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SYMPOSIUM

Repeatability of Infrared Plantar Thermography in Diabetes Patients: A Pilot Study

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Abstract

Objective:

Infrared (IR) thermography has been used as a complementary diagnostic method in several pathologies, including distal diabetic neuropathy, by tests that induce thermoregulatory responses, but nothing is known about the repeatability of these tests. This study aimed to assess the repeatability of the rewarming index in subjects with type 2 diabetes mellitus (T2DM) and nondiabetic control subjects.

Methods:

Using an IR camera, plantar IR images were collected at baseline (pre-) and 10 min after (post-) cold stress testing on two different days with 7 days interval. Plantar absolute average temperatures pre- and post-cold stress testing, the difference between them (ΔT), and the rewarming index were obtained and compared between days. Repeatability of the rewarming index after the cold stress test was assessed by Bland–Altman plot limits of agreement.

Results:

Ten T2DM subjects and ten nondiabetic subjects had both feet analyzed. Mean age did not differ between groups (p = .080). Absolute average temperatures of plantar region pre- (p = .033) and post-cold stress test (p = .019) differed between days in nondiabetic subjects, whereas they did not differ in T2DM subjects (pretest, p = .329; post-test, p = .540). ΔT and rewarming index did not differ between days for both groups, and the rewarming index presented a 100% agreement of day-to-day measurements from T2DM subjects and 95% with nondiabetic subjects.

Conclusions:

The rewarming index after cold stress testing presented good repeatability between two days a week in both groups. Despite T2DM subjects presenting no differences on absolute temperature values between days, ΔT or rewarming index after cold stress testing remain recommended beside absolute temperature values for clinical use.

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Abbreviations: (AV) arteriovenous, (IR) infrared, (MNSI) Michigan Neuropathy Score Instrument, (SD) standard deviation, (T2DM) type 2 diabetes mellitus

Keywords: body temperature regulation, diabetes, repeatability of tests, thermography

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Introduction

Thermal infrared (IR) imaging cameras have been increasingly used in clinical situations for accurate and objective thermal mapping of the human body, particularly as a complementary, noninvasive, nonradioactive diagnostic method.[1–5]

In clinical diagnostics, IR imaging is used as a physiological test that measures the subtle physiological changes that might have been caused by many conditions, including diabetes mellitus and associated pathology.[1,2,6,7] In the case of foot temperature imaging by IR radiation in diabetes patients with neuropathy, important parameters such as mean foot temperature, temperature difference (ΔT), and recovery index after cold stress testing can be used for neuropathy screening.[5,7,8] However, few of them report the repeatability of thermal imaging in healthy subjects with different pathologies or in diabetes patients.[2,9–12]

Thermoregulation of the skin is coordinated and regulated by the neurovegetative nervous system through central and peripheral vasomotor activity. The skin temperature recorded and measured by the IR camera is more stable in the trunk, but in the extremities, the variation is great and seems to depend on several endogenous factors such as the activity of the neurovegetative sympathetic nervous system as well as on the environmental temperature.[1,2,13,14]

The significance of thermography's diagnostic is based on the contralateral ΔT because it is believed to indicate a dysfunction of the sympathetic nerves.[1] In normal, healthy conditions, this system is anatomically and physiologically symmetrical, but in diabetic autonomic neuropathy, abnormalities of sweating, increased or decreased foot skin temperature, and absent or diminished vasomotor function has been described as typical features of this condition. This mechanism seems to be an interaction between microcirculation damage (functional or structural) and autonomic neuropathy.[1,2,13,15–17]

Peripheral neurovegetative sympathetic nerve degeneration in advanced neuropathy would damage neurogenic control mechanisms that regulate capillary and arteriovenous (AV) shunt flow, leading to an increase in the AV shunt in a diabetic neuropathic foot.[1,2,13,15–18] Surface plantar foot skin contains a large number of AV anastomoses or AV shunts, which are highly innervated structures involved in thermoregulatory processes. In humans, cutaneous blood vessels are controlled by both neurogenic reflexes and local factors; the regulation of blood flow to the skin is complex, involving long descending neurovegetative fibers that mediate central reflex control of vascular tone, short reflex arcs through the spinal cord, and local reflexes within the skin. Arteriovenous shunts provide a potential low-resistance pathway by which blood flow can be diverted from the arteriolar to venular circulations, bypassing the capillary bed. These AV shunts are maintained in the constricted state by neurovegetative sympathetic tone. Loss of this tone due to sympathetic neuropathy results in opening of the shunt and deviating blood flow from the skin.[15,19–22] Cutaneous sensory nerve-mediated vasodilation is an important component of normal microvascular responsiveness to thermal and nonthermal stimuli. It is known that both neural and microvascular function can be impaired in type 2 diabetes mellitus when there is neuropathy.[23]

