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The Effects of Protective Sensation on Functional Capacity, Peripheral Muscle Strength, and Balance in Patients with Type 2 Diabetes Mellitus

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Abstract

Background: Diabetes-related foot complications are among the most common complications in individuals with type 2 diabetes mellitus. The prevention of foot problems that are at risk of developing because of type 2 diabetes mellitus should be addressed within the framework of preventive approaches prior to treatment. The aim of this study was to evaluate protective sensation in people with type 2 diabetes mellitus who have not been diagnosed with early diabetes-related foot complications and to investigate the effects of protective sensation on peripheral muscle strength, balance, and functional capacity. Methods: This study included 42 volunteer patients (56.71 ± 7.59 years) who were followed up with a diagnosis of type 2 diabetes mellitus and met the inclusion criteria. Individuals were evaluated prospectively and via face-to-face interviews. Light-touch, vibration, and discrimination sense was evaluated to determine protective sensation. Peripheral muscle strength (quadriceps femoris, biceps brachii, and hand grip) was measured and a 6 min walking test for functional capacity and balance evaluation were performed. Spearman correlation analysis was conducted using SPSS Statistics 21.0 for data analysis. Results: At least one of the components of protective sensation was moderately correlated with peripheral muscle strength, functional capacity, and balance scores. Reduced protective sensation was also observed in individuals with type 2 diabetes mellitus without neuropathy. Conclusions: In type 2 diabetes mellitus patients, decreases in light-touch, vibration, and discrimination sense are moderately associated with parameters of peripheral muscle strength, functional capacity, and balance. In patients with type 2 diabetes mellitus, early foot sole sensory examination may prevent the development of neuropathy and support clinicians in early diagnosis.

Keywords: diabetes complications; diabetic neuropathy; sensory functions

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1. Introduction

Type 2 diabetes mellitus (T2DM), which is the most common chronic metabolic disease in the world, is a disease that occurs as a result of inadequacy of insulin release, a decrease

in insulin sensitivity, or a defect in the release mechanism despite preserved function of the beta cells of the pancreas [1]. Type 2 diabetes mellitus can lead to complications affecting multiple organs. The peripheral and central nervous systems, kidneys, and retina are the most commonly affected tissues and organs. Diabetic peripheral neuropathy is one of the most common and serious complications of T2DM experienced by patients [2].

Loss of cutaneous sensation is an important risk factor for the development of diabetic foot ulcers. When diabetic foot ulcers develop in these patients, the risk of amputation increases in the following years [3,4]. The development of complications adversely affects people with T2DM physically, mentally, socially, and economically [3,5]. The American Diabetes Association recommends that pressure sensitivity, vibration sensitivity, and two-point discrimination be investigated [5].

In the literature, early diagnosis of diabetes-related foot complications, which can develop because of T2DM, is indicated to prevent the need for amputation because of diabetic ulcers [6]. For this reason, prevention of foot problems that are at risk of developing because of T2DM should be addressed within the framework of preventive approaches prior to treatment. In all patients with T2DM, it is very important to perform a foot sole sensory examination starting in the early period within the scope of prevention and early diagnosis. In patients with a low risk of developing diabetes-related foot complications, it has been reported that awareness regarding these complications is limited; therefore, routine assessments hold greater significance. However, the number of studies examining the effect of protective sensory loss before the development of neuropathy is small [7–9].

2. Materials and Methods

This research article was approved by the clinical research ethics committee of Bezmialem Vakif University (2022/37) and registered at ClinicalTrials.gov with ID number NCTT05904262. This study was conducted in the Physiotherapy and Rehabilitation Department of the Faculty of Health Sciences at Bezmialem Vakif University between March 2022 and February 2023 in accordance with the Declaration of Helsinki.

The inclusion criteria were having been diagnosed with T2DM for at least one year, being between 18 and 65 years of age, having any level of physical activity, having an A1C value between 6.5 and 11% and being able to ambulate independently. The exclusion criteria were inability to cooperate, cognitive and mental problems, uncontrolled hypertension and arrhythmia, various vestibular system disorders such as vertigo, severe neurological and respiratory system diseases, cardiac pacemaker or percutaneous transluminal coronary angiography, major musculoskeletal problems, chronic renal failure, chronic liver disease, and pregnancy.

Each T2DM patient was informed about the content of the study before starting the study, and all participants read and signed the informed consent form. Among the patients who were treated at Bezmialem Vakif Universty Hospital Internal Medicine Polyclinic, 42 who met the inclusion criteria for the study were referred to our department after evaluation by a medical doctor. The assessment of the protective sensation in the patients was performed by a physiotherapist who was the researcher of the study. For this purpose, light-touch, two-point discrimination, and vibration sense of the plantar surfaces of the patients' feet was evaluated.

