The application of infrared thermography in evaluation of patients at high risk for lower extremity peripheral arterial disease

Chi-Lun Huang, MD,[a,b] Yen-Wen Wu, MD, PhD,[b,c,d] Chueh-Lung Hwang, BS,[e] Yuh-Shiun Jong, MD,[a] Chia-Lun Chao, MD, PhD,[b] Wen-Jone Chen, MD, PhD,[b] Ying-Tai Wu, PhD,[e,f] and **Wei-Shiung Yang, MD, PhD,[b,g]** *Taoyuan, Taipei, and Hsin-Chu, Taiwan*

Objective: **We investigated the usefulness of infrared thermography in evaluating patients at high risk for lower extremity peripheral arterial disease (PAD), including severity, functional capacity, and quality of life.**

Methods: **A total of 51 patients (23 males; age 70 ± 9.8 years) were recruited. They completed three PAD-associated questionnaires, including walking impairment, vascular quality of life, and 7-day physical activity recall questionnaires before a 6-minute walking test (6MWT). Ankle-brachial index (ABI) and segmental pressure were analyzed for PAD diagnosis and stenotic level assessment. The cutaneous temperature at shin and sole were recorded by infrared thermography before and after the walk test. Detailed demographic information and medication list were obtained.**

Results: **Twenty-eight subjects had abnormal ABI (ABI <1), while PAD was diagnosed in 20. No subjects had non-compressible artery (ABI >1.3). Demographic profiles and clinical parameters in PAD and non-PAD patients were similar, except for age, smoking history, and hyperlipidemia. PAD patients walked shorter distances (356 ± 102 m vs 218 ± 92 m; *P* < .001). Claudication occurred in 14 patients, while seven failed in completing the 6MWT. The rest temperatures were similar in PAD and non-PAD patients. However, the post-exercise temperature dropped in the lower extremities with arterial stenosis, but was maintained or elevated slightly in the extremities with patent arteries (temperature changes at sole in PAD vs non-PAD patients: −1.25 vs −0.15°C; *P* < .001). The exercise-induced temperature changes at the sole were not only positively correlated with the 6MWD (Spearman correlation coefficient = 0.31, *P* = .03), but was also correlated with ABI (Spearman correlation coefficient = 0.48, *P* < .001) and 7-day physical activity recall scores (Spearman correlation coefficient = 0.30, *P* = .033).**

Conclusion: **By detecting cutaneous temperature changes in the lower extremities, infrared thermography offers another non-invasive, contrast-free option in PAD evaluation and functional assessment.** **(J Vasc Surg 2011;54:1074-80.)**

Peripheral arterial disease (PAD) of the lower extremities is highly prevalent. It is estimated to affect between 4.5% and 29% worldwide and more than 20% of those over 75 years of age.[1] PAD significantly impairs functional capacity and life quality and is an indicator of future cerebrovascular and cardiovascular events.[2] Diabetes mellitus (DM) and smoking are the major risk factors for symptomatic PAD. Other risk factors include old age, male gender, dyslipidemia, hypertension, hyperhomocyteinemia, and renal insufficiency.[3] When these risk factors coexist, the risk of PAD increases several-fold. However, PAD is frequently overlooked and not appropriately treated.[4] Several techniques are currently being used to screen lower extremity PAD. These include ankle-brachial index (ABI), segmental limb pressure, toe pressure, and Duplex ultrasound. Computed tomography angiography, magnetic resonance angiography, and digital subtraction angiography are usually left for diagnosis confirmation, severity assessment, anatomical evaluation, and treatment planning.