Plantar thermography has been used as a complementary diagnostic method for various clinical entities, including distal diabetic neuropathy.[5,8,17,20,21,24] Thermometry of the plantar skin temperature constitutes an important parameter for assessing the risk of ulceration in diabetes patients by the presence of either inflammation or neuropathy.[25] At IR thermographic diabetes evaluation, it is useful to apply provocative tests to the peripheral circulation and skin area of interest.[5,6,24,26] The most used test is the cold stress test, in which the dorsal surface of the hands or plantar feet is covered with thin plastic and immerged in cold water for 1 min or longer. Basal and 10 min post-cooling immersion IR images are recorded, and a rewarming index is calculated. Rapid rewarming or recovery in a time such as 10 min post-cooling by immersion usually indicates a normal response. A delayed and prolonged recovery, with fingers colder than before immersion, may be typical of vascular pathologies or neuropathy. Besides, some may produce overspill of recovery, reactive hyperemia, where fingers become hotter for a time than the rest of the hand or foot. The advantage of IR imaging is that this test can be graded for severity by quantification, and the effects of any prescribed medication to improve the symptoms can be measured.[6,24]

Although there is considerable evidence for clinical IR applications,[1,2,6] according to some authors, thermography is not a reliable diagnostic tool because of the low stability of the skin temperature day-to-day. These opinions are restricting the recommended use of thermography to research purposes.[3,9,11,26–29] These controversial findings can be attributed to the dynamic characteristics of skin temperature regulation,[1,29] which, in fact, may reflect adaptive physiological changes.

Considering this, the objective of this research was to compare the measures of plantar temperatures between days and to assess the repeatability of the plantar rewarming index after cold stress testing on two different days, in two groups of subjects: diabetic and nondiabetic.

Methods

This study was performed in 2011, over four consecutive months. The principles of the Declaration of Helsinki[30] were applied, and all patients gave written informed consent to participate. The study was approved by the Ethics Committee of the Hospital de Clinicas de Porto Alegre, Rio Grande do Sul, Brazil, in decision number 09-446, January 2010.

Subject Selection

Ten diabetes subjects with a confirmed diagnosis of type 2 diabetes mellitus, by referred physicians collaborating in the research, following the American Diabetes Association[30] criteria, were assigned from the Department of Endocrinology of the Hospital de Clinicas de Porto Alegre, Rio Grande do Sul, Brazil. Ten nondiabetic subjects were recruited as healthy control subjects following a call for volunteers made among graduate students and professors at Federal University of Rio Grande do Sul who had a normal test for fasting glucose in the past 3 months. Inclusion criteria for T2DM and nondiabetic subjects were[31] age between 29 and 69 years, both genders, and absence of neuropathy at a clinical assessment with the Michigan Neuropathy Screening Instrument (MNSI): plantar aspect of the hallux with preserved Semmes–Weinstein 5.07 (10 g) monofilament sensibility; preserved 128 Hz vibratory sensibility at the top of the first foot phalange; positive Achilles tendon reflex response; and without callus, ulcer, or important deformities at the foot.[32] Exclusion criteria included presence of other potential causes of distal neuropathy, lumbosacral pain radiating to the leg, or plantar pain of any kind at the time of IR image registration.

Infrared Images Acquisition

Infrared thermographic images acquisition followed the guidelines proposed by the recommendations of the American Academy of Thermology, item 1.13 of guideline 1, when cold stress examinations are being performed, which include noningestion of caffeine and nicotine 4 h before testing and avoiding medications that alter sympathetic function 24 h prior to testing.

