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RESEARCH

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Evaluation of smartphone-assisted infrared thermal imaging efficiency in carpal tunnel syndrome

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Abstract

Background Thermography is an industrial method for surface temperature measurements, and although it is medically safe and non-invasive, its place in daily practice has been limited. With the development of technology, thermal cameras have become more accessible and practical via adaptation to mobile phones. Among patients evaluated with bilateral nerve conduction studies (NCS) for suspected carpal tunnel syndrome (CTS), those with electrophysiological findings consistent with mild-to-moderate unilateral CTS were accepted for this prospective study. The hands with positive NCS findings were the study group, and the unaffected hands were the control group. The images were evaluated with the thermal analysis software (*FLIR Tools ver. 6.4, Windows 10*) and compared with NCS for statistical significance. In addition, thermal images were examined by three orthopaedic surgeons, and interobserver correlation was analyzed. Our study aims to evaluate the mobile phone-assisted thermal camera (*FLIR One Pro, FLIR Systems, Wilsonville, OR, USA*) as a suitable tool to diagnose CTS.

Results 48 patients, 35 women and 13 men were included in the study. Bilaterally, a total of 96 hands were evaluated. 18 patients had mild, and 30 patients had moderate NCS stages unilaterally. The mean temperature difference at the region of interest in the palm, first and third fingers were statistically significant between the study and control groups ($p < 0.05$). NCS values and stages were correlated with the temperature difference in the third finger ($p = 0.002$). The inter-observer reliability was high (ICC = *0.858*) while detecting temperature differences.

Conclusions Since smartphone-assisted thermal cameras are easy and convenient to use, we think they are helpful in the daily practice of diagnosing mild-to-moderate carpal tunnel syndrome.

Keywords Carpal tunnel syndrome, Thermography, Infrared, Smart-phone-assisted, Electromyography

Introduction

The temperature increase is a classic inflammatory marker. Various diseases may affect changes in the skin surface and body core temperature, and physical factors affect temperature changes in the human body [1]. When the skin temperature elevation is at a level that cannot be evaluated by touch, to determine the temperature, tools like mercury or electronic contact thermometers are used by placing them into the axillary fossa or a body cavity. But contact methods measure temperature from narrow regions and cannot measure the surface temperature and temperature distribution [2]. The essential noninvasive and noncontact method to measure surface temperature distribution is infrared thermography (IRT) [3].

The use of infrared thermal cameras has increased with the COVID-19 pandemic, as it has become necessary to perform on-site body temperature measurements of masses of people in a particular location. In this setting,

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thermal cameras are large, heavy, and difficult to mobilize; therefore, they are used with a tripod. With technological innovation, thermal infrared cameras have become smaller in size and mountable on smartphones so that they can be used without restrictions of place and time; this allows them to be used to evaluate patients quickly and effectively in the outpatient setting [4].

Carpal tunnel syndrome (CTS) is the most common compression neuropathy in which thermal imaging may aid the diagnosis [5]. Physical examination tests, such as Phalen, Tinnel, or Durcan test, and Nerve Conduction Studies (NCS) are used to diagnose CTS. The assumption of sympathetic neural pathology in CTS has been well described. Because the sympathetic fibres are very thin and unmyelinated, they are probably especially vulnerable to impairment in CTS, which may be evident in the early stages of CTS [1]. When the sympathetic fibres are affected, changes in vasomotor reflex in the related area and variations in skin temperature levels can be expected [6]. Thus, evaluating the skin surface temperature of the affected area may further understand the function of affected sympathetic fibres and permit earlier diagnosis [5].

This study aims to determine the relationship between the temperature measurements assessed by smartphone-assisted infrared thermography and NCS, the gold standard diagnostic test, to show potential benefits for earlier diagnosis and treatment.

Methods

Among patients recommended for bilateral NCS for suspected CTS, those with electrophysiological findings consistent with mild-to-moderate unilateral CTS were included in the study. Upper extremity nerve conduction studies were performed using standard techniques of supramaximal percutaneous stimulation with a constant current stimulator and surface electrode recording. Median and ulnar sensory transmissions were measured antidromically by placing recording electrodes on the 2nd and 5th fingers, and stimulating electrodes on the wrist, respectively. Median-ulnar peak latency was recorded from the 4th finger. In the median nerve motor conduction study, abductor pollisis brevis was recorded from the abductor digiti minimi muscle for ulnar nerve motor response, and distal latency, amplitude and nerve conduction rates were calculated. Electrophysiologically the patients were classified according to the criteria according to Stevens [7]. Mild; the difference between the distal latency of the median sensory response and the distal latency of the ulnar sensory response is >1 ms or the difference between the 4th finger registered median-ulnar nerve peak latency is >0.5 ms. Moderate; in addition to the above, the prolongation of the distal latency of the median motor nerve (>4.0 ms). Severe; often low/absent of sensory potential amplitude and decrease in motor response amplitude (5.5 ms). Patients with bilateral or severe carpal tunnel syndrome findings upon NCV, or history of corticosteroid injection, physical therapy or upper extremity surgery, vascular disease or other local blood flow disturbances, or peripheral nervous system pathologies were excluded. A research assistant performed thermal imaging according to the previously described standard infrared imaging protocol in medicine in a dedicated room where the temperature was stabilized at 23.0 ± 1.0 °C [3, 8]. The patients were taken to the dedicated room 15 min before imaging; their clothes were removed, and they were not allowed to use their hands. A single researcher used the FLIR ONE Pro device (FLIR Systems, Inc, Wilsonville, OR) in conjunction with the iPhone X (Apple, Cupertino, CA) to obtain all images, placing the camera at the head of the patient (Fig. 1). A blinded research assistant analyzed the thermal images using FLIR Tools for Windows 10 (FLIR Systems, Inc., Wilsonville, OR). Lines drawn along the first, second, and third fingers and palm (Fig. 2) were identified as regions of interest (ROI); here, mean temperature values were measured and then statistically compared with mean temperature values on the opposite side.