Light-touch sensation was evaluated with the Semmes–Weinstein monofilament test. The assessment was performed bilaterally at four different sites on the sole of the foot (first toe, first metatarsal head, fifth metatarsal head, and heel midpoint) while the patient lay supine with the eyes closed [10]. The test started with the thinnest filament, which resulted in the least pressure, and continued by gradually increasing the thickness of the filament. Each filament touched each test point on the sole of the foot three times at a right angle for

1.5 to 2 s until slight bending occurred. When the patient correctly recognized one of these three touches, the thickness of the filament was noted as the light-touch threshold value for that test point [9–11]. Two-point discrimination was evaluated with an aesthesiometer. The assessment was performed bilaterally at four different sites on the sole of the foot (first toe, first metatarsal head, fifth metatarsal head, and heel midpoint) while the patient lay supine with eyes closed [10]. The test sites were started at a distance of 2 cm, which is the distance at which the patient can easily distinguish two points. Pressure was applied to the four test points on the sole of the foot by applying equal pressure with both ends of the aesthesiometer until the skin turned white. The test points were touched three times with both ends of the aesthesiometer. The distance at which the patient said they felt two of the three double touches as a single point was recorded as their two-point discrimination sense [9,12].

Vibration sense was evaluated via a 128 Hz tuning fork. A sample test of the wrist (ulnar styloid process) was performed to determine the patient's sense of vibration. The assessment was performed bilaterally at two different sites on the foot (first toe dorsal bony prominence and medial malleolus) while the patient lay supine. After the tuning fork was applied vertically to the relevant area, the stopwatch was started and the time was stopped when the patient stated that the vibration had disappeared. Three repetitions were performed and the mean time was recorded in seconds.

Functional capacity was assessed via the 6 min walk test according to the American Thoracic Society criteria [13]. Heart rate, blood pressure, oxygen saturation, perceived fatigue (modified Borg fatigue scale), and dyspnea (modified Borg dyspnea scale) were assessed before and after the test. For the calculation of the 6 min walk distance (6MWD), the reference equation of Enright [14] was used.

Musculus quadriceps femoris and musculus biceps brachii muscle strength was measured bilaterally with an electronic hand dynamometer. For musculus quadriceps femoris strength, the patient was asked to bring the knee to full extension while sitting upright in a chair. Maximum resistance was applied from 2 to 3 cm above the medial malleolus with a hand dynamometer and the patient was asked to maintain the position of resistance for at least 3 s. For the strength of the biceps brachii muscle, when the patient was lying on their back with the elbow in 90° flexion, maximum resistance was applied from the wrist in the direction of extension with the hand dynamometer and the patient was asked to maintain the position of resistance for at least 3 s. A total of three measurements were performed and the isometric strength of the musculus quadriceps femoris and musculus biceps brachii was recorded as the mean value [15].

Hand grip strength was measured bilaterally with a hydraulic hand dynamometer. The measurements were performed in a comfortable position in a chair with the arm adjacent to the body, the shoulder in adduction, the elbow in 90° flexion, and the forearm and wrist in a neutral position. The patient was asked to squeeze the dynamometer using the maximum squeezing force [16]. Three measurements were made with 5 s of contraction and 30 s of rest and the average of the data was recorded.

Postural stability and balance were evaluated with the Biodex Balance System (Biodex Medical Systems, Inc, Shirley, NY, USA). Patients underwent three tests with the Biodex Balance System: the postural stability test, the limits of stability test, and the test of sensory interaction in balance [17].

2.1. Postural Stability Test

The postural stability test evaluates the ability of a person to maintain the center of gravity of the body. Higher scores indicate worse postural stability. For the test, patients were asked to remove their shoes and stand on the platform. With the help of a point

monitored on the screen, they were asked to bring their balance center to the fixed center point on the screen, with the movement provided by their ankles. The foot position values were then entered into the system and the deviations of the patients from the center point in the anteroposterior and mediolateral directions were calculated and averaged by the system. The total score was recorded.

2.2. Limits of Stability Test

The limits of stability test is used to evaluate the ability to change and control the body's center of gravity between support surfaces. Higher scores indicate better postural control. For testing, each patient was asked to follow the colored balls in different directions on the screen of the system. The scores obtained in the overall forward, backward, left, right, forward/left, forward/right, backward/left, and backward/right directions were recorded as percentage values.

2.3. Test of Sensory Interaction in Balance

The test of sensory interaction in balance is used to evaluate how different senses affect the maintenance of balance and how well patients can maintain balance when one or more of these senses are eliminated. Patients' balance was assessed under four different conditions: on a fixed platform with eyes open and closed and on a soft-foam surface with eyes open and closed. The oscillation index was calculated for each position. High oscillation index scores indicate that the amount of oscillation is too high.

3. Statistical Analysis

In the literature, moderate correlations (r = 0.005–0.650) have been reported between sole sensation and functional ambulation parameters [7]. In our study, a minimum of 42 individuals were necessary to obtain an expected correlation of r = 0.500 with a 95% confidence level and 80% power [18].