An IR camera (IRISYS®, model IRI 4010, United Kingdom) with wavelength formats sensitivity of 8.0 to 14.0 μM, uncertainty index of 2% or 0.02 °C, suitable for application in clinical diagnosis as it includes the wavelength emitted by human skin (9.4 μm) was used for the IR thermographic images acquisition. Device calibration is automatic, as recommended by the manufacturer, occurring constantly while it is connected. A precise thermometer (Minipa®, Brazil) was used to monitor the ambient temperature, which was maintained at between 23 and 24 °C.

The images were recorded on two different days for all subjects, day 1 and day 2, with an interval of 7 days between them. All measurements were performed in the morning to eliminate diurnal temperature variation influence. All subjects were asked to remain in a prone position on the examination table, with bare legs and feet, for 15 min to achieve equilibration with the controlled ambient temperature. The cold stress test was performed to obtain the rewarming index. The cold stress test increases the sensitivity of the diagnostic test for neuropathy and consists of immersing both feet, covered by a thin, waterproof plastic bag, in water at 15 °C for 60 s (modified from guidelines of the American Academy of Thermology[32]). Vasomotor response can be assessed by rewarming index. Two IR images were obtained for all subjects: one baseline (pre-cold stress test), and other 10 min after the cold stress test (post-cold stress test), both images in the same position. The IR camera was positioned one meter away from the subject and held perpendicular (90°) to the plantar foot region.

Data Analysis

The IR thermographic images were analyzed using IeSYS 4000 Software®, provided by the manufacturer of the camera used. Five marker points were selected in the plantar region (hallux, first metatarsal, third metatarsal, fifth metatarsal, and heel), and based on the absolute temperature of these points, the average temperature of the foot was calculated for pre- and post-cold stress test (**Figure 1**). For the rewarming index, the relative average temperature post-cold stress test was calculated in relation to the average temperature pre-cold stress test as follows:

$$\text{Rewarming Index} = \frac{\text{Average Temperature Post-Cold Stress Test} \times 100}{\text{Average Temperature Pre-Cold Stress Test}}$$

