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Comparison of neurosensory devices in detecting cutaneous thresholds related to protective sensibility: A cross-sectional study in São Paulo, Brazil

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ABSTRACT

Aims: To quantify the static and moving cutaneous sensibility threshold of diabetic patients using a neurosensory device for quantitative pressure detection.
Methods: Three hundred thirty-four (n = 334) patients with type 2 diabetes and no previous history of wounds on the feet were studied using the one- and two-point static (1SP;2 SP) and one- and two-point moving (1MP;2 MP) tests through the pressure-specified sensory device (PSSD) on the cutaneous territory of the dorsal first web, hallux pulp, and medial calcaneal. In addition, patients were evaluated using the Semmes-Weinstein monofilament (SWM) No. 5.07 and tuning fork (128 Hz), which were used as normality parameters to detect the loss of protective sensibility. The same examinations were used to assess the control group (228 nondiabetic).
Results: Altered values were observed for the static and moving tests over the three studied nerve territories. In comparing the sensibility threshold between diabetic patients who were sensitive and nonsensitive to SWM 5.07, we observed that this filament is not the most indicated for identifying the loss of sensibility in these patients. The prevalence of patients at risk varied between 85 and 89%. The biochemical marker associated with these high rates was HbA1c (p = 0.02).

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Conclusions: Numeric quantification of the pressure threshold allowed us to determine the functional deficit of nerve fibers. Our findings suggest that the neurosensory device should be used as an adjuvant tool to evaluate the degree of loss of sensation on the skin.

1. Introduction

Diabetes mellitus (DM) is one of the most chronic diseases worldwide and is associated with high mortality and morbidity rates [1]. In Brazil, it is estimated that five million people have diabetes; however, a significant number, approximately 50% of cases, are unaware of their diagnosis [2].

Chronic complications affecting diabetic patients are serious and costly, and some of these complications affect the lower limbs (LL) [3]. The major consequence of DM on the LL is the total or partial amputation of one or both limbs or the formation of wounds that are difficult to heal [4,5].

According to researchers, the loss of sensibility caused by diabetic neuropathy, compared with other diseases that also damage peripheral nerves, is an irreversible process [6,7]. The medical literature describes surgical techniques and clinical procedures that are used to avoid an increase in damage caused by diabetic neuropathy; however, there is still no consensus regarding the best treatment [8,9]. Most specialists point to prevention measures as the best means to holding off consequences imposed by diabetic neuropathy [10–13].

Prophylaxis of neuropathic complications begins with the identification of the degree of neuropathy and, therefore, the neurological deficit with which diabetic patients present [14]. One of the possible methods to accomplish this is investigating the lesion in the sensory nerve fibers through tests of cutaneous sensibility [15]. Nevertheless, this task is challenging, as there is no optimal method available that can identify sensory changes objectively [16].

The methodology for sensibility tests has developed from qualitative observation to quantification of numeric variables [15]. Although many tools have been described for sensory evaluation, there is no single standard because of the different methodologies used, from the design of the model to the presentation of the results [12].

In 1988, Dellon et al. developed the Pressure Specified Sensory Device (PSSD; NK Biotechnical Engineering Company, Minneapolis, MN, USA). This device is capable of quantifying the threshold of pressure applied to the skin that is necessary for the patient to feel the stimulus of a static point (similar to the Semmes-Weinstein® monofilament [SWM]), a moving point, two static points, and two moving points. This has provided us with a unique means to evaluate the slow and fast adaptation fiber systems and their respective peripheral receptors [17].

The SWM is one of the most frequently used screening tools around the world for identifying loss of protective sensation [18]. In particular, loss of protective sensation has been defined as the inability to perceive the 5.07 SWM, which is associated with neuropathy [19,20].

The use of the PSSD™ in Brazil started in 2000. Ferreira et al. used it to evaluate the pre- and postoperative mastoplasty sensibility [21]. A preliminary study on the cutaneous sensibility in the LL of diabetic patients was performed by Ferreira et al. in 2004 [22]. The PSSD™ has contributed to determining the cutaneous sensibility values in other anatomical regions such as the abdomen [23], face [24,25], diabetic foot [26,27], and areas submitted to surgical procedures [28].

In this way, the purpose of the present study was to quantify the threshold of static and moving cutaneous sensibility, mediated by receptors of slow and fast adaptation, in the LL of diabetic patients and to compare devices in common use, such as the SWM and vibratory testing, with the PSSD™. We evaluated the ability of these devices to identify changes in sensibility that occur before the 5.07 filament and/or 128-Hz tuning fork.

2. Methods

This was a cross-sectional observational study, followed by a descriptive analysis for the diabetic group (DG) and the nondiabetic control group (CG) separately. After determining the control values established from the CG, a comparative statistical treatment was carried out with results obtained from the DG.