Statistical analyses were performed using SPSS Statistics 21.0 (IBM, Armonk, NY, USA). The conformity of all data to a normal distribution was evaluated via the Shapiro–Wilk test. Spearman correlation analysis was performed between numerical data. Mean ± SD and percentage were used as descriptive statistics for numerical variables and categorical variables, respectively. The strength of the relationship between variables was interpreted as weak when the correlation coefficient was between 0 and 0.29, moderate when it was between 0.30 and 0.70, and strong when it was between 0.70 and 0.99 [19].

4. Results

A total of 53 patients were interviewed. Nine patients were not willing to participate in the study, and two did not meet the inclusion criteria. Forty-two patients (29 females, 13 males) were evaluated and the study was completed. Among the 42 evaluated participants, 30 patients were using only oral antidiabetic drugs for diabetes treatment. Twenty-three participants had hypertension and 12 participants had hyperlipidemia. Based on the body mass index values of the participants, six (14%) were classified as normal weight, ten (24%) were classified as overweight, ten (24%) were classified as type 1 obese, and 16 (38%) were classified as type 2 obese. The demographic and clinical characteristics of the patients are shown in Table 1. The participants' protective sensation measurements are shown in Table 2.

Table 1. Demographic and clinical characteristics of patients with type 2 diabetes mellitus.

Characteristic	Total (N = 42)
	Mean ± SD Range
Age, years	56.71 ± 7.59	36–65
Height, cm	163.23 ± 7.57	148–178
Weight, kg	82.64 ± 15.33	53.10–111
BMI, kg/m^2	31.07 ± 5.57	20.30–40.00
Diabetes duration, years	9.95 ± 7.39	1–30
HbA1c, %	6.91 ± 1.14	6.50–10.30
Fasting plasma glucose, mg/dL	136.52 ± 37.92	96–252
Right quadriceps femoris strength, kg/N	11.33 ± 2.99	5.40–18.00
Left quadriceps femoris strength, kg/N	11.76 ± 3.20	5.00–19.50
Right biceps brachii strength, kg/N	9.12 ± 1.82	6.80–15.60
Left biceps brachii strength, kg/N	9.05 ± 2.32	6.0–15.60
Right grip strength, kg/N	24.62 ± 6.98	12.00–40.60
Left grip strength, kg/N	25.40 ± 7.60	12.00–43.30
6MWD, m	447.88 ± 90	120–620

Abbreviations: BMI, body mass index; HbA1c, hemoglobin A1c; 6MWD, 6 min walk distance.

Table 2. Protective sensation measurements of patients with type 2 diabetes mellitus.

Variable	Right	Left
	Mean ± SD	Mean ± SD
SWMT		
First toe, g	8.46 ± 46.10	9.11 ± 46.65
First metatarsal head, g	1.23 ± 1.64	1.17 ± 1.05
Fifth metatarsal head, g	9.39 ± 46.01	8.87 ± 46.63
Heel midpoint, g	31.79 ± 88.13	10.90 ± 46.38
Two-point discrimination		
First toe, mm	12.02 ± 6.05	9.51 ± 5.09
First metatarsal head, mm	11.30 ± 5.41	12.26 ± 4.96
Fifth metatarsal head, mm	12.14 ± 5.75	12.38 ± 4.45
Heel midpoint, mm	12.50 ± 4.71	14.04 ± 5.08
Vibration sense		
First toe dorsal bony prominence, s	8.71 ± 5.07	8.07 ± 4.05
Medial malleolus, s	8.02 ± 3.09	8.00 ± 3.24

Abbreviation: SWMT, Semmes–Weinstein monofilament test.

One participant (2%) did not feel light touch at the left first toe, first metatarsal head, fifth metatarsal head, or heel midpoint. Four participants (10%) did not feel vibration at the dorsal bony prominence of the right first toe and two participants (5%) did not feel vibration at the dorsal bony prominence of the left first toe. The relationships between sole sensation and functional capacity and quadriceps femoris muscle strength are shown in Table 3.

Table 3. Relationship between protective sensation measurements and functional capacity and quadriceps femoris muscle strength in patients with type 2 diabetes mellitus.