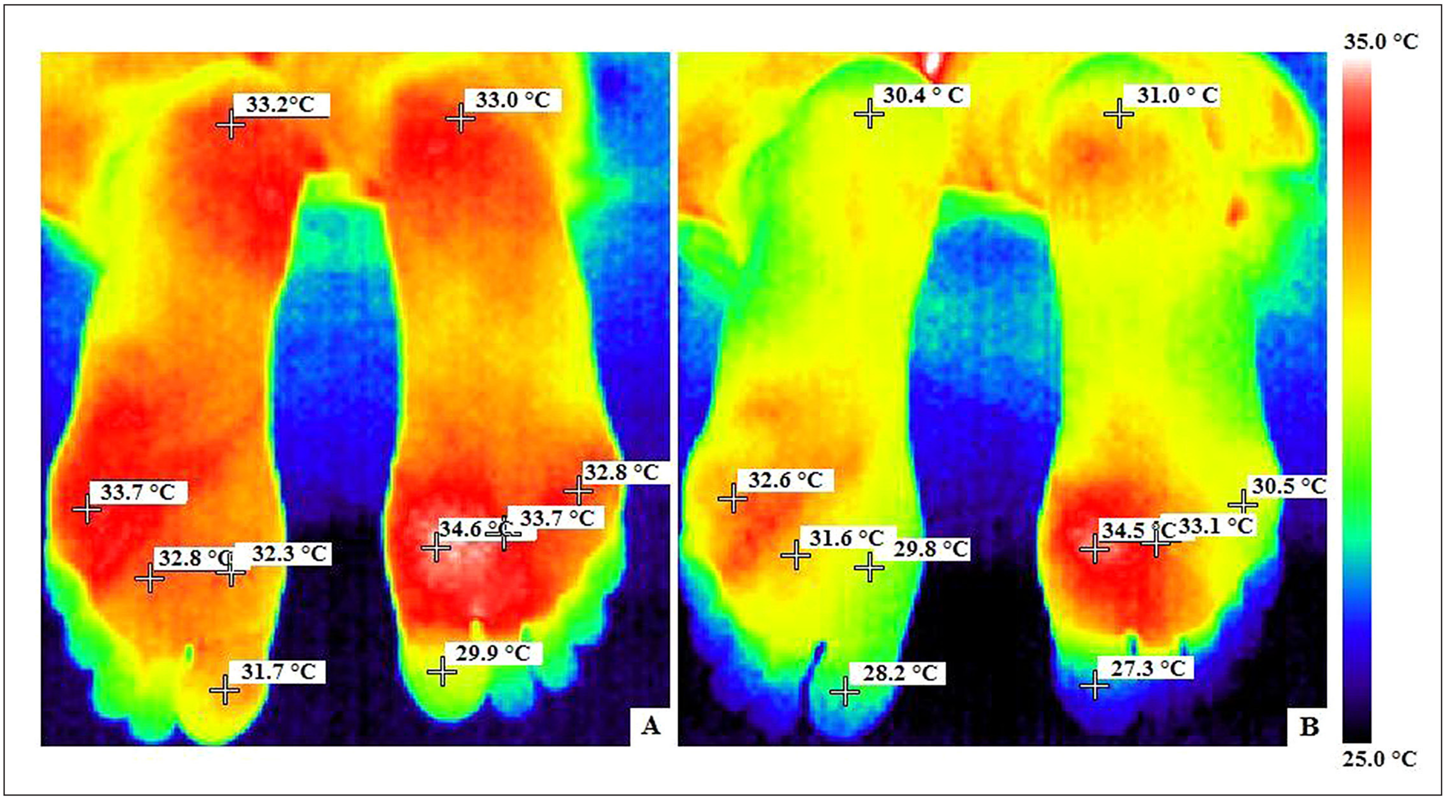

Figure 1. Infrared images from a T2DM subject **(A)** pre- and **(B)** post-cold stress test with the marker point for the average temperature in regions of interest in plantar surface. **(A)** The heel to **(B)** three areas in metatarsal (first, third, and fifth metatarsal) and **(C)** hallux.

The variation of temperature (ΔT) between the average temperature pre- and post-cold stress test was calculated for each day by subtracting the post-cold stress test averaged temperature from pre-cold stress test averaged temperature.

The right and left feet of each individual were counted as independent samples, resulting in 14 feet from T2DM and 20 feet from nondiabetic subjects.

Statistical Analysis

All numerical values are expressed as mean ± standard deviation (SD). Normal distribution was tested using Shapiro–Wilk test. The average temperature pre- and post-cold stress test, ΔT, and rewarming index comparisons between days 1 and 2 were evaluated using the *t*-test for dependent samples (the paired *t*-test). The comparison of age and rewarming index between diabetes patients and nondiabetic subjects was performed by *t*-test for independent samples. A significance level of $\alpha \leq 0.05$ was adopted. An analysis of the day-to-day repeatability for rewarming index was carried out using the Bland–Altman limits of agreement plot. SPSS 17.0 software was used for the statistical analysis.

Results

The 10 T2DM subjects (7 women, mean age 51.8 ± 12.5 years) and the 10 nondiabetic subjects (8 women, mean age 39.7 ± 16.8 years) had both feet (20 feet from T2DM subjects and 20 feet from nondiabetic subjects) analyzed in two different days with an interval of 7 days between them. Mean age did not differ between the two groups (p = .080).

Considering the sample size and the adopted significance in this study, according to the t-distribution,[33] the estimated t-value for between-group comparison is 2.024 and for intragroup comparison is 2.093. When the absolute t-value (**Table 1**) is greater than its estimated value, there is a greater probability that the p value and the pointed difference are not related with a sampling error, decreasing the chances of a type 1 error.

The average temperature pre-cold stress test did not differ between day 1 and day 2 for T2DM subjects, and average temperature post-cold stress test was not different in these subjects between days. In nondiabetic subjects, both pre- and post-cold stress test average temperature were significantly different from day 1 and day 2 (**Table 1**). Values of ΔT and rewarming index did not differ between days (**Table 1**). The rewarming index did not differ between diabetes patients and nondiabetic subjects at day 1 (p = .347) and day 2 (p = .445).