The data collection was conducted from 2016 to 2018, following the sequence described as follows: A, initial interview; B, evaluation of peripheral vascular disease; C, evaluation of the cutaneous sensibility threshold through PSSD™; D, application of the 5.07 SWM (Sorri Bauru, Bauru, Brazil), followed by the 128-Hz tuning fork. In order to confirm the participant, was diabetic, in addition to consulting the medical record to know his history, fasting glycemia and glycated haemoglobin (HbA1c) were collected on the same day of the test with the PSSD™. The project received approval from our institutional review board (No. 356/06) in compliance with Resolution 466/12 of the National Health Council of the Brazilian Ministry of Health.

The initial interview was carried out through telephone calls. At that time, items selected for the inclusion criteria for the DG included a minimum age of 18 years, the presence of type 2 DM, not having presented wounds and/or amputation in the LL at any time during their life, presence of peripheral vascular disease and neurological dysfunction that compromised peripheral nerve function, and able to respond adequately about their state of health. The inclusion criteria for the CG were volunteers who were age-matched to the DG, with a relative deviation of about 5 years; no DM type 1, 2, gestational, or acquired forms; presence of the peripheral vascular disease; suffered trauma and/or surgery in the LL; and neurological disease.

Peripheral vascular disease was assessed by noninvasive means. Physical examination evaluated the color of feet at 45°, capillary filling time (standard time less than 5 s), and palpation of the posterior tibial and pedis arteries. After palpation, the calculus of the ankle-brachial index was carried out. Normality followed standards determined by the Brazilian Society of Angiology and Vascular Surgery [29]. Only patients showing values considered normal for evaluation of peripheral vascular disease were part of this group.

To evaluate the cutaneous sensibility threshold, we used the PSSD™, which is a pressure transducer connected to a computer that has software able to codify an electric sign in pressure, expressed in grams/square millimeter (g/mm^2).

The PSSD™ examination consists of a touch of one or two rounded metal prongs (according to test modality chosen) in the area of skin over the nerve territory to be evaluated. The patient holds a bell and is instructed to press it when he or she feels the touch of the metallic rod(s). The software registers the value of the pressure perceived at the moment the bell is activated via electric sign.

The present study evaluated the cutaneous sensibility of three peripheral nerves located in the lower limb: deep fibular nerve, tested in the dorsal region of the foot between the interdigital space of the first and second toes ("dorsal web space"); medial plantar nerve, studied in the skin of the hallux pulp ("great toe pulp"); and calcaneus nerve, searched in the medial surface of the heel of the heel ("heel – medial"), according to Fig. 1.

To avoid selection bias, the principal investigator (PI) did not participate in the recruitment of the sample. A research assistant selected and collected information from the participants. In this way, the PI would not know the details of the patients' clinical history at the time of the tests.

The cutaneous sensibility of the right and left sides was measured using nerve fibers of slow adaptation when using one or two static points (1SP and 2SP). The fast adaptation fibers were tested by touch in moving or a moving touch of one or two points (1MP and 2MP).

Care was taken to obtain the most reliable measurements possible. The value of the final cutaneous sensibility threshold is a result of the average of five measurements, as shown in Fig. 2(A and B) for one and two static points and 2C and 2D for one and two points moving. However, it is possible to notice in the first four measurements besides the blue column, which represents the value of the pressure applied to the patient's skin, there is another yellow column (indicated by the arrow). This column is a feature present in the software that allows the examiner to perceive the degree of oscillation with which he touched the patient. That is, how much that touch did not remain uniform. In the fifth measure, we did not see the yellow column, which means that the contact of the metal rod with the skin was kept regular throughout the application of pressure. The smaller the oscillation of the hand of the observer, the more uniform the measurement for static and moving two-point tests (2SP and 2MP). However, for these two modalities, not only was the oscillation controlled but also the corresponding contact of the metallic rods on the skin. Because of the oscillation control feature, only sequences of five measurements similar to those shown in Fig. 2(B and D) were considered valid.

Before the 2SP and 2MP tests, an indirect measurement of the minimal distance the needed to discriminate two static points (D2SP) and two moving points (D2MP) was necessary. This was accomplished with the aid of the Disk-Criminator™. This device is composed of a set of octagons, whose edges host metallic rods that are separated 1 mm from each other.

After finishing the PSSD™ test, we continued with the application of the SWM No. 5.07. The SWM was applied to the same nerve territories tested by the PSSD™. The extremity of the SWM was gently placed perpendicularly to the surface until it was curved. The contact time with skin, starting from pressure to filament removal, did not exceed 5 s. The 128-Hz tuning fork test was applied to the medial malleolus on both sides. With the device vibrating, we touched the malleolus for 10 s. The touch and vibrational sensibility were regarded as preserved for those who felt it within the prescribed time.