The correlation between body temperature and various diseases has been known for centuries. Because of the advent of new technologies, skin temperature measurement has been used as a convenient and effective diagnostic tool.[5] The first documented application of thermography was for early preclinical diagnosis of breast cancer in 1956.[6] Infrared thermography has the advantages of being non-invasive, fast, reliable, non-contact, and capable of producing multiple recordings at short time intervals; furthermore, it is safe for patients and doctors. It has recently been used for breast cancer detection, osteoarthritis diagnosis, and pain evaluation.[7] Because vascular integrity and function are the major determinants of cutaneous temperature, several studies have investigated its application in the diagnosis of diabetic foot,[8] detection of peripheral vascular

From the Department of Internal Medicine, Taoyuan General Hospital, Taoyuan[a]; the Department of Internal Medicine[b] and the Department of Nuclear Medicine,[c] National Taiwan University Hospital, Taipei; the Department of Radiology, Hsin-Chu General Hospital, Hsin-Chu[d]; the School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, Taiwan[e]; the Division of Physical Therapy, Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, Taiwan[f]; and the Graduate Institute of Clinical Medicine, College of Medicine, National Taiwan University, Taiwan.[g]

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Reprint requests: Wei-Shiung Yang, MD, PhD, Graduate Institute of Clinical Medicine, College of Medicine, National Taiwan University, 1 Chang-Te Street, Taipei, 100, Taiwan (e-mail: wsyang@ntu.edu.tw) and Ying-Tai Wu, PhD, The School and Graduate Institute of Physcial Therapy, National Taiwan University, Floor 3, 17, Xuzhou Road, Zhongzheng District, Taipei 100, Taiwan (e-mail: ytw@ntu.edu.tw).

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disease,[9] and assessment of Raynaud's phenomenon,[10] although all were limited to case reports.

The aim of this study was to investigate the correlation between cutaneous temperature detected by infrared thermography and well-known lower extremity PAD parameters, including ABI, 6-minute walk distance (6MWD), and PAD-associated questionnaire scores. We hypothesized that impairment of blood flow and vasodilatory capacity in stenotic peripheral arteries would influence the cutaneous temperature during exercise, and the extent of temperature changes probably correlated to the PAD severity, functional impairment, and life quality.

METHODS

Patient population. Subjects at high risk for lower extremity PAD, defined as those with documented atherosclerotic disease, adults older than 70 years of age, or adults older than 50 years of age with diabetes or tobacco use,[11] were recruited from cardiovascular clinics. Patients with end-stage renal disease (ESRD) were also enrolled. Patients with advanced heart failure (New York Heart Association [NYHA] functional classes III and IV), pregnancy, recent myocardial infarction, unstable angina, or inability to walk because of cerebrovascular disease or critical limb ischemia were excluded. The study was approved by the local research ethics committee, and all participants gave written, informed consent. All demographic information, including height, weight, waist measurement, cardiovascular risk factors, comorbid conditions, claudication history, and a list of current medications were obtained before examination. Subjects with systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg, as well as those receiving antihypertensive agents, were considered hypertensive. Prevalent DM was defined as a fasting glucose of ≥6.99 mmol/L, and/or a history of DM with management. Patients with cholesterol levels ≥5.17 mmol/L or low-density lipoprotein cholesterol levels ≥3.36 mmol/L or those receiving lipid-lowering agents were defined as hyperlipidemic. Coronary artery disease was defined by a history of myocardial infarction or coronary intervention, or stable angina with demonstrable ischemia on exercise testing or perfusion scintigraphy. Cerebrovascular disease was defined by a history of ischemic stroke or transient ischemic attack, or by ultrasonographic evidence of carotid atherosclerosis (>50% stenosis of one or more carotid segments).

Questionnaire assessment. All participants completed three questionnaires before the walk test. The Walking Impairment Questionnaire (WIQ) includes a self-reported ambulatory ability evaluation using a validated questionnaire for PAD patients that assesses the ability to walk at various speeds and distances and to climb stairs.[12] The 7-day Physical Activity Recall (7D-PAR) Questionnaire consists of eight items that estimate the time spent performing physical activities (moderate to vigorous) and inactivity.[13] The Vascular Quality of Life (VASQoL) Questionnaire, a 25-item instrument, quantifies pain, symptoms, activities, and social and emotional aspects of PAD.[14] All three questionnaires have been well validated and extensively used in PAD evaluation.