Table 1.
Mean Values for Plantar Temperatures and Rewarming after 10 Minutes of Cold Stress Test Measured 7 Days Apart in T2DM and Nondiabetic Subjects by Infrared Thermography Images[a]

	T2DM (n = 20)					Nondiabetic (n = 20)				
	Mean (SD)		Diff (SD)	t	p	Mean (SD)		Diff (SD)	t	p
	D1	D2				D1	D2			
$PreCST_{AT}$, °C	28.5 (2.5)	27.7 (3.4)	0.9 (4.0)	1.002	0.329	29.7 (2.9)	28.2 (2.5)	1.5 (3.0)	2.306	0.033
$PostCST_{AT}$, °C	26.5 (2.3)	26.2 (3.8)	0.5 (3.9)	0.624	0.540	28.2 (3.1)	26.8 (1.7)	1.3 (2.3)	2.579	0.019
ΔT, °C	2.0 (1.6)	1.5 (1.2)	-0.4 (1.7)	-0.946	0.356	1.6 (1.0)	1.4 (1.9)	-0.25 (2.0)	-0.526	0.606
RI, %	93.1 (5.3)	93.9 (5.9)	-0.9 (5.3)	-0.807	0.430	94.5 (3.5)	95.5 (6.3)	-0.97 (6.3)	-0.674	0.509

[a] Values are presented as mean and SD. Difference is significant when $p \leq .05$. D1, day 1; D2, day 2; Diff (SD), differences of the means and SD; t, coefficient of dependent t test; $PreCST_{AT}$, average temperature before cold stress test; $PostCST_{AT}$, average temperature 10 min after cold stress test; ΔT, temperature variation from PreCSTAT to PostCSTAT; RI %, rewarming index.

The assessment of the repeatability of the measures between the two different days using the Bland–Altman analysis for the nondiabetic subjects is shown in **Figure 2** and for T2DM subjects in **Figure 3**. The difference in the responses between day 1 and day 2 is plotted as a function of the average of the responses of both days for IR. Nondiabetic subjects showed 5% of all IR measures between days outside the 95% agreement limits. For T2DM subjects, not one of the measures falls outside the 95% agreement limits.

Discussion

In this pilot study, no differences were found regarding ΔT and rewarming index between days in both the assessed groups, and the rewarming index presented only 5% or less of the measures between days outside the limits agreement. A significant difference of the plantar average temperature between two days was found in nondiabetic subjects at baseline and 10 min after the cold stress test, whereas no differences were found in the average plantar temperature of T2DM subjects submitted to the same procedures. This work is the first one to assess the repeatability of a functional protocol that aims to evoke thermoregulatory responses. Repeatability has important decision-making implications for clinicians and researchers when assessing individuals, as it is used to determine the likely range for a single measurement and a change in a measurement in response to an intervention.[34,35]

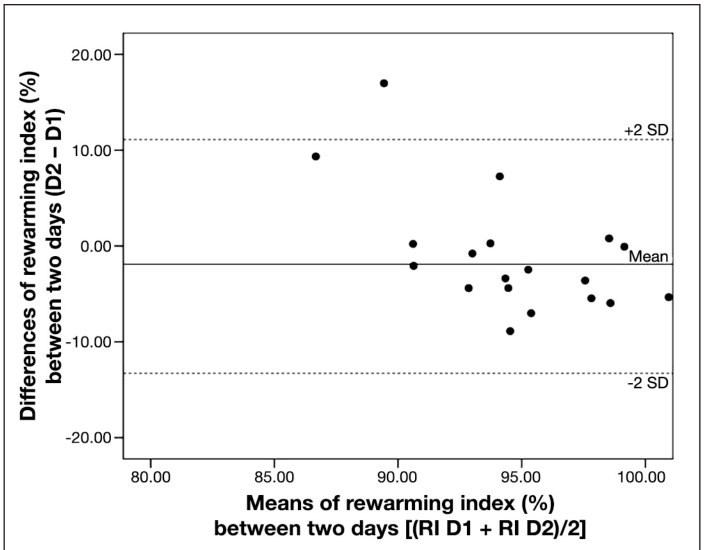

Figure 2. Bland–Altman plot for the assessment of the day-to-day repeatability of rewarming index measurements after 10 min of cold stress testing, obtained 7 days apart in nondiabetic subjects using IR thermography images. The difference in the responses measured on the two days (day 2–day 1) is plotted against the means of the responses [(day 1 + day 2) / 2]. The solid lines correspond to the mean of the differences, and the dashed lines indicate the 95% limits of agreement for the differences between the days. D1, day 1; D2, day 2; RI, rewarming index.