Results were analyzed according to descriptive statistics. In our study, we have chosen to express the quantitative vari-

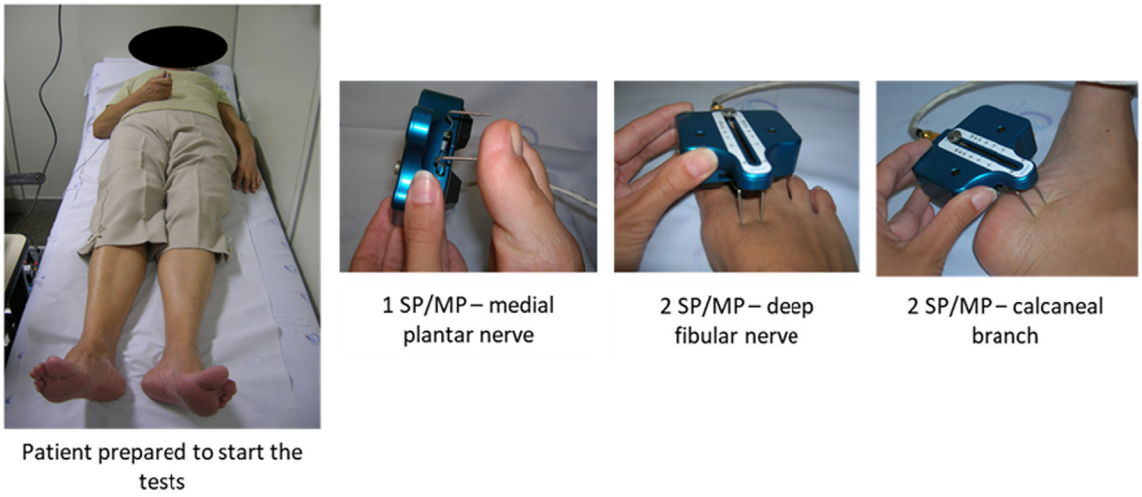

Fig. 1 – Cutaneous sensibility test using PSSD™ in the medial plantar, deep fibular, and calcaneal branch nervous territories.