Ankle-brachial index and segmental blood pressure measurement. ABI and segmental blood pressure were measured using the Nicolet VasoGuard (Nicolet Vascular Inc, Madison, Wisc), a device that allows simultaneous systolic blood pressure measurements from upper and lower extremities, including four cuffs at thigh, above-knee, below knee, and ankle, by means of photoplethysmography. Measurements were carried out in optimal conditions (supine position, room temperature, after resting for 10 minutes) by trained vascular nurses. The brachial artery pressure in ESRD patients was taken from the side without an arteriovenous shunt/fistula. Smoking and alcohol ingestion were forbidden before testing. Subjects with an ABI of ≤0.9 on either side were considered to have lower extremity PAD, and the lower ABI value was used for further statistical analysis. A significant drop in segmental pressures (≥20 mm Hg) between two adjacent cuffs indicates a narrowing of the artery in this portion of the leg.

Six-minute walk test. Each subject was instructed to walk as far as possible during a 6-minute period over a 30-meter course in an indoor hospital corridor. The course was identified by two traffic cones, and the corridor was marked every 3 meters according to American Thoracic Society standards.[15] Instructions and verbal encouragement given to the subjects were standardized. Encouragement was given every minute during the test until subject exhaustion. The end of the test was determined either by the subject, for any reason, or by the physical therapist conducting the test. Chest pain, intolerable dyspnea, dizziness, leg cramps, diaphoresis, and pallor were additional criteria for immediately stopping the test. Before and after each test, the following data were obtained: pulse rate, respiratory rate, and blood pressure. The overall distance walked within 6 minutes was recorded as 6MWD. The predicted 6MWD was estimated by body height, weight, and age.[16] The percentage of 6-minute walk distance (% 6MWD) was calculated as the absolute 6MWD divided by the predicted 6MWD.

Infrared thermography. Infrared thermography was performed at rest and after the 6MWT. The subjects were allowed to rest in a room where relative humidity and room temperature were controlled at 24°C (to equilibrate body temperature with ambient temperature). No body parts of the patient were near to or in contact with any hot or cold sources. The patients were kept away from air convection sources. These precautions were taken to minimize the variables that might influence temperature measurement. The local temperature of both shins and soles were measured by a digital infrared thermal image system (Spectrum 9000-MB Series; United Integrated Service Co. Ltd, Taipei Hsien, Taiwan) with a temperature resolution of 0.05 K.

The infrared thermal camera was positioned 1 meter away from the examination table, and a reference black plate that reflected the room temperature was placed beside the feet. The thermo-images were recorded before, imme-