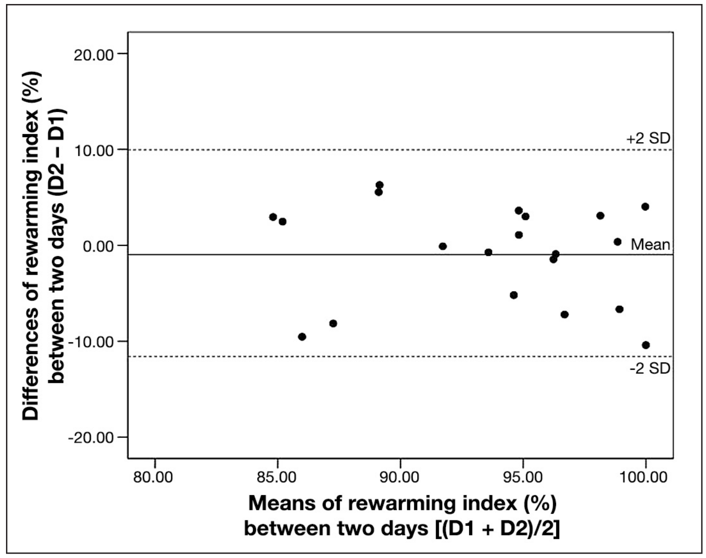

Figure 3. Bland–Altman plot for the assessment of the day-to-day repeatability of rewarming index measurements after 10 min of cold stress testing, obtained seven days apart in diabetes subjects using IR thermography images. The difference in the responses measured on the two days (day 2–day 1) is plotted against the means of the responses [(day 1 + day 2) / 2]. The solid lines correspond to the mean of the differences, and the dashed lines indicate the 95% limits of agreement for the differences between the days. D1, day 1; D2, day 2; RI, rewarming index.

Previous studies using an IR camera in the body temperature measurements of healthy subjects have shown that the skin temperature is more stable in the trunk, but in the extremities, the variation side-by-side (contralateral ΔT) and day-by-day is great and seems to depend on several endogenous factors, such as the activity of the neurovegetative sympathetic nervous system as well as on the environmental temperature.[1,2,13–16] Considering that, in this study, the environmental temperature and factors that could interfere in the sympathetic activity were controlled. The finding that the absolute average temperatures were different between days for the nondiabetic subjects and did not differ in T2DM subjects agrees with the neurovegetative variability that is common in other types of autonomic assessments, such as heart rate variability that shows great variability in healthy people and decreased variability in patients with some factors that suppress sympathetic function, such as diabetes subjects.[17]

Other findings related to this is with regard to the ΔT of T2DM subjects, which was greater than that of the nondiabetic subjects, leading to a decrease in the T2DM subjects' rewarming index compared with the nondiabetic subjects, although it was not a significant difference. There was no clinical neuropathy in this T2DM group initially assessed by MNSI, but studies of heart rate variability, also a manifestation of the neurovegetative system as skin temperature variation, showed reduced variability in diabetes patients with cardiac autonomic neuropathy, even when subclinical, which is related to the lack of physiological adaptation to different environmental demands.[15,20,24]

The good repeatability of IR in both groups assessed is concordant with the conclusions of previous authors that, for a neurovegetative function evaluation, the measure of the temperature should be performed in a stressing maneuver that evokes a thermoregulatory response, much in the same way that other stressing maneuvers evoke other physiological responses—for example, the assessment of endothelial function is evaluated by ischemic stress.[36]

Limitations of this study are related to sample size, as it was proposed as a pilot study. Also, we did not include neurophysiological study to investigate the presence of diabetic peripheral neuropathy or autonomic neuropathy. The MNSI was the clinical protocol performed, but it did not identify neuropathy in the T2DM subjects. Thus, not surprisingly, the results had been similar to those of nondiabetic subjects. In our view, this fact does not compromise the present study, which aimed to evaluate only the repeatability of different measurements in these two groups.

Despite the statistical correlation found in this work, it would be interesting to carry out further studies to evaluate the reproducibility of the results found here, including repetitions that include recorded IR images in the shortest time interval. The continuity of this research includes the intra- and inter-repeatability of this method and the analysis of the repeatability on peripheral and autonomic neuropathy in a larger sample.