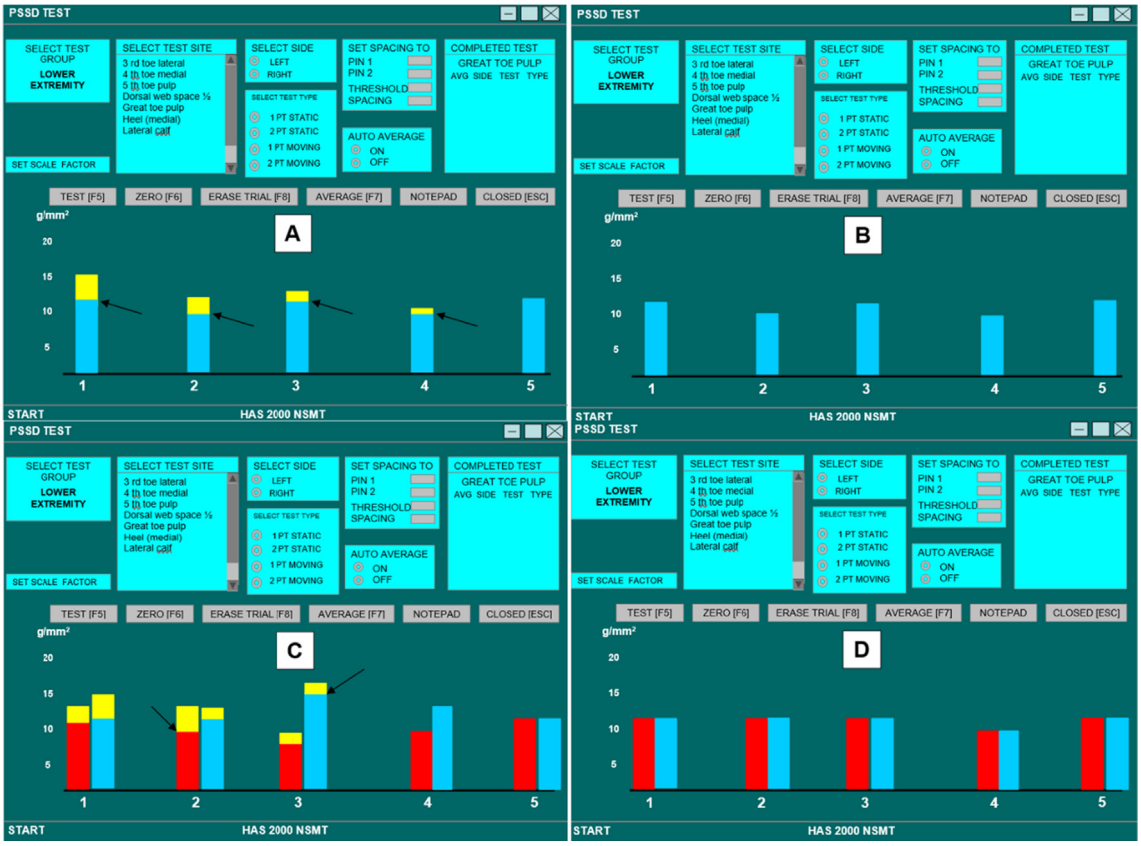

Fig. 2 – A – Hypothetical sequence display of 1 SP or 1 MP measurements; B – Accepted sequence display of measurements of 1 SP or 1 MP; C – Hypothetical sequence display of 2 SP or 2 MP measurements; D – Accepted sequence display of 2 SP or 2 MP measurements.

ables in the form of average and median and the dispersion values by the standard deviation.

Some patients from the DG were not able to perceive the 1SP, 1MP, 2SP, and 2MP, in addition to not being able to discriminate the distance between the static points (D2SP) and moving ones (D2MP). For these participants, we attributed the value of 100 g/mm^2 for the threshold test of cutaneous sensibility and 20 mm for the discrimination tests between the two points in the modality and nerve territories where touch stimuli could not be recognized. This decision resulted in the inclusion of all patients in the mathematical calculus; however, discrepant values about the average were accounted.

For both the DG and CG, the values of the median variables of the right and left foot were compared using the Wilcoxon test, which is actively used for paired observations (right and left sides of the same patient) of the asymmetric character of distribution [30].

To relate the variables obtained with the SWM test, which are qualitative, to the measures of the PSSD™ test, which are quantitative, we chose to compare them, in a nondichotomized way, through the Kruskal-Wallis proof. This proof is useful to decide whether the independent sample results, in fact, represent a significant difference [31].

3. Results

Three hundred thirty-four diabetic patients who met the study inclusion criteria were evaluated. The patients' age ranged from 38 to 82 years, with an average of 61.1 ± 11.1 years of age. The average time of knowledge of DM diagnosis was 13.5 ± 6.02 years of age, ranging from 2 to 26 years. Blood samples collected from diabetic participants revealed fasting glycemia of 153.8 ± 54.6 mg/dL and glycated hemoglobin 8.2 ± 1.3%. There was equitable distribution between sexes, with a predominance of Caucasians patients (73.5%). The CG was formed with 228 participants, with a mean age of 60.6 ± 12.2 years. Approximately 71% were white and 57% were female.

Tables 1–3 show the results obtained by the DG and CG for tests of 1 static point (1SP), 1 moving point (1MP), 2 static points (2SP), 2 moving points (2MP), and static (D2SP) and moving two-points discrimination (D2MP) in the territory of the deep fibular nerve (DFN), medial plantar (MPN), and calcaneal branch (CBN) of the posterior tibial nerve.

Statistically nonsignificant differences ($p > 0.05$), for both the mean and median values, for the detection of the cutaneous sensitivity threshold and for discrimination between two points, in the static and moving modalities of the right

Table 1 – Threshold of cutaneous sensibility and two-point discrimination to static and moving pressure in the deep fibular nerve territory in the diabetic and control groups.

Diabetic group Deep fibular nerve						Control group Deep fibular nerve				
N	M	SD	MD	Min-Max		N	M	SD	MD	Min-Max
334	13.7	16.8	11.6	0.7–100	1 SP (g/mm^2)	228	2.1	1.5	1.3	0.7–5.2
334	12.6	22.7	6.2	0.7–100	1 MP (g/mm^2)	228	1.4	0.8	1.0	0.4–3.0
334	26.5	36.0	7.3	1.4–100	2 SP (g/mm^2)	228	22.1	4.7	20.4	15.2–34.3
334	24.1	36.3	6.7	1.2–100	2 MP (g/mm^2)	228	11.8	3.2	11.2	6.8–24.2
334	13.8	3.7	13.0	8–20	D2SP (mm^2)	228	7.2	1.2	7.0	6.0–10
334	13.5	4.0	12.0	6–20	D2MP (mm^2)	228	7.0	1.3	7.0	5.0–10

Note: N: total number; M: mean; MD: median; SD: standard deviation; Min: minimum value; Max: maximum value; one static point (1SP), one moving point (1MP), two static points (2SP), two moving points (2MP), two-point static discrimination (D2SP) and two-point moving discrimination (D2MP).