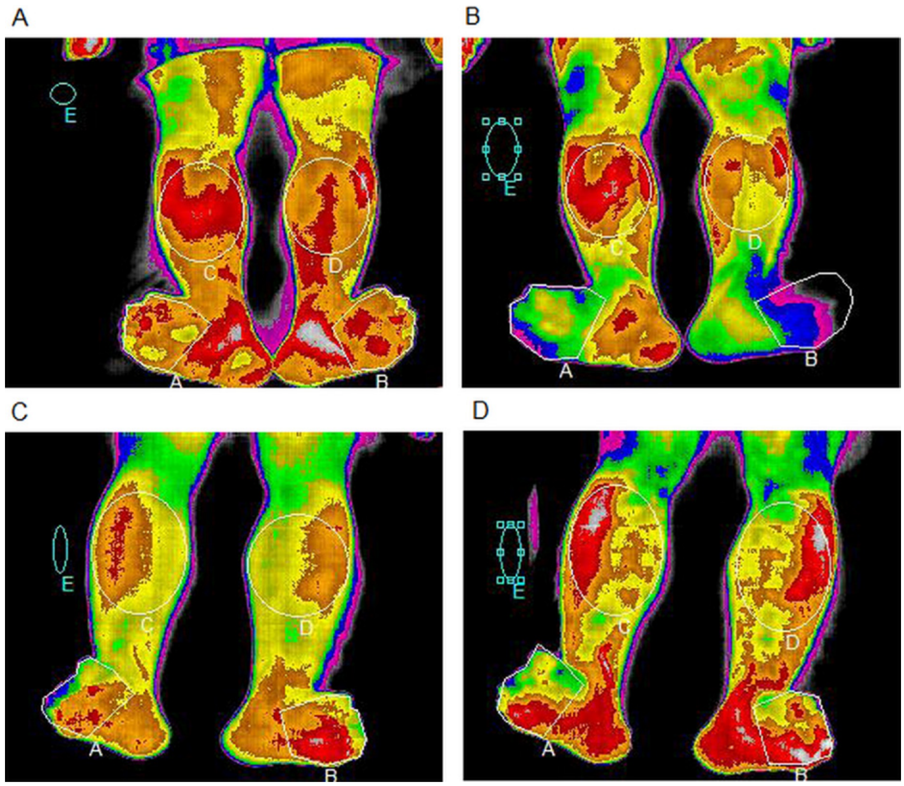

Fig 1. Infrared theromoimages before and after 6-minute walk test in lower extremity peripheral arterial disease (PAD) **(A, B)** and non-PAD patients **(C, D)**.

diately after, and 1 minute after exercise to record the trend of temperature changes. A high-resolution color image, which could be viewed on a miniature screen, was provided in real time. The surface temperature profiles were recorded automatically and analyzed later by the software. Using the spot meter, area, and profiling tools, the changes in temperature in the region of interest were determined (Fig 1). The exercise-induced temperature change (eTC) was defined as the post-exercise temperature minus the pre-exercise temperature. The post-exercise temperature recovery was defined as the temperature 1 minute after exercise minus the post-exercise temperature. Data from the extremity with lower ABI were used for further analysis.

Statistical analysis. Continuous data are expressed as mean ± SD. Categorical data are presented as frequencies. Group comparisons were performed by the Mann-Whitney two-sample rank sum test for continuous and categorical variables. Cutaneous temperature differences before and after 6MWT were analyzed by the Wilcoxon signed-rank test. Univariable relationships between cutaneous temperature, exercise-induced temperature change, clinical variables, ABI, 6MWD, and PAD-associated questionnaire scores were assessed with Spearman's rank correlation. Analyses were performed using Stata statistical software (release 10.0; Stata Corp., College Station, Tex). All statistical tests were two-sided. Differences were considered to be statistically significant when a P value of $<.05$ was obtained.

RESULTS

A total of 51 high-risk subjects were enrolled in this single-center trial. Twenty-eight subjects had abnormal ABI (ABI <1), while PAD was diagnosed in 20. No subjects had non-compressible arteries (ABI >1.3). Demographic profiles and clinical parameters are shown in Table I. PAD patients were older and more likely to have history of smoking but less likely to have hyperlipidemia. The relatively low hemoglobin levels were related to ESRD patient recruitment (30%). Aspirin and/or clopidogrel were administered to 32 patients, and beta-blockers were administered to 23 patients (45% in each group). In segmental pressure analysis, most PAD patients had multi-segment arterial stenosis, usually at the levels of popliteal artery and tibial artery. In-flow disease was diagnosed in five patients. In the 6MWT, PAD patients walked shorter distances (218 ± 92 m vs 356 ± 102 m; $P < .001$). After adjusting the predicted 6MWD, the % 6MWD was still lower in PAD patients (50.3% vs 73.4%; $P < .001$). Claudication occurred in 14 patients, while seven failed to complete the 6MWT.

The rest temperature at the shin and sole was not different between PAD and non-PAD group patients (Ta-

Table I. Demographic and clinical characteristics of the participants (n = 51)

	PAD (n = 20)	*Non-PAD (n = 31)*	P *value*
Age (years)	72.9 ± 10.6	68.2 ± 8.9	.04[a]
Male	45% (9)	45% (14)	.99
Body mass index (kg/m^2)	23.9 ± 4.10	25.4 ± 3.58	.06
Hypertension	70% (14)	87% (27)	.14
Diabetes	80% (16)	65% (20)	.24
Hyperlipidemia	35% (7)	65% (20)	.04[a]
Coronary artery disease	65% (13)	48% (15)	.25
End-stage renal disease	40% (8)	23% (7)	.19
Old myocardial infarction	35% (7)	23% (7)	.34
Cerebral vascular accident	10% (2)	6% (2)	.65
Smoking	45% (9)	19% (6)	.04[a]
Low-density lipoprotein cholesterol (mg/dL)	108.7 ± 31.2	113.8 ± 36.5	.36
High-density lipoprotein cholesterol (mg/dL)	42.1 ± 9.3	41.4 ± 14.1	.93
Hemoglobin (g/dL)	10.6 ± 1.68	11.0 ± 1.57	.57
Hemoglobin A1c (%)	8.0 ± 1.8	7.3 ± 1.4	.34
Antiplatelet agents	50% (10)	71% (22)	.13
Beta-blockers	45% (9)	45% (14)	.99

PAD, Peripheral artery disease.
[a]$P < .05$.