Conclusion

The results suggest that plantar thermography carried out in suitable laboratory conditions and preceded by a strict pre-examination protocol reveals the physiological conditions existing at the time of data acquisition, being repeatable in time. Rewarming index after cold stress testing presented good repeatability between two days, with a 1-week interval, in both groups. Despite T2DM subjects having shown no differences on absolute temperature values (averaged temperatures) between days, thermographic measurements such as ΔT and rewarming index after cold stress testing are recommended for clinical purposes, following the suggestion of previous authors.

References:

1. Uematsu S, Edwin DH, Jankel WR, Kozikowski J, Trattner M. Quantification of thermal asymmetry. Part 1: Normal values and reproducibility. J Neurosurg. 1988;69(4):552–5.
2. Uematsu S, Jankel WR, Edwin DH, Kim W, Kozikowski J, Rosenbaum A, Long DM. Quantification of thermal asymmetry. Part 2: Application in low-back pain and sciatica. J Neurosurg. 1988;69(4):556–61.
3. Leclaire R, Esdaile JM, Jéquier JC, Hanley JA, Rossignol M, Bourdouxhe M. Diagnostic accuracy of technologies used in low back pain assessment. Thermography, triaxial dynamometry, spinoscopy, and clinical examination. Spine (Phila Pa 1976). 1996;21(11):1325–31.
4. Brioschi ML, Macedo JF, Macedo RA. Skin thermography: new concepts. J Vasc Bras. 2003;2(2):151–60.
5. Bharara M, Cobb JE, Claremont DJ. Thermography and Thermometry in the assessment of diabetic neuropathic foot: a case for furthering the role of thermal techniques. Int J Low Extrem Wounds. 2006;5(4):250–60.
6. Ring F. Thermal imaging today and its relevance to diabetes. J Diabetes Sci Technol. 2010;4(4):857–62.
7. Bagavathiappan S, Philip J, Jayakumar T, Raj B, Rao PN, Varalakshmi M, Mohan V. Correlation between plantar foot temperature and diabetic neuropathy: a case study by using an infrared thermal imaging technique. J Diabetes Sci Technol. 2010;4(6):1386–92.
8. Brioschi ML, Mehl A, Oliveira AG, Freitas MA, Macedo JF, Matias JEF, Macedo RAC. Diabetic foot evaluation by infrared skin thermometry. Rev Med Paraná 2007;65(1):33–41.
9. Sherman RA, Karstetter KW, Damiano M, Evans CB. Stability of temperature asymmetries in reflex sympathetic dystrophy over time and changes in pain. Clin J Pain. 1994;10(1):71–7.
10. Zaproudina N, Varmavuo V, Airaksinen O, Närhi M. Reproducibility of infrared thermography measurements in healthy individuals. Physiol Meas. 2008;29(4):515–24.
11. McCoy M, Campbell I, Stone P, Fedorchuk C, Wijayawardana S, Easley K. Intra-examiner and inter-examiner reproducibility of paraspinal thermography. PLoS One. 2011;6(2):e16535.
12. Nagase T, Sanada H, Takehara K, Oe M, Iizaka S, Ohashi Y, Oba M, Kadowaki T, Nakagami G. Variations of plantar thermographic patterns in normal controls and non-ulcer diabetic patients:Novel classification using angiosome concept. J Plast Reconstr Aesthet Surg. 2011;64(7):860–6.
13. Vinik AI, Erbas T, Park TS, Pierce KK, Stansberry KB. Methods for evaluation of peripheral neurovascular dysfunction. Diabetes Technol Ther. 2001;3(1):29–50.
14. Zaproudina N, Ming Z, Hänninen OO. Plantar infrared thermography measurements and low back pain intensity. J Manipulative Physiol Ther. 2006;29(3):219–23.
15. Flynn MD, Tooke, JE. Microcirculation and the diabetic foot. Vasc Med. 1990;1(2):121–38.
16. Papanas N, Papatheodorou K, Papazoglou D, Kotsiou S, Maltezos E. Association between foot temperature and sudomotor dysfunction in type 2 diabetes. J Diabetes Sci Technol. 2010;4(4):803–7.
17. Vinik AI, Maser RE, Mitchell BD, Freeman R. Diabetic autonomic neuropathy. Diabetes Care. 2003;26(5):1553–79.
18. Vinik AI, Erbas T, Park TS, Stansberry KB, Scanelli JA, Pittenger GL. Dermal neurovascular dysfunction in type 2 diabetes. Diabetes Care. 2001;24(8):1468–75.
19. Langer L, Fagerberg SE, Johnsén C. Peripheral circulation in diabetes mellitus--a study with infrared thermography. Acta Med Scand. 1972;191(1-2):17–20.