Table 2 – Threshold of cutaneous sensibility and two-point discrimination to static and moving pressure in the medial plantar nerve territory in the diabetic and control groups.

Diabetic group Medial plantar nerve						Control group Medial plantar nerve				
N	M	SD	MD	Min-Max		N	M	SD	MD	Min-Max
334	10.4	6.9	8.8	1.7–32.9	1 SP (g/mm^2)	228	2.4	1.6	1.9	0.7–6.3
334	12.2	16.4	9.8	1.10–100	1 MP (g/mm^2)	228	1.7	0.9	1.2	0.8–3.7
334	31.1	37.7	10.3	2.4–100	2 SP (g/mm^2)	228	24.5	5.6	23.4	10.5–37.4
334	28.4	37.5	9.4	3.7–100	2 MP (g/mm^2)	228	13.7	5.8	11.9	9.2–31.6
334	13.3	4.4	14	7.0–20	D2SP (mm^2)	228	7.5	1.1	7.0	6.0–10
334	13.3	4.5	12.5	7.0–20	D2MP (mm^2)	228	6.9	1.2	7.0	5.0–10

Note: N: total number; M: mean; MD: median; SD: standard deviation; Min: minimum value; Max: maximum value; one static point (1SP), one moving point (1MP), two static points (2SP), two moving points (2MP), two-point static discrimination (D2SP) and two-point moving discrimination (D2MP).

Table 3 – Threshold of cutaneous sensibility and two-point discrimination to static and moving pressure in the calcaneus branch of the posterior tibial nerve in the diabetic and control groups.

Diabetic group Calcaneus branch						Control group Calcaneus branch				
N	M	SD	MD	Min-Max		N	M	SD	MD	Min-Max
334	10.8	6.9	10.3	0.8–31.6	1 SP (g/mm^2)	228	6.6	3.6	6.2	0.6–16.3
334	11.1	16.8	6.5	1.4–100	1 MP (g/mm^2)	228	4.3	2.1	4.1	1.7–12.5
334	30.3	37.4	10.5	1.4–100	2 SP (g/mm^2)	228	27.1	5.5	26.1	18.9–41.9
334	27.4	38.2	7.8	1.0–100	2 MP (g/mm^2)	228	12.3	5.5	11.0	4.7–32.6
334	14.4	4.3	15.0	8.0–20	D2SP (mm^2)	228	7.4	1.2	7.0	6.0–10
334	13.6	4.3	13.0	8.0–20	D2MP (mm^2)	228	6.9	1.3	7.0	5.0–10

Note: N: total number; M: mean; MD: median; SD: standard deviation; Min: minimum value; Max: maximum value; one static point (1SP), one moving point (1MP), two static points (2SP), two moving points (2MP), two-point static discrimination (D2SP) and two-point moving discrimination (D2MP).

and left feet, were identified in the nervous territories of the CG and DG. Thus, the values presented in the following tables are the arithmetic mean of the sensitivity threshold and the discrimination between two points on the right and left sides.

We observed that for all four modalities of tests and in all three nerve territories studied, values of the average and median variables for the thresholds of cutaneous sensibility were similar in the CG.

For the territory of the deep fibular nerve, we show in Table 1 that in all test modalities carried out, 1SP, 1MP, 2SP, and 2MP, there were minimal and maximal discrepant values, with the value of the standard deviation increasing and becoming higher than the average and median variables. A similar situation was observed in 1MP, 2SP, and 2DP in the territories of the medial plantar nerves and calcaneus branch of the posterior tibial nerve. However, the same did not occur for 1SP of the two last nerve territories. Minimal and maximal values were not discordant, did not raise the standard deviation, and approximated the average and median variables numerically, according to Tables 2 and 3.

For the discrimination threshold between two points, in the three nervous territories studied (DFN, MPN, and CBN), the DG required distances more significant than those indicated by the CG to perceive and differentiate the touch of the two points on the surface of the skin, in both the static mode and dynamic mode.

Regarding the touch perception to SWM 5.07, we found that 66.7% of patients in the study identified the stimulus produced by monofilament 5.07. Eighty percent of patients in the DG were able to recognize the vibrational stimulus caused by the 128-Hz tuning fork. Thus, the prevalence of participants with loss of protective sensitivity identified by the SWM and the tuning fork was 33.3% and 20%, respectively. However, the calculated prevalence for loss of cutaneous pressure sensibility with PSSD™ (one static point) was 85% and one moving point 89%, according to Table 4.