Variable	Right Quadriceps Femoris Strength, kg/N				Left Quadriceps Femoris Strength, kg/N				6MWD, m			
	Right		Left		Right		Left		Right		Left	
SWMT	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***
First toe, g	−0.105	0.508	−0.283	0.070	0.125	0.430	−0.118	0.455	−0.184	0.244	0.037	0.814
First metatarsal head, g	0.073	0.645	0.140	0.378	−0.012	0.942	0.014	0.931	−0.074	0.643	0.168	0.288
Fifth metatarsal head, g	−0.133	0.399	0.063	0.692	−0.156	0.323	0.022	0.890	−0.042	0.792	−0.011	0.946
Heel midpoint, g	0.259	0.098	0.323	0.037*a*	0.379	0.013*a*	0.191	0.226	0.259	0.098	0.308	0.047*a*
Two-point discrimination												
First toe, mm	−0.209	0.183	−0.248	0.113	−0.155	0.328	−0.161	0.308	−0.330	0.033*a*	−0.348	0.024*a*
First metatarsal head, mm	−0.010	0.950	0.086	0.587	0.060	0.704	0.080	0.616	−0.141	0.372	−0.123	0.436
Fifth metatarsal head, mm	−0.026	0.868	−0.109	0.494	−0.167	0.291	−0.166	0.292	−0.110	0.488	−0.222	0.159
Heel midpoint, mm	0.098	0.537	−0.185	0.240	0.150	0.344	−0.247	0.114	0.058	0.716	−0.400	0.802
Vibration sense												
First toe dorsal bony prominence, s	0.116	0.465	0.224	0.155	0.119	0.453	0.315	0.042*a*	0.043	0.788	0.125	0.085
Medial malleolus, s	0.154	0.330	0.116	0.463	0.337	0.029*a*	0.261	0.095	0.125	0.430	0.430	0.594

Abbreviations: 6MWD, 6 min walk distance; SWMT, Semmes–Weinstein monofilament test. *a* Expresses a meaningful relationship.

There was a moderate correlation between right and left first toe discrimination sense and functional capacity. A moderate correlation was found between heel midpoint light-touch sensation and contralateral extremity quadriceps femoris muscle strength. The relationships between protective sensation and biceps brachii muscle strength and grip strength of the participants are shown in Table 4.

There was a moderate to high correlation between the strength of the biceps brachii muscle of the left extremity and the light-touch sensation of the base of the left first toe, left fifth metatarsal head, and left heel midpoint. There was a moderate correlation between right foot medial malleolus strength and bilateral biceps brachii muscle strength. There was a moderate correlation between left foot heel midpoint light-touch sensation and right grip strength. There was a moderate correlation between right and left first toe discrimination sense and contralateral extremity grip strength. The relationships between the participants' protective sensation and balance are shown in Table 5.

Moderate correlations were found between discrimination sense and sensory integration in postural stability and balance. There was a moderate correlation between vibration sense of the right first toe dorsal bony prominence and postural stability.

Table 4. Relationship between protective sensation measurements and biceps brachii muscle strength and grip strength in patients with type 2 diabetes mellitus.

Variable	Right Biceps Brachii Strength, kg/N				Left Biceps Brachii Strength, kg/N				Right Grip Strength, kg/N				Left Grip Strength, kg/N			
	Right		Left		Right		Left		Right		Left		Right		Left	
SWMT	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***
First toe, g	−0.021	0.895	−0.286	0.067	0.045	0.776	− 0.325	0.035*a*	−0.089	0.577	0.054	0.732	−0.135	0.393	0.071	0.656
First metatarsal head, g	0.014	0.928	0.005	0.973	0.033	0.834	− 0.094	0.554	−0.027	0.867	0.248	0.113	−0.063	0.691	0.219	0.164
Fifth metatarsal head, g	−0.252	0.108	0.083	0.601	− 0.306	0.048*a*	− 0.040	0.801	0.133	0.403	0.002	0.990	0.001	0.993	−0.093	0.558
Heel midpoint, g	0.131	0.409	0.275	0.078	0.039	0.806	− 0.001	0.994	0.243	0.121	0.399	0.009*a*	0.210	0.182	0.202	0.200
Two-point discrimination																
First toe, mm	−0.295	0.058	−0.265	0.090	− 0.291	0.061	− 0.335	0.030*a*	−0.200	0.203	−0.394	0.010*a*	−0.307	0.048*a*	−0.275	0.078
First metatarsal head, mm	−0.016	0.919	0.082	0.606	− 0.157	0.320	− 0.098	0.539	−0.034	0.829	−0.043	0.788	−0.101	0.523	−0.001	0.093
Fifth metatarsal head, mm	−0.085	0.593	−0.220	0.162	− 0.427	0.005	− 0.435	0.004*a*	0.086	0.586	−0.128	0.420	−0.116	0.464	−0.148	0.349
Heel midpoint, mm	0.108	0.495	−0.244	0.119	− 0.138	0.384	− 0.522	<0.001*a*	0.066	0.678	−0.005	0.976	−0.035	0.827	−0.113	0.475
Vibration sense																
First toe dorsal bony prominence, s	0.002	0.992	0.185	0.240	0.069	0.063	0.233	0.137	0.002	0.989	−0.074	0.642	−0.086	0.587	−0.041	0.798
Medial malleolus, s	0.310	0.046*a*	0.199	0.207	0.342	0.026*a*	0.173	0.273	0.076	0.631	0.046	0.771	0.140	0.376	0.148	0.349

Abbreviation: SWMT, Semmes–Weinstein monofilament test. *a* Expresses a meaningful relationship.

