A Cross-Sectional Study Comparing Two Quantitative Sensory Testing Devices in Individuals With Diabetes

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OBJECTIVE — This study was designed to compare circumference discrimination thresholds, as assessed by the Tacticon (Tacticon, Inc., Westtown, PA), a new quantitative sensory testing (QST) device, with vibratory thresholds, an assessment modality of large sensory nerve fibers, in individuals with diabetes.

RESEARCH DESIGN AND METHODS — In this study, 150 individuals with diabetes were evaluated. Vibratory thresholds and circumference discrimination thresholds, evaluated with the Tacticon, were determined using a two-alternative forced-choice procedure.

RESULTS — Vibratory thresholds increased with decreasing ability to discriminate differences in circumference ($P < 0.001$) for those below and above 50 years of age. Agreement between the two QST devices was assessed via the κ-statistic in both age-groups (i.e., ≤50 years old [κ = 0.67], >50 years old [κ = 0.55]). In multiple logistic regression, where circumference discrimination thresholds were the dependent variable, age, duration of diabetes, and height were found to be independently associated for those >50 years old.

CONCLUSIONS — The Tacticon offers a simple method of assessing the complex function of area discrimination. Our results suggest that the Tacticon can detect neuropathy in the primary care setting. Its cost, portability, and ease of use provide some advantages over existing QST equipment.

Historically, diabetic neuropathy has been assessed on signs and symptoms of neuropathy. Clinical assessment of neuropathy lacks precision and reliability, is semiquantitative at best, and often leaves subtle forms of nerve dysfunction undetected. Quantitative sensory testing (QST) was recommended by a consensus conference as a modality to be used in the full assessment and classification of diabetic neuropathy for both clinical and research purposes (1). QST (e.g., vibratory thresholds) permits the application of precise stimulus intensities to determine quantitative sensory thresholds. QST involves examination of the entire somatosensory afferent pathway. It is both noninvasive and simple, and is, therefore, valuable for the longitudinal monitoring of at-risk patients. Additionally, it is useful for the screening of large populations.

Although the strengths of QST are many, extant equipment is relatively bulky and expensive. Here we report on a new relatively inexpensive QST device called the Tacticon (Tacticon, Inc., Westtown, PA) (Fig. 1). This device, a tactile circumference discriminator, was specifically designed for portability and ease of testing. The Tacticon is an anodized aluminum disk, 6.5 oz. in weight, 2.5 inches in diameter, and 0.75 inches in height, out of which eight rods protrude for a distance of ~1 inch. The rods are arranged in a semicircle around ~65% of the circumference of the disk. They are placed in order of increasing circumference (i.e., 12.5 mm to 40 mm).

In this study, vibratory thresholds (assessment modality of large sensory nerve fibers) were determined and compared with an individual's ability to discriminate circumference. Circumference discrimination is dependent on the functionality and integrity of the distal mechanoreceptors, distal axon, the dorsal root ganglia, and the spinothalamic track that permits a synchronous volley of depolarization to arrive intact to the brain for reconstruction of the relative circumferences of the rods.

RESEARCH DESIGN AND METHODS

Study population

There were 150 participants (73 men, 77 women) with diabetes evaluated at the Diabetes and Metabolic Diseases Center, Medical Center of Delaware, Wilmington, Delaware. The only patients who were disqualified from participating were those with amputations of the great toe.

QST procedures

Vibratory thresholds were measured on the plantar aspect of the great toe on the dominant side of the body using the Vibratron II (Physitemp Instruments, Clifton, NJ). The stimulating surfaces of the Vibratron II were two identical posts that protruded through a metal case. Vibration, at a fixed frequency of 120 Hz, was driven by an electromagnetic unit of one post. Details of the sensory threshold determination procedure have been previously published (2). Briefly, a two-alternative forced-choice method was used that involved presenting the participant with two events, one of which was an active stimulus and the other an inactive or comparative stimulus. The voltage setting was reduced 10% with each subsequent trial until the participant made an error. Then, the voltage setting was repeated twice. If the stimulus was correctly identified on two of three trials, the voltage was further reduced by 10%. If errors were made on two of three trials, the voltage was raised 10%. Testing was completed when five errors had been made. The vibration threshold was determined by identifying the five errors and the five lowest correct scores, eliminating the highest and lowest, and calculating the mean

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C.L. holds stock in Tacticon, Inc., which produces and markets the Tacticon.
CDT, circumference discrimination threshold; QST, quantitative sensory testing.