The Kruskal-Wallis test was applied to compare the results obtained for cutaneous sensibility between the 1SP with PSSD™ versus the SWM No. 5.07 and PSSD™ versus the 128-Hz tuning fork. Results for the one static point (1SP) are presented in Table 5, for deep fibular nerves, medial plantar, and calcaneal branch of the posterior tibial nerve.

When comparing the median variable of the thresholds to sensibility to pressure for 1SP obtained with the PSSD™, for patients who were sensitive to the 5.07 SWM, and for those insensitive to this device, we observed that there was a statistically significant difference between the two groups: $p = 0.045$ for deep fibular nerve and $p = 0.018$ for the medial plantar. The opposite was found for the calcaneus branch of the posterior tibial nerve, where the value was not statistically different between patients sensitive and insensitive to the 5.07 monofilament in the 1SP modality, with $p = 0.113$.

In both ends of the posterior tibial nerve, the medial plantar nerve, and the calcaneal branch, the differences found for the pressure sensitivity thresholds in motion (1MP) were not significantly different among patients with sensibility and no sensibility to the 128-Hz tuning fork, with $p = 0.099$ in the pump region of the hallux and $p = 0.183$ on the medial aspect of the heel.

In order to identify possible systemic causes for high sensitivity thresholds, as well as for distance to discriminate two points, we investigated the correlation between these variables and age, time of knowledge of diabetes, fasting glycemia and glycated hemoglobin. Only the HbA1c showed a correlation with the modality a static point, in the three nervous territories evaluated, with p = 0.02.

Based on the results obtained, through the PSSD™ test, we established cutaneous sensitivity threshold values in long-standing diabetic patients, without complications in the feet, so we suggested adopting a prophylactic measures algorithm [32] to avoid injuries and amputations, show in Fig. 3:

4. Discussion

To optimize the assistance for diabetic individuals, the American Diabetes Association (ADA) [33] and other medical associations [34,35] have promoted guidelines for foot care of diabetic patients and recommend conducting an examination at least once a year for measuring the threshold of cutaneous sensibility.

In this study, we did not aim at establishing a diagnosis of diabetic neuropathy in the population studied. Our purpose was to investigate the threshold for cutaneous sensibility in the feet of diabetic patients through the PSSD™, which is a device used to evaluate the minimal pressure needed (threshold) for an individual to notice the touch sensation, not only in static mode but also with rod(s) in movement. It is a quantitative test of sensibility (QTS).

From a technical view, we can divide the QTS according to the methodology applied to its construction: quantitative tests of sensibility based on threshold methods and QTS based on the levels method [36]. In the current study, we evaluated the touch and vibrational modalities employing the PSSD™, which measures thresholds for static and moving

Table 4 – Prevalence of patients with loss of protective sensibility assessed with neurosensory testing - PSSD™.

	Deep Fibular Nerve (%)	Medial Plantar Nerve (%)	Calcaneus Branch (%)	Global (%)
1 SP	88	94	74	85
1 MP	94	97	76	89
D2SP	100	97	100	99
2 SP	35	32	26	31
D2MP	97	85	100	94
2 MP	32	26	35	31

Table 5 – SWM n° 5.07 *vs.* PSSD™ – 1 SP in the territories of the deep fibular, medial plantar and calcaneal branch nerves of the posterior tibial nerve.

	1 SP - Deep fibular nerve					1 SP - Medial plantar nerve					1 SP - Calcaneal branch				
	N	M	SD	MD	Min-Max	N	M	SD	MD	Min-Max	N	M	SD	MD	Min-Max
No detection SWM	111	21.7	26.7	15.3	0.7–100	111	13.7	6.1	13.6	4.9–22.8	112	12.7	6.9	12	4.5–30.7
Detection SWM	223	9.9	7.3	8	1.0–30.4	223	8.8	6.8	6.3	1.7–32.9	222	9.8	6.9	8.4	0.8–31.6
	p = 0.045					p = 0.018					p = 0.113				