Table 5. Relationship between protective sensation measurements and balance in patients with type 2 diabetes mellitus.

Variable	Biodex Postural Stability Average				Biodex Limits of Stability Average				Biodex Limits of Stability Completion Time, s				Biodex Sensory Interaction in Balance Total Score			
	Right		Left		Right		Left		Right		Left		Right		Left	
SWMT	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***
First toe, g	0.270	0.084	0.095	0.548	−0.015	0.924	−0.351	0.023*a*	0.211	0.180	0.261	0.095	−0.082	0.604	0.102	0.522
First metatarsal head, g	0.196	0.213	−0.027	0.867	−0.063	0.691	0.013	0.937	−0.017	0.916	−0.041	0.797	−0.139	0.380	−0.177	0.261
Fifth metatarsalhead, g	−0.017	0.915	0.026	0.870	−0.017	0.916	0.011	0.946	0.104	0.511	0.151	0.341	−0.024	0.882	−0.034	0.831
Heel midpoint, g	−0.181	0.250	−0.204	0.196	0.117	0.460	0.169	0.284	−0.172	0.276	−0.102	0.520	−0.391	0.010*a*	−0.300	0.054
Two-point discrimination																
First toe, mm	0.309	0.046*a*	0.302	0.052	−0.085	0.594	−0.147	0.353	0.057	0.718	0.119	0.451	0.183	0.245	0.287	0.065
First metatarsal head, mm	0.016	0.922	0.069	0.666	−0.065	0.682	−0.007	0.967	0.151	0.339	0.068	0.670	0.150	0.344	0.226	0.151

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Table 5. *Cont.*

Variable	Biodex Postural Stability Average				Biodex Limits of Stability Average				Biodex Limits of Stability Completion Time, s				Biodex Sensory Interaction in Balance Total Score			
	Right		Left		Right		Left		Right		Left		Right		Left	
SWMT	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***
Fifth metatarsal head, mm	0.136	0.389	0.329	0.034*a*	−0.027	0.867	−0.202	0.199	−0.013	0.935	0.229	0.144	0.363	0.018*a*	0.007	0.963
Heel midpoint, mm	−0.052	0.744	0.086	0.588	−0.056	0.724	−0.206	0.191	0.157	0.322	0.301	0.053	0.028	0.861	0.013	0.937
Vibration sense																
First toe dorsal bony Prominence, s	−0.324	0.036*a*	−0.279	0.074	0.260	0.096	0.148	0.348	−0.017	0.916	−0.044	0.783	0.124	0.433	0.081	0.610
Medial malleolus, s	−0.244	0.120	−0.297	0.056	0.208	0.187	0.056	0.723	−0.170	0.281	−0.036	0.819	0.028	0.862	−0.090	0.570

Abbreviation: SWMT, Semmes–Weinstein monofilament test. *a* Expresses a meaningful relationship.

5. Discussion

In our study, we examined the effects of protective sensation on peripheral muscle strength, balance, and functional capacity in people with T2DM. We found a moderate to low correlation between protective sensation and muscle strength, balance, and functional capacity in people with T2DM.

Increased pressure alone in certain plantar areas during walking has been shown to contribute to the development of diabetic foot ulcers caused by loss of protective sensation [20]. In a study by Galal et al. [21] investigating the predictors of diabetes-related foot complications, it was reported that decreased vibration sense was an important risk factor for the development of these complications.

Çıtaker et al. [9] reported a mean vibration time of 8 s in a study in which they compared sole sensation in male and female participants with T2DM. Temlett [22] reported that in patients without neurologic problems, the duration of vibration was less than 10 s and vibration sense decreased with age. Our study revealed that the duration of vibration in our patients was 8 s. Based on the aforementioned literature, we can say that our patients' vibration sense was reduced.

Bell et al. [23] reported that in the Semmes–Weinstein monofilament test kit, values of 2.36 to 2.83 indicate normal sensation, values of 3.22 to 3.61 indicate decreased light-touch sensation, values of 3.84 to 4.31 indicate decreased protective sensation, and values of 4.56 to 6.65 indicate loss of protective sensation. According to the threshold values given by the authors, our patients experienced sensory loss on the bilateral plantar surface.

Stone [24] reported that 0 to 5 mm indicates normal discrimination sense, 6 to 10 mm indicates decreased discrimination sense, 11 to 15 mm indicates weak discrimination sense, one-point perception indicates protective sensation, and the absence of perception indicates the presence of anesthesia. According to the author, our patients' sense of discrimination was weak.

Functional capacity is a factor affected by chronic and lifelong disease. Kuziemski et al. [25] examined the functional capacity and respiratory parameters of healthy individuals and people with T2DM and reported that people with T2DM (6MWD = 528.5 m) had lower functional capacity (Δ = –108.8 m) than healthy individuals (6MWD = 637.3 m). The average 6MWD of our patients was 447.88 m, indicating that our patients had low functional capacity.