Correlation analysis was performed with NCV values and stages. Three orthopaedic surgeons experienced in hand surgery blindly evaluated the thermographic images without using thermal analysis software and identified

Fig. 1 Position of the thermal camera to obtain the images. The thermal camera is placed the patients head level and serial thermographic images taken from the palmar side of the hand

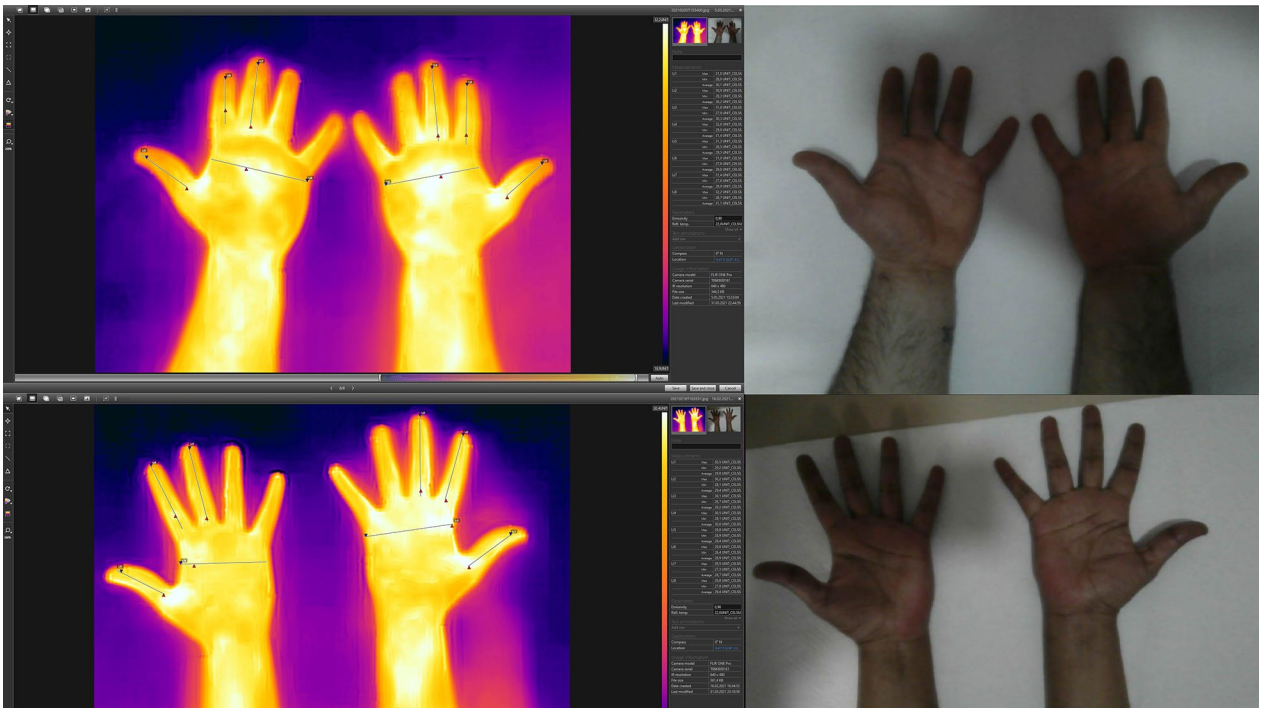

Fig. 2 Analysis of the photographs using the thermal image software. There are three lines which originate from proximal finger crease had drawn; Line 1: to the thumb tip, Line 2: to the second fingertip, Line 3: to the third fingertip and 4. line is drawn through the distal palmar crease. The software calculates the mean temperature values among the lines

the hands with increased temperature and possible carpal tunnel syndrome. Intraclass correlation coefficient (ICC) with 95% confidence intervals was calculated using a two-way mixed-effects model with absolute agreement. The independent samples *t* test and Mann–Whitney *U* test were used to analyse independent quantitative data, and the Wilcoxon test was used for dependent quantitative data. In the analysis of independent qualitative data, the Chi-square test was utilised. Analyses were performed using the IBM SPSS version 25.0 statistical software (IBM Corp., Armonk, NY, USA). Comparisons were analysed by the Mann–Whitney *U* and Wilcoxon tests, which can be used to compare two independent groups of sampled data. *P* values smaller than *0.05* were considered statistically significant. The institutional review board has approved this study of the authors' affiliated institutions.

Table 