Table II. Cutaneous temperature before exercise, changes during exercise, and recovery after exercise in PAD and non-PAD patients

	PAD (n = 20)	*Non-PAD (n = 31)*	P *value*
Rest temperature (°C)			
Shin	32.6 ± 0.86	32.6 ± 0.91	.81
Sole	31.0 ± 1.75	30.4 ± 2.37	.30
Exercise-induced temperature change (°C)			
Shin	−0.01 ± 0.89	0.32 ± 0.52	.16
Sole	−1.25 ± 1.58	−0.15 ± 1.31	<.001[a]
Temperature recovery (°C)			
Shin	−0.05 ± 0.20	0.01 ± 0.16	.38
Sole	−0.02 ± 0.26	0.02 ± 0.30	.78

PAD, Peripheral artery disease.
[a]$P < .05$.

ble II). After a 6-minute walk, the cutaneous temperature elevated slightly in non-PAD patients (from 32.6°C to 32.9°C; $P < .001$). However, the temperature did not elevate in PAD patients; the sole temperature actually lowered dramatically (from 31.0°C to 29.7°C; $P < .001$). The eTC at the sole was quite different between the two groups (PAD vs non-PAD patients: −1.25°C vs −0.15°C; $P < .001$). In other words, the post-exercise temperature dropped in the lower extremities with arterial stenosis, but was maintained or elevated slightly in the extremities with patent arteries. The eTC at the sole was not only positively correlated with the 6MWD (Spearman correlation coefficient = 0.31, $P = .03$, 95% confidence interval [CI], .07-.55), but was also correlated with ABI, an indicator of PAD severity (Spearman correlation coefficient = 0.48, $P < .001$, 95% CI, 0.21-0.70). The receiver-operator characteristic (ROC) curve revealed that the ideal cut-off point for PAD screening was −0.99°C for eTC (Fig 2), a value that would optimize the relationship between subjects with positive and false-positive results. The eTC of −0.99°C showed 81.7% sensitivity and 65.0% specificity. Current medications and underlying comorbidities did not associate with rest temperature and eTC. The pattern of postexercise temperature recovery did not differ between the two groups.

The functional capacity, walking impairment and life quality were measured by three PAD-associated questionnaires. PAD patients had more severe walking impairments, lower vascular qualities of life, and fewer daily physical activities, according to questionnaire results (Table III). ABI was also positively correlated with the 6MWD and all three PAD-associated questionnaire scores, while eTC was correlated with 7D-PAR scores (Table IV).

DISCUSSION

To the best of our knowledge, this is the first study to evaluate the application of infrared thermography for high-risk PAD group evaluation. Analysis of the cutaneous temperature changes before and after exercise and their relationship to PAD is also a novel approach. In this study, we demonstrated that exercise-induced temperature changes

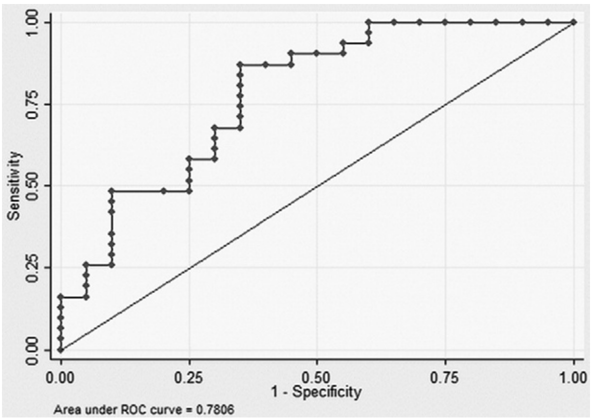

Fig 2. The receiver-operator characteristic (*ROC*) curve of exercise-induced temperature change (eTC) for the identification of peripheral arterial disease (PAD) in high-risk subjects.

were correlated with PAD severity (ABI), walking capacity (6MWD), and physical activity (7D-PAR scores).