The gait cycle is provided by the integrated and correct functioning of autonomic and somatic inputs. In addition to the components of the musculoskeletal system that are effective in providing motor control during walking, sensory receptors in the plantar region receive the necessary information from the external environment. In people with T2DM, changes in gait kinematics are observed owing to disruptions in the functioning of autonomic and somatic information. These differences include increased time spent in the stance phase, slower and shorter stride length, larger support surface, and changes in pressure distribution in the plantar region [26]. Decreased protective sensation alone causes excessive pressure in the foot during walking, especially in the forefoot and first metatarsal joint regions. The prolonged stance phase in people with T2DM may lead to increased ground pressure, loss of tissue sensitivity, and injury [27]. Decreased 6MWD in patients with T2DM may result from decreased functional capacity because of impaired glycemic balance and gait kinematics. Zhang et al. [28] reported that individuals with T2DM with reduced light-touch sensation had decreased 6MWD.

In the current study, we found a statistically significant relationship between light-touch sensation (heel midpoint) and discrimination sense (first toe) and between light-touch sensation and functional capacity. The decrease in functional capacity with decreasing discrimination sense (first toe) has not been studied in the literature. We also found a

negative correlation between light-touch sensation and discrimination sense and the 6 min walk test. According to our results, decreases in these senses may predict a decrease in functional capacity; therefore, we believe that functional capacity should be evaluated in the early period in patients with decreased light-touch and discrimination sense.

The causes of impaired motor function in individuals with T2DM are varied and complex. Frequently, these causes include impaired mitochondrial and fatty acid metabolism and inadequate perfusion of the muscles owing to changes in vascular structure [29]. Andersen et al. [30] reported that isometric muscle strength of the wrist and forearm flexion-extension muscles in the upper extremities and knee extensor muscles in the lower extremities was preserved in patients with T2DM, whereas isometric muscle strength of the knee flexor and ankle extensor and flexor muscles was lower than that in healthy individuals. Park et al. [31] reported that musculus quadriceps femoris and hand grip strength in people with T2DM was lower than that in healthy individuals.

Reduced quadriceps femoris strength results in less loading on the related side during walking and more loading on the strong side, causing weight transfer toward this part. For this reason, sensory input to the sole of the foot on the side of the weak extremity decreases and the pressure distribution on the sole differs [32]. Additionally, an increase in light-touch sensation at the heel midpoint was found to be positively correlated with the strength of the contralateral quadriceps femoris muscle. This indicates that in the extremity with lower quadriceps femoris muscle strength, the light-touch sensation is also decreased.

In patients with diabetic peripheral neuropathy, as the duration of the disease increases, symptoms of neuropathy also occur in the upper extremity muscles. Additionally, as the symptoms of diabetic peripheral neuropathy progress toward the proximal portion of the lower extremities, a reduction in upper extremity muscle strength begins [31,33]. In the literature, no studies have examined the relationship between upper extremity muscle strength and protective sensation. In our study, the significant relationships between upper extremity muscle strength and all three sensory examinations support the relationship between upper extremity muscle strength and protective sensation.

The complications observed in patients with T2DM cause damage to the systems that provide and maintain balance. Postural imbalance is not a problem that is directly caused by T2DM; it is associated with chronic complications, such as advanced age and neuropathy [34]. Meyer et al. [35] investigated plantar cutaneous sensation in healthy participants and reported that decreased plantar sensation had no effect on bipedal balance position when vision was present, but when the postural control system was challenged by standing on one leg or closing the eyes, the loss of plantar sensation caused an increase in the rate of postural oscillation. The authors also noted that feedback from plantar cutaneous afferents is important when vision is not available and that plantar sensation may be particularly important in patients with peripheral neuropathy. Patients with T2DM show more oscillation in the anteroposterior and mediolateral directions than healthy individuals, resulting in decreased balance control [36].

In our study, the balance scores of patients with T2DM were poor, similar to the findings reported in the literature. We also found that balance scores, which were better on fixed surfaces with eyes open, deteriorated when the eyes were closed and on dynamic surfaces. We observed that people with T2DM need fixed surfaces and visual stimuli to maintain their balance because of decreased protective sensation. In addition, we found significant correlations between the balance parameters evaluated with the Biodex Balance System and light-touch and two-point discrimination. We believe that our results indicate the presence of clinically undiagnosed neuropathy in our patients.

6. Limitations

This study has several limitations, one of which is the lack of a healthy control group with whom to compare the data of our patients with T2DM. Another limitation is that we did not evaluate the strength of the muscles around our patients' feet or ankles to prove the loss of motor dysfunction, which may indicate the presence of neuropathy. Finally, we did not perform a gait analysis or evaluate pressure distribution on the sole of the foot to better understand the effect of protective sensation on gait.