20. Sundkvist G, Almér LO, Lilja B. Autonomic neuropathy and toe circulation. A prospective study. Acta Med Scand. 1986;219(3):305–8.

21. Hauer JL, Boland OM, Ewing DJ, Clarke BF. Hand skin blood flow in diabetic patients with autonomic neuropathy and microangiopathy. Diabetes Care. 1991;14(10):897–902.

22. Hile C, Veves A. Diabetic neuropathy and microcirculation. Curr Diab Rep. 2003;3(6):446–51.

23. Strom NA, Sawyer JR, Roberts SK, Kingsley-Berg SM, Charkoudian N. Local sensory nerve control of skin blood flow during local warming in type 2 diabetes mellitus. J Appl Physiol. 2010;108(2):293–7.

24. Zotter H, Kerbl R, Gallistl S, Nitsche H, Borkenstein M. Rewarming index of the lower leg assessed by infrared thermography in adolescents with type 1 diabetes mellitus. J Pediatr Endocrinol Metab. 2003;16(9):1257–62.

25. Nishide K, Nagase T, Oba M, Oe M, Ohashi Y, Iizaka S, Nakagami G, Kadowaki T, Sanada H. Ultrasonographic and thermographic screening for latent inflammation in diabetic foot callus. Diabetes Res Clin Pract. 2009;85(3):304–9.

26. Ring EF, Ammer K. Infrared thermal imaging in medicine. Physiol Meas. 2012;33(3):R33–46.

27. So YT, Aminoff MJ, Olney RK. The role of thermography in the evaluation of lumbosacral radiculopathy. Neurology. 1989;39(9):1154–8.

28. Hoffman RM, Kent DL, Deyo RA. Diagnostic accuracy and clinical utility of thermography for lumbar radiculopathy. A meta-analysis. Spine (Phila Pa 1976). 1991;16(6):623–8.

29. Wasner G, Schattschneider J, Baron R. Skin temperature side differences--a diagnostic tool for CRPS? Pain. 2002;98(1-2):19–26.

30. World Medical Association. Declaration of Helsinki: ethical principles for medical research involving human subjects, as amended by the 52nd WMA Assembly, Edinburgh, Scotland, October 2000; note of clarification in paragraph 29 added by the WMA General Assembly, Washington DC, 2002.

31. American Diabetes Association. Diagnosis and classification of diabetes mellitus. Diabetes Care. 2011;34 Suppl 1:S62–9.

32. The Michigan Diabetes Research and Training Center; Michigan University. Michigan Neuropathy Screening Instrument (MNSI). http://www.med.umich.edu/mdrtc/profs/survey.html#mnsi. Accessed March 2010.

33. American Academy of Thermology. http://www.americanacademyofthermology.org. Accessed March 2010.

34. Gravetter FJ, Wallnau LB. Statistical for the behavioral sciences. 8th ed. Belmont: Cengage Learning; 2009, 729.

35. Tomkinson GR, Shaw LG. Quantification of the postural and technical errors in asymptomatic adults using direct 3D whole body scan measurements of standing posture. Gait Posture. 2013;37(2):172–7.

36. Corretti MC, Anderson TJ, Benjamin EJ, Celermajer D, Charbonneau F, Creager MA, Deanfield J, Drexler H, Gerhard-Herman M, Herrington D, Vallance P, Vita J, Vogel R; International Brachial Artery Reactivity Task Force. Guidelines for the ultrasound assessment of endothelial-dependent flow-mediated vasodilation of the brachial artery: a report of the international brachial artery reactivity task force. J Am Coll Cardiol. 2002;39(2):257–65.