ABI, defined as the ratio of systolic pressures in the lower and upper extremities, is a widely accepted, simple, non-invasive diagnostic test. The ABI generally is 1.0 to 1.29, and an ABI ≤0.9 is used to diagnose PAD in the clinical setting.[17,18] Well validated by angiography findings, ABI was found to be 90% sensitive and almost 95% specific for PAD.[19] According to guidelines, it is recommended to obtain the ABI early in patients with exercise leg symptoms or nonhealing wounds and in those who are asymptomatic but in the high-risk category.[11] However, the utility of ABI is limited in the presence of calcified non-compressible vessels, which are common in patients with diabetes and renal failure. Because it is an indirect examination, the exact stenotic location, number, and nature of lesions are also unknown.

Infrared thermal imaging has been used to study blood flow, detect breast cancer and muscular performance,[20] and quantify sensitive changes in skin temperature in relation to disease.[7] Compared with other conventional devices, the major advantage of infrared thermography is its ability to instantaneously measure the absolute temperature of the skin surface over a large area without direct contact with the skin. The relationship between blood flow and surface temperature was identified in 1993.[21] Based on one-dimensional simplification of the heat transfer from arterioles to the dermis, the dermis to the epidermis, and the epidermis to the surroundings, a linear relationship between blood flow and surface temperature may be demonstrated with a physical model. Because the temperature of extremities is largely dependent on peripheral blood flow vessels, this imaging tool is useful in vascular diseases.[22] However, we did not find significant differences in rest temperature between PAD and non-PAD patients. Similarly, different stenotic levels did not result in different temperature gradients between the shin and sole in PAD patients. Bagavathiappan et al[9] reported that temperature gradients are observed in the affected regions of patients with vascular disorders and ischemic gangrene. The temperature in the affected regions was 0.7°C to 1°C above that in the normal regions because of slow blood circulation. However, owing to the mixed arterial and venous vascular diseases in that study, the rest temperature gradient needed further investigation in pure arterial occlusive patients. Because most varicose veins occur in the calf, we focused on the temperature changes in the sole in our study.

Dynamic analysis has previously been used in vascular functional studies. One example is post-exercise ABI measurement, which enhances the sensitivity of PAD detection.[23] Like perfusion scintigraphy used in ischemic cardiomyopathy detection, the temperature of the skin area supplied by stenotic arteries might elevate to a lesser extent or even decrease during exercise, as we proposed before examination. The severity of stenosis, vasodilatory capacity, endothelial function, and autonomic activity may all contribute to the eTC. The development of collateral circulation also could affect and even reverse the temperature changes. The underlying disease (DM and ESRD) and medication (statins, beta-blockers, and calcium channel blockers) were known to affect endothelial function and vasodilatory capacity. Nevertheless, they were not independent predictors of eTC in the current study. Further large-scale, prospective study designs may be needed to confirm these results.

Several studies have investigated the correlation between serum biomarkers, comorbidity, and limb hemodynamics with walking distance, physical function, and quality of life. Our study demonstrated that ABI, eTC, hypertension, and ESRD are the most predictive of 6MWD. Gardner[24] found that PAD patients with more metabolic syndrome components had worsened intermittent claudication, physical function, health-related quality of life, and peripheral circulation. Serum biomarkers, including D-dimer, C-reactive protein (CRP), interleukin-6 (IL-6), soluble vascular cellular adhesion molecule-1 (sVCAM-1), soluble intracellular adhesion molecule-1 (sICAM-1), and homocysteine were associated with lower extremity performance as assessed by the 6MWT.[25] In our study, we found that high-sensitivity CRP negatively correlated with 7D-PAR scores, but not 6MWD results (data not shown).