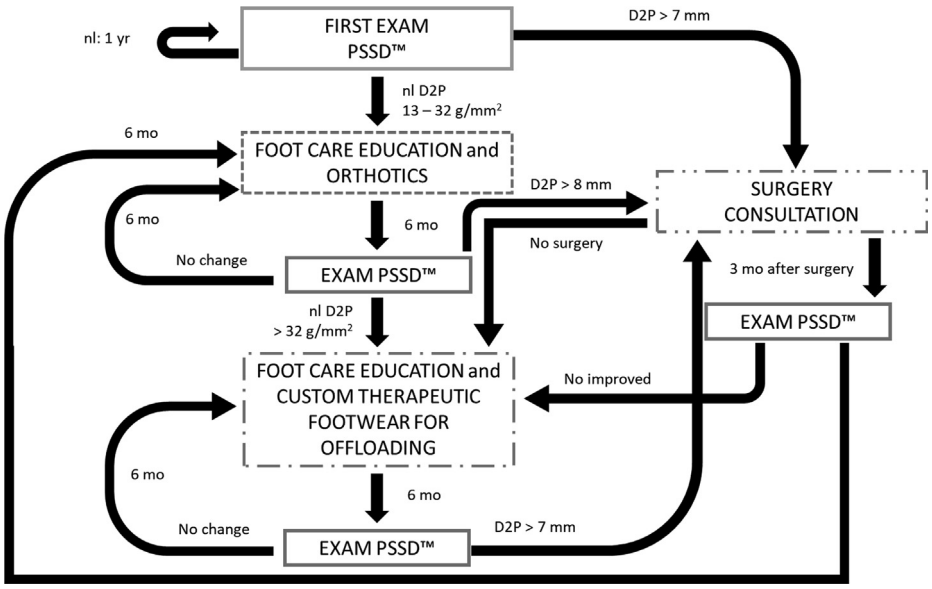

Fig. 3 – Algorithm adapted to the thresholds of cutaneous sensibility and discrimination of two points for Brazilian diabetics, with the objective of prophylactic follow-up of the foot care in diabetics without wounds.

pressure. To compare results obtained with the PSSD™, we employed the 5.07 SWM and the 128-HZ tuning fork, two quantitative tests of sensibility based on the levels method.

In our casuistic, evaluated by the 5.07 SWM, we found that approximately 70% of diabetic patients were sensitive to the stimulus caused by this device. McGill et al.[37] found similar results using a filament of the same number, testing the same nerve territories we examined. When performing the Kruskal-Wallis test, we compared the median variables of sensibility thresholds to static pressure (1SP) among the sensitive and insensitive patients to the 5.07 SWM. There was a statistically significant difference for the 1SP in the nerve territory of the deep fibular and medial plantar. In the current study, patients showed essential alterations in the threshold of cutaneous sensibility, as well as in the value of discrimination between two points, which was not detected earlier by the 5.07 SWM.

According to what is written above and to the pressure values that can be reached by means of filaments in touch with the skin surface (Table 5), patients we analyzed would have early detection of touch sensibility loss if evaluated by the 3.61 SWM, which constitutes pressure of 17.7 g/mm^2 when applied against the skin [38]. For Sosenko et al. [39] and Kumar et al. [40], the monofilament that best identified the loss of cutaneous sensibility in their patients was the 4.21 SWM and the 4.17 SWM, respectively.

When carrying out a study with the PSSD™ in patients with no diabetes and in diabetic patients who were noncarriers of wounds in the lower limbs, Tassler et al. [41] found significant differences for the threshold sensibility in 1SP, 1MP, 2SP, and 2MP modalities among the two groups in all nerve territories tested. The current study found a similar scenario. The average thresholds for the DG were higher and showed a statistical difference in the CG. The same average sensibility thresholds to the static and moving pressures of the DG in our study were slightly higher when compared with the values reached for diabetic individuals in the American study.

In the same study, a limit to the sensibility threshold was found for diabetic patients, as from these values, patients developed hallux ulceration— in other words, in the territory of the medial plantar nerve: for 1SP, 9.1 g/mm^2; for 2SP, 32.9 g/mm^2; and for D2SP, 9 mm was the minimal distance. Analyzing the difference data to the thresholds of cutaneous sensibility and discrimination between two points for the static modality for the hallux pulp region, we noticed that the mean value found was 10.4 g/mm^2 for 1SP, 31.1 g/mm^2 for 2SP, and 13.3 mm for D2SP. Thus, the values for the DG were above the threshold found by Tassler et al. [41]; however, feet wounds were not found.

Elevated sensibility thresholds do not mean that the patient will develop a wound. However, patients with thresholds similar to those described by Tassler et al. [41] and the ones found in the present study establishes a limit before the wound takes place. This is relevant to avoid damage imposed by the loss of cutaneous sensibility [10–13,26].

The test performed with the PSSD™ not only allows a graphical evolution of the worsening of the loss of skin protection against trauma, but also offers a range of possibilities for implementing actions and therapies exclusively aimed at the prevention of foot injuries and amputations [42]. These actions include education for foot care [43], preparation of orthoses [44,45], insoles/shoes [46], therapeutic footwear for offloading [47,48], or planning of surgical procedures such as Achilles tendon lengthening [49], surgical correction of skeletal abnormalities [50], plantar fat augmentation [51] and decompression of peripheral nerves [52,53], as suggested in the algorithm of foot care for diabetics without wounds.