7. Conclusions

In people with T2DM, early foot sole sensory examination may prevent the development of neuropathy and support clinicians in early diagnosis. Decreases in light-touch, vibration, and discrimination sense in people with T2DM may be moderately associated with various parameters of peripheral muscle strength, functional capacity, and balance. Future studies comparing people with T2DM without neuropathy with healthy individuals and studies involving a larger patient population could provide evidence to strengthen this relationship.

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References

1. Alberti, K.G.; Zimmet, P.Z. Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: Diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. *Diabet. Med.* **1998**, *15*, 539. [CrossRef]
2. Battula, P.; Afreen, S.; Meena, E.; Reddy, S.S.R. Prevalence of sensory peripheral neuropathy in diabetic patients at diabetes care center: A cross-sectional study. *Int. J. Res. Med. Sci.* **2017**, *5*, 4066. [CrossRef]
3. Johannesson, A.; Larsson, G.U.; Ramstrand, N.; Turkiewicz, A.; Wiréhn, A.-B.; Atroshi, I. Incidence of lower-limb amputation in the diabetic and nondiabetic general population: A 10-year population-based cohort study of initial unilateral and contralateral amputations and reamputations. *Diabetes Care* **2009**, *32*, 275. [CrossRef]
4. Kärvestedt, L.; Mårtensson, E.; Grill, V.; Elofsson, S.; von Wendt, G.; Hamsten, A.; Brismar, K. The prevalence of peripheral neuropathy in a population-based study of patients with type 2 diabetes in Sweden. *J. Diabetes Complicat.* **2011**, *25*, 97. [CrossRef] [PubMed]
5. American Diabetes Association. (2) Classification and diagnosis of diabetes. *Diabetes Care* **2015**, *38*, S8. [CrossRef]
6. Ogrin, R.; Sands, A. Foot assessment in patients with diabetes. *Aust. Fam. Physician* **2006**, *35*, 419. [PubMed]
7. García-Madrid, M.; López-Moral, M.; Tardáguila-García, A.; Molines-Barroso, R.J.; García-Álvarez, Y.; Lázaro-Martínez, J.L. Disease knowledge and behavior regarding the diabetic foot in persons at different risks for foot ulceration according to the International Working Group on the Diabetic Foot guidelines. *JAPMA* **2024**, *114*, 22. [CrossRef]
8. Kraiwong, R.; Vongsirinavarat, M.; Hiengkaew, V.; von Heideken Wågert, P. Effect of sensory impairment on balance performance and lower limb muscle strength in older adults with type 2 diabetes. *Ann. Rehabil. Med.* **2019**, *43*, 497. [CrossRef]
9. Çıtaker, S.; Kafa, N.; Yetkin, İ.; Atalay Güzel, N.; Tuna, Z.; Hazar Kanık, Z. Kadın ve erkek diyabet hastalarının ayak taban duyularının karşılaştırılması. *Gazi Sağlık Bilim.* **2018**, *3*, 29.