There were several limitations in our study. The lack of angiography to confirm stenotic severity, stenotic level, and collateral circulation was a major limitation. Thereafter, we could not determine whether a different stenotic pattern or collateral circulation could influence the dynamic temperature changes. Although all subjects had ABI ≤1.3, the occurrence of non-compressible vessels still could not be ruled out, especially in patients with ESRD. Because ABI is normal in subjects with isolated pedal arch stenosis, these patients could be misclassified to non-PAD group. Although we encouraged all subjects to exercise with shorts and sports shoes, different clothing/shoes materials and

Table III. The results of 6-minute walk test and three PAD-associated questionnaire scores

	PAD (n = 20)	*Non-PAD (n = 31)*	P *value*
6-Minute Walk Distance (m)	218 ± 92	356 ± 102	.0001[a]
Walking Impairment Questionnaire scores	1.27 ± 0.55	1.74 ± 0.58	.008[a]
Vascular Quality of Life scores	4.91 ± 0.97	5.65 ± 0.79	.009[a]
7-day Physical Activity Recall (kcal/kg/day)	32.1 ± 1.74	34.0 ± 2.68	.007[a]

PAD, Peripheral artery disease.
[a]$P < .05$.

Table IV. The Spearman correlation coefficients between ankle brachial index, exercise-induced temperature change, 6-minute walk distance, and PAD-associated questionnaire scores

	Ankle brachial index			*Exercise-induced temperature change*		
	Rho	*95% confidence interval*	P *value*	*Rho*	*95% confidence interval*	P *value*
6-Minute Walk Distance (m)	0.64	0.40-0.77	<.0001[a]	0.31	0.07-0.55	.030[a]
Walking Impairment Questionnaire scores	0.41	0.07-0.60	.0027[a]	0.27	0.47-0.62	.059
Vascular Quality of Life scores	0.45	0.17-0.66	.0009[a]	0.22	−0.13-0.65	.132
7-day Physical Activity Recall (kcal/kg/day)	0.40	0.16-0.72	.004[a]	0.30	0.002-0.56	.033[a]

PAD, Peripheral artery disease; *Rho,* Spearman correlation coefficient.
[a]$P < .05$.

incidental floor contact all possibly interfered with the extent of the temperature changes.

CONCLUSION

By detecting cutaneous temperature changes in the lower extremities, infrared thermography offers another non-invasive, contrast-free option in PAD evaluation and functional assessment. Undeniably, ABI is still the most reliable and convenient parameter in the meantime. We look forward to the potential role of infrared thermography in PAD treatment assessment and outcome prediction, although further comprehensive study is needed.

AUTHOR CONTRIBUTIONS

Conception and design: CLC, WJ, YW, CLHu
Analysis and interpretation: CLHu, CLHw, YW
Data collection: YS, CLHu, CLHw
Writing the article: CLHu
Critical revision of the article: YT, WS, CLC, WJ
Final approval of the article: YT, WS
Statistical analysis: CLHu, CLHw
Obtained funding: Not applicable
Overall responsibility: WS