In both the CG and DG, we observed differences between the sensibility thresholds to static pressure, mediated by receptors of slow adaptation, and those of pressure in moving/moving, carried out by receptors of fast adaptation. Comparing these modalities in both groups, we notice that the values reached were higher for the sensibility threshold in

the static modality in all nerve territories evaluated. This may have happened because of the existing physiologic relationship between the number of nerve fibers associated with specific cutaneous receptors [54].

We observed another sign of cutaneous sensibility to movement delays in presenting hazards taking place in nerve fibers of fast adaptation when we compared the median variables of sensibility thresholds of the 1MP, carried out with the PSSD™, among patients sensitive and insensitive to the 128-Hz tuning fork in the medial malleolus region—in other words, the region where the posterior tibial nerve sends two of its terminal branches, medial plantar and calcaneus nerves. Kruskal-Wallis proof demonstrated that no statistical difference between the sensibility thresholds reached by the patients who noticed the vibration caused by the tuning fork and those who did not perceive the same form of stimulus.

The test for discrimination between the two points in the movement in hands was described by Dellon in 1978 [55]. The capacity for discriminating between two points in the movement was previously observed by the discrimination between two static points. Thus, the D2SP could underestimate the real ability of hand physiology. The D2MP occurs prior to D2SP, probably because of the ease of Meissner's corpuscles reinnervation compared with Merkel's cells [56].

A study by Aszmann and Dellon [57] evaluated the hand sensibility of 20 healthy individuals and eight with peripheral nerve disorder (4 with carpal tunnel syndrome and the other 4 with diabetic neuropathy, diagnosed by clinical criteria). The study identified an inverse relationship between the sensibility threshold and the discrimination of two points in the four groups; in other words, the smaller the distance needed to notice that the two points touch, the greater the necessary pressure.

The inverse relation found for hands [57] was observed in the present study in terms of the feet of diabetic and nondiabetic patients. When comparing only the sensibility threshold values to pressure in the CG and DG, we found an apparent contradiction in the two modalities evaluated (static and moving), as the CG registered a median variable higher than the DG. However, we must consider the discrimination threshold between two points for both groups.

When comparing the minimal necessary distance for discriminating the touch between two points among the DG and CG of our study to the values in Tassler et al. [41], we notice that the thresholds we found were higher in all nerve territories tested, not only for the static modality (D2SP) but also for the moving (D2MP). However, we must observe the age range of patients examined and the running time of DM. The age range of the American group was of 46.4 years, whereas ours was 60.4 years. We evaluated diabetic patients with knowledge of the disease for 13.5 years, and the age range of our patients was 10.5 years.

This being so, a higher discriminatory pattern was expected in our study because of the advanced age of both groups control and diabetics and longer period of exposition to the effects caused by DM in the DG [58]. However, mathematically the variable that showed association with the high sensibility thresholds was glycated hemoglobin. This important marker reveals poor glycemic control [59] and has been pointed out by many investigations as a risk factor for complications of macro and microvascular order, among them diabetic neuropathy, which has direct reflex in the loss of protective cutaneous sensibility [60–62].

This investigation is on a cross-section, so it was possible to calculate the prevalence of loss of protective skin sensation among people with diabetes without foot complications. Through traditional methods of identifying risk for wound development, SWM and tuning fork, the prevalence rates of susceptible individuals were 33% and 20%. While, the prevalence indicated by the 1 SP and 1 MP test performed with the PSSD™, showed 85 and 89%, respectively. A study conducted in Austria involving 55 patients with type 1 diabetes (n = 14) and 2 (n = 41), with a mean age of 64.3 years, diabetes duration of 12.2 ± 10.3 years and HbA1c of 8.1 ± 1.6% analyzed prevalence rates for the symptomatic group (SG) and the non-symptomatic group (nonSG). Results from nerve conduction studies (NCS) were SG 64; nonSG 71.4%, for SWM SG 59.1; nonSG 27% and PSSD SG 88.2;nonSG 92% [63]. Although we did not classify the participants of the Brazilian study in symptomatic or non-symptomatic patients, the patients presented similar clinical characteristics, as well as, the prevalence rates for loss of cutaneous sensitivity very much resemble for the non-symptomatic Austrian group examined with the SWM and for participants, symptomatic and non-symptomatic, of beloved nationalities, tested with the PSSD™.

5. Conclusion

According to the results obtained by this cohort, it is possible to identify threshold values for cutaneous sensitivity and discrimination between two threshold points for the progression of chronic complications of diabetes related to inadequate glycemic control. As well as, it shows that the prevalence is closely linked to the method of choice for the risk assessment and the clinical specificities of the population sample. As a result of these propositions, we infer that our findings support the use of PSSD™ as a diagnostic tool.

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Declaration of Competing Interest

The authors have disclosed no financial relationships related to this article.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2019.107821.

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