10. Schaper, N.C.; van Netten, J.J.; Apelqvist, J.; Bus, S.A.; Hinchliffe, R.J.; Lipsky, B.A.; IWGDF Editorial Board. Practical guidelines on the prevention and management of diabetic foot disease (IWGDF 2019 update). *Diabetes Metab. Res. Rev.* **2020**, *36*, e3266. [CrossRef]
11. Feng, Y.; Schlösser, F.J.; Sumpio, B.E. The Semmes Weinstein monofilament examination is a significant predictor of the risk of foot ulceration and amputation in patients with diabetes mellitus. *J. Vasc. Surg.* **2011**, *53*, 220. [CrossRef]
12. Dellon, A.L.; Mackinnon, S.E.; Crosby, P.M. Reliability of two-point discrimination measurements. *J. Hand Surg. Am.* **1987**, *12*, 693. [CrossRef] [PubMed]
13. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATSstatement: Guidelines for the six-minute walk test. *Am. J. Respir. Crit. Care Med.* **2002**, *166*, 111. [CrossRef]
14. Enright, P.L. The six-minute walk test. *Respir. Care* **2003**, *48*, 783.
15. Buckinx, F.; Croisier, J.L.; Reginster, J.Y.; Dardenne, N.; Beaudart, C.; Slomian, J.; Leonard, S.; Bruyère, O. Reliability of muscle strength measures obtained with a hand-held dynamometer in an elderly population. *Clin. Physiol. Funct. Imaging* **2017**, *37*, 332. [CrossRef] [PubMed]
16. Cetinus, E.; Buyukbese, M.A.; Uzel, M.; Ekerbicer, H.; Karaoguz, A. Hand grip strength in patients with type 2 diabetes mellitus. *Diabetes Res. Clin. Pract.* **2005**, *70*, 278. [CrossRef]
17. Arnold, B.L.; Schmitz, R.J. Examination of balance measures produced by the Biodex stability system. *J. Athl. Train.* **1998**, *33*, 323.
18. Algina, J.; Olejnik, S. Sample size tables for correlation analysis with applications in partial correlation and multiple regression analysis. *Multivar. Behav. Res.* **2003**, *38*, 309. [CrossRef]
19. Evans, J.D. *Straightforward Statistics for the Behavioral Sciences*; Thomson Brooks/Cole Publishing Co.: Pacific Grove, CA, USA, 1996.
20. Gopalakrishna Prabhu, K.; Mothiram Patil, K.; Srinivasan, S. A new method of analysis of standing foot pressure images for detection of the plantar ulcers in early-stage diabetic neuropathy. *Front. Med. Biol. Eng.* **2001**, *11*, 31. [CrossRef]
21. Galal, Y.S.; Khairy, W.A.; Taha, A.A.; Amin, T.T. Predictors of foot ulcers among diabetic patients at a tertiary care center, Egypt. *Risk Manag. Healthc. Policy* **2021**, *14*, 3817. [CrossRef] [PubMed]
22. Temlett, J.A. An assessment of vibration threshold using a biothesiometer compared to a C128-Hz tuning fork. *J. Clin. Neurosci.* **2009**, *16*, 1435. [CrossRef]
23. Bell-Krotoski, J.A.; Fess, E.E.; Figarola, J.H.; Hiltz, D. Threshold detection and Semmes-Weinstein monofilaments. *J. Hand Ther.* **1995**, *8*, 155. [CrossRef] [PubMed]
24. Stone, J.H. Sensibility. In *Clinical Assessment Recommendations*; American Society of Hand Therapists: Chicago, IL, USA, 1992; p. 71.
25. Kuziemski, K.; Słomiński, W.; Jassem, E. Impact of diabetes mellitus on functional exercise capacity and pulmonary functions in patients with diabetes and healthy persons. *BMC Endocr. Disord.* **2019**, *19*, 2. [CrossRef] [PubMed]
26. Brach, J.S.; Talkowski, J.B.; Strotmeyer, E.S.; Newman, A.B. Diabetes mellitus and gait dysfunction: Possible explanatory factors. *Phys. Ther.* **2008**, *88*, 1365. [CrossRef]
27. Turner, D.E.; Helliwell, P.S.; Burton, A.K.; Woodburn, J. The relationship between passive range of motion and range of motion during gait and plantar pressure measurements. *Diabet. Med.* **2007**, *24*, 1240. [CrossRef]
28. Zhang, F.; Sun, M.; Qu, F.; Lewis, K.; Choi, J.H.; Song, Q.; Li, L. The effect of loss of foot sole sensitivity on H-reflex of triceps surae muscles and functional gait. *Front. Physiol.* **2023**, *13*, 1036122. [CrossRef]
29. Nomura, T.; Kawae, T.; Kataoka, H.; Ikeda, Y. Assessment of lower extremity muscle mass, muscle strength, and exercise therapy in elderly patients with diabetes mellitus. *Environ. Health Prev. Med.* **2018**, *23*, 20. [CrossRef] [PubMed]
30. Andersen, H.; Nielsen, S.; Mogensen, C.E.; Jakobsen, J. Muscle strength in type 2 diabetes. *Diabetes* **2004**, *53*, 1543. [CrossRef]
31. Park, S.W.; Goodpaster, B.H.; Strotmeyer, E.S.; de Rekeneire, N.; Harris, T.B.; Schwartz, A.V.; Tylavsky, F.A.; Newman, A.B. Decreased muscle strength and quality in older adults with type 2 diabetes: The health, aging, and body composition study. *Diabetes* **2006**, *55*, 1813. [CrossRef]
32. Andersen, H.; Poulsen, P.L.; Mogensen, C.E.; Jakobsen, J. Isokinetic muscle strength in long-term IDDM patients in relation to diabetic complications. *Diabetes* **1996**, *45*, 440. [CrossRef]
33. Tracy, J.A.; Dyck, P.J.B. The spectrum of diabetic neuropathies. *Phys. Med. Rehabil. Clin. N. Am.* **2008**, *19*, 1. [CrossRef] [PubMed]
34. Simoneau, G.G.; Ulbrecht, J.S.; Derr, J.A.; Becker, M.B.; Cavanagh, P.R. Postural instability in patients with diabetic sensory neuropathy. *Diabetes Care* **1994**, *17*, 1411. [CrossRef]
35. Meyer, P.F.; Oddsson, L.I.; De Luca, C.J. The role of plantar cutaneous sensation in unperturbed stance. *Exp. Brain Res.* **2004**, *156*, 505. [CrossRef] [PubMed]
36. Yamamoto, R.; Kinoshita, T.; Momoki, T.; Arai, T.; Okamura, A.; Hirao, K.; Sekihara, H. Postural sway and diabetic peripheral neuropathy. *Diabetes Res. Clin. Pract.* **2001**, *52*, 213. [CrossRef] [PubMed]