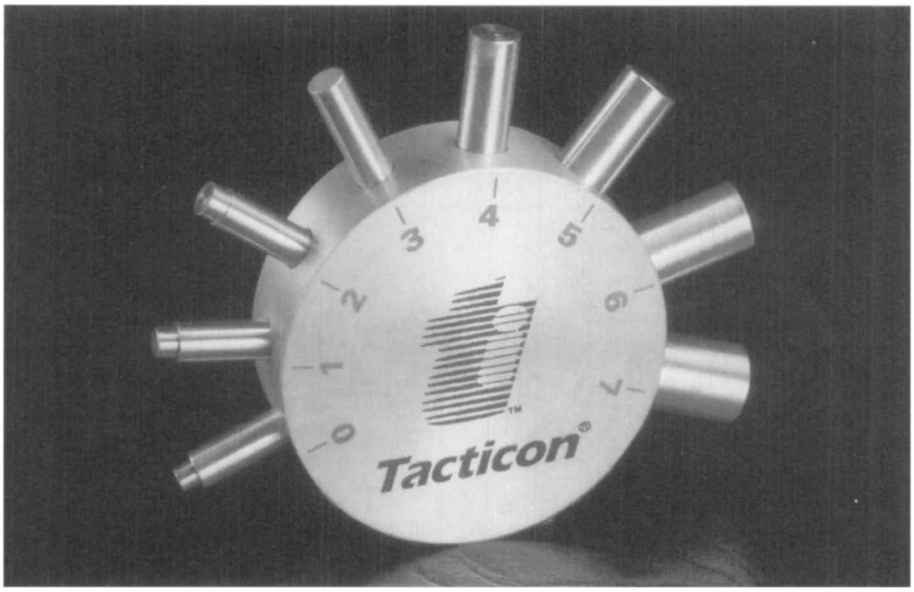

Figure 1—*Tacticon.*

for the remaining eight scores. Repeat testing of vibratory thresholds for individuals with diabetes has revealed a mean coefficient of variation of 8–9% (2,3).

Testing with the Tacticon was directed at determining the participant's ability to discriminate the smallest difference in circumference of seven metal rods (i.e., 15 mm [rod 1] to 40 mm [rod 7]) compared with the circumference of the reference rod (i.e., rod 0 = 12.5 mm). Thus, the circumference discrimination threshold (CDT) equaled the individual's circumference threshold minus the circumference of the reference rod (i.e., CDT = threshold [mm] − 12.5 mm). An ascending and descending method of stimuli presentation and a two-alternative forced-choice response procedure were used to determine an individual's threshold. Specifically, the subject was asked to discriminate which of the two rods presented was smaller. Initially, the reference rod and an easily discriminated larger rod were presented in series for three trials. The timing of rod presentation was standardized at ~2 s. The disk was pivoted by the tester to bring different rods into contact with skin surface. The order of rod presentation was randomized with the aid of a computer-generated sequence. Subjects were tested with their eyes closed and with the tested surface (i.e., great toe) in a relaxed and supported position. If the subject correctly discriminated the smaller rod, the next smaller rod was presented in comparison with the reference rod for an additional three trials. This procedure was repeated until the subject made a mistake during the three trials at one level. If this occurred, the next larger rod was presented for three trials. The individual's threshold was defined as the rod circumference that was the smallest, correctly identified on all trials with at least two errors on the levels below. Repeat testing of circumference discrimination thresholds for individuals with diabetes has revealed a mean coefficient of variation of <10% (n = 15).

Statistical analysis

Vibratory thresholds were not normally distributed and, thus, logarithmic ($\log_{10}$) transformation was used for statistical testing. Univariate analyses included the Student's t test for continuous variables. To compare vibratory thresholds by groups, analysis of variance was used. The κ-statistic was used to evaluate the agreement between assessment modalities. The κ-statistic is a standardized measure that corrects for agreement that could occur by chance. It has been suggested that the κ-statistic can be ranked by three categories (0.75–1.00, excellent; 0.40–0.74, fair to good; and 0.01–0.39, poor [4]). Multiple logistic regression was used to examine the relationship between the binary dependent variable (i.e., CDT [grouped normal or abnormal]) and the independent variables. Each full model was analyzed using backward stepping, where nonsignificant variables leave the model and coefficients for the remaining variables are recomputed.

RESULTS — There were 150 participants in this study aged 52 ± 17 (mean ± SD) years, with self-reported diabetes duration of 12 ± 9 years and a BMI of 30 ± 7 kg/m^2. Of the study cohort, 67% were diagnosed with NIDDM and the remainder were diagnosed with IDDM. All patient diagnoses were confirmed or determined by an endocrinologist at the Diabetes and Metabolic Diseases Center, Medical Center of Delaware, based on standard historical, clinical, and laboratory findings. Because thresholds increase with age (5,6), we stratified the study cohort into two major age-groups (i.e., ≤50 years old [n = 67] and >50 years old [n = 83]). In the younger group, the mean vibratory threshold was 3.7 ± 3 vibration units, and the mean CDT was 11.9 ± 8 mm. In the older group, the mean vibratory threshold was 8.3 ± 5

