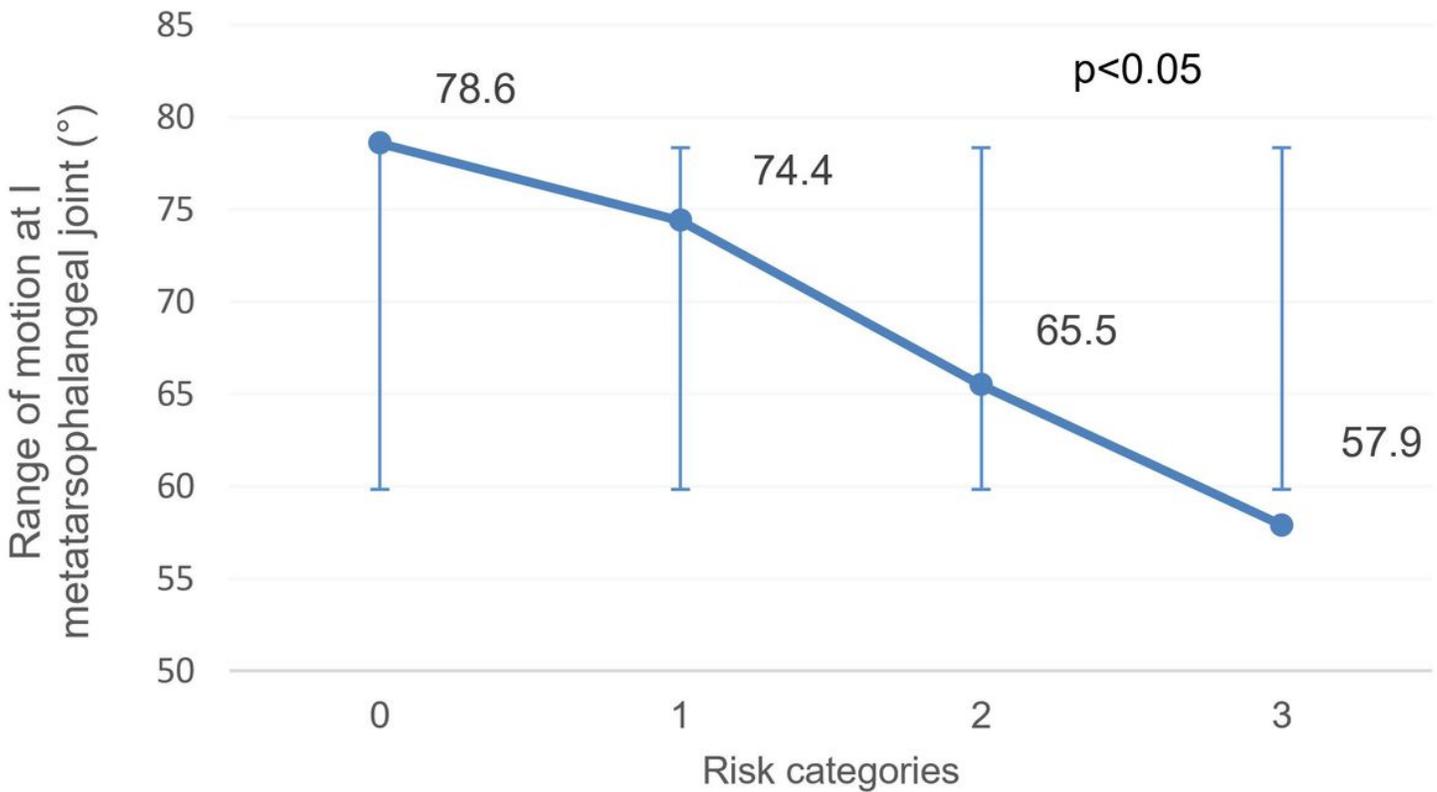


Figure 4

The range of motion at first metatarsophalangeal joint and risk for diabetic foot ulceration The average range of motion (ROM) at first metatarsophalangeal joint (I MTP) in groups of patients classified into different diabetic foot ulcer risk categories significantly declines with risk progression; $p < 0.05$. Points represent the average ROM at I MTP in the groups of diabetic patients classified into certain risk category followed by straight lines that represent their SDs.