REFERENCES

1. Meijer WT, Hoes AW, Rutgers D, Bots ML, Hofman A, Grobbee D. Peripheral arterial disease in the elderly: the Rotterdam study. Arterioscler Thromb Vasc Biol 1998;18:185-92.
2. Norgren L, Hiatt WR. TASC II guidelines. Eur J Vasc Endovasc Surg 2007;33 (Suppl 1):1-75.
3. Fowkes FG, Housley E, Cawood EH, Macintyre CC, Ruckley CV, Prescott RJ. Edinburgh Artery Study: prevalence of asymptomatic and symptomatic peripheral arterial disease in the general population. Int J Epidemiol 1991;20:384-92.
4. Rehring TF, Sandhoff BG, Stolepart RS, Merenich JA, Hollis HW Jr. Atherosclerotic risk factor control in patients with peripheral arterial disease. J Vasc Surg 2005;41:816-22.
5. Anbar M, Gratt BM, Hong D. Thermology and facial telethermography. Part I: history and technical review. Dentomaxillofac Radiol 1998; 27:61-7.
6. Lawson R. Implications of surface temperatures in the diagnosis of breast cancer. CMAJ 1956;75:309-10.
7. Jones BF. A reappraisal of the use of infrared thermal image analysis in medicine. IEEE Trans Med Image 1998;17:1019-27.
8. Cheng KS, Yang JS, Wang MS, Pan SC. The application of thermal image analysis to diabetic foot diagnosis. J Med Biol Eng 2002;22: 75-82.
9. Bagavathiappan S, Saravanan T, Philip J, Jayakumar T, Raj B, Karunanithi R, et al. Infrared thermal imaging for detection of peripheral vascular disorders. J Med Phys 2009;34:43-7.
10. Clark S, Dunn G, Moore T, Jayson M, King TA, Herrick AL, et al. Comparison of thermography and laser Doppler imaging in the assessment of Raynaud's phenomenon. Microvasc Res 2003;66:73-6.
11. Hirsch AT, Haskal ZJ, Hertzer NR, Bakal CW, Creager MA, Halperin JL, et al. ACC/AHA 2005 practice guidelines for the management of patients with peripheral arterial disease (lower extremity, renal, mesenteric, and abdominal aortic): a collaborative report from the American Association for Vascular Surgery/Society for Vascular Surgery, Society for Cardiovascular Angiography and Interventions, Society for Vascular Medicine and Biology, Society of Interventional Radiology, and the ACC/AHA Task Force on Practice Guidelines (Writing Committee to Develop Guidelines for the Management of Patients with peripheral Arterial Disease): endorsed by the American Association of Cardiovascular and Pulmonary Rehabilitation; National Heart, Lung, and Blood Institute; Society for Vascular Nursing; TransAtlantic Inter-Society Consensus and Vascular Disease Foundation. Circulation 2006;113: e463-654.
12. Regensteiner JG, Steiner JF, Panzer RJ. Evaluation of walking impairment by questionnaire in patients with peripheral arterial disease. J Vasc Med Biol 1990;2:142-52.
13. Sallis JF, Haskell WI, Wood SP, Fortmann SP, Rogers T. Physical activity assessment methodology in the five-city project. Am J Epidem 1985;121:91-106.
14. Morgan MB, Crayford T, Murrin B, Fraser SC. Developing the vascular quality of life questionnaire: a new disease-specific quality of life measure for use in lower limb ischemia. J Vasc Surg 2001;33:679-87.
15. ATS, Committee on Proficiency Standards for Clinical, Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002;166:111-7.

16. Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. Am J Respir Crit Care Med 1998;158:1384-7.
17. Schroll M, Munck O. Estimation of peripheral arteriosclerotic disease by ankle blood pressure measurements in a population study of 60-year-old men and women. J Chronic Dis 1981;134:261-9.
18. Stoffers H, Kester A, Kaiser V, Rinkens PE, Kitslaar PJ, Knottnerus JA. The diagnostic value of the measurement of the ankle-brachial systolic pressure index in primary health care. J Clin Epidemiol 1996;12: 1401-05.
19. Criqui MH. Systemic atherosclerosis risk and the mandate for intervention in atherosclerotic peripheral arterial disease. Am J Cardiol 2001; 88:43J-7J.
20. Cook RJ, Thakore S, Nichol NM. Thermal imaging – a hotspot for the future? Inj Extra 2005;36:395-7.
21. Wu JY. Thermogram analysis and its clinical application. Master Thesis, National Cheng Jung University. Tainan, Taiwan: ROC; 1995.
22. Herrick L. Vascular imaging. Best Pract Res Clin Rheumatol 2004;18: 957-79.
23. Stein R, Hriljac I, Halperin JL, Gustavson SM, Teodorescu V, Olin JW, et al. Limitation of the resting ankle-brachial index in symptomatic patients with peripheral arterial disease. Vasc Med 2006;11: 29-33.
24. Gardner AW, Montgomery PS. The effect of metabolic syndrome components on exercise performance in patients with intermittent claudication. J Vasc Surg 2008;47:1251-8.
25. McDermott MM, Liu K, Ferrucci L, Tian L, Guralnik JM, Green D, et al. Circulating blood markers and functional impairment in peripheral arterial disease. J Am Geriatr Soc 2008;56:1504-10.

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