Table 1—*Vibratory thresholds by 90th percentile for CDTs*

Age-group	n	Neuropathy classification	CDT	Vibratory thresholds
≤50 years				
	37	Normal (rods 1–3)	2.5–7.5	2.0 ± 1.0
	21	Mild neuropathy (rods 4–5)	12.5–17.5	3.9 ± 1.8
	4	Moderate neuropathy (rods 6–7)	22.5–27.5	6.4 ± 2.5
	5	Severe neuropathy (rod >7)	>32.5	13.1 ± 3.8
				$P < 0.001$*
>50 years				
	24	Normal (rods 1–4)	2.5–12.5	3.6 ± 1.2
	15	Mild neuropathy (rods 5–6)	17.5–22.5	7.2 ± 2.9
	9	Moderate neuropathy (rod 7)	27.5	9.1 ± 3.3
	35	Severe neuropathy (rod >7)	>32.5	11.9 ± 4.3
				$P < 0.001$*

Data are means ± SD. CDT = participant's circumference threshold (mm) − 12.5 mm (reference rod circumference). For vibratory thresholds, statistical tests were performed on $\log_{10}$ transformed data. *P value indicates statistical significance for difference among means by analysis of variance for vibratory thresholds.

Table 2—*Multivariate associations of CDTs*

Age-group	Dependent variable	Independent variable	Coefficient	SE	*P* value
≤50 years	CDT	Age	0.190	0.047	<0.001
		Duration	0.072	0.040	<0.07
>50 years	CDT	Age	0.101	0.040	<0.05
		Duration	0.147	0.049	<0.01
		Height	8.831	3.210	<0.01

CDT = participant's circumference threshold (mm) − 12.5 mm (reference rod circumference).

vibration units, while the mean CDT was 23.5 ± 9 mm.

Using 90th percentile circumference thresholds and potential classification of normal, mild, moderate, or severe neuropathy as suggested by the manufacturer (5), we examined the relationship between the CDT and vibratory thresholds. Table 1 shows that vibratory thresholds increased as an individual's ability to discriminate differences in circumference decreased ($P < 0.001$) for those above and below 50 years of age. This relationship of an increase in vibratory thresholds with an individual's decreased ability to discriminate differences in circumference remained statistically significant while controlling for potential differences in age, duration of diabetes, and height in both age-groups.

Agreement between vibratory thresholds and the CDT (grouped normal or abnormal) was also evaluated. The criteria for an abnormal vibratory threshold was >2.6 and >2.9 vibration units for those ≤50 and >50 years old, respectively (6). The criteria for an abnormal CDT was >7.5 and >12.5 mm for those ≤50 and >50 years old, respectively (5). Agreement, as assessed by the κ-statistic, was slightly better in the youngest age-group (i.e., ≤50 years old [$\kappa = 0.67$], >50 years old [$\kappa = 0.55$]). When elevated vibratory thresholds were used as the marker for the presence of neuropathy, circumference discrimination thresholds were shown to have similar sensitivities for each age-group, while specificity was slightly better in the older age-group (≤50 years old [sensitivity = 79%; specificity = 88%], >50 years old [sensitivity = 82%; specificity = 100%]).

In multivariate analyses (Table 2), with circumference discrimination thresholds as the dependent variable, age, duration of diabetes, and height were found to be independently associated for those >50 years old. In the group ≤50 years old, only age and duration of diabetes (borderline statistically significant) were independently associated with the CDT.

CONCLUSIONS — The Tacticon offers a simple method of assessing the complex function of area discrimination. While testing with this new device may be simple, surface area (i.e., circumference) discrimination is quite physiologically complex, requiring intact synchronous firing of nerve fibers to accurately discriminate area.

In this study, we demonstrated that increasing thresholds for large sensory nerve fibers (i.e., vibratory thresholds) were associated with decreasing ability to discriminate circumference. We also examined agreement of these two QST devices for the detection of the presence of nerve fiber dysfunction. Suggested categorization by Fleiss (4) with regard to the κ-statistic indicates that agreement between the two QST devices is in the fair-to-good range, with better agreement in the ≤50 years age-group.

Previously, we have shown that age, duration of diabetes, and height are independently associated with the presence of elevated vibratory thresholds (3). Other investigators have also shown similar relationships with large sensory nerve fiber function in individuals with IDDM or NIDDM (7–11). Multivariate analyses for those >50 years old in this study revealed that age, duration of diabetes, and height were also independently associated with a decreased ability to discriminate circumference. In those ≤50 years old, age and duration of diabetes were independently associated with circumference discrimination thresholds. Although height did not play a significant role in explaining the CDT in the younger group, height was associated in the older group. As has been previously shown, height is a marker for the greater susceptibility of the longer neurons in diabetic subjects (7–10).

Our results suggest that the Tacticon can detect neuropathy in the primary care setting. It may also serve as an efficient screening device for determining neuropathy levels in candidates being considered for entry into peripheral neuropathy clinical studies. Further studies are needed to determine the ability of this method to predict progression of diabetic neuropathy. The cost (approximately one-third of the least-expensive QST device that the authors are currently aware of), portability, and ease of use provide some advantages over existing equipment. Because this device can test sensory function at different body sites (e.g., the face), it may also be of general use in clinical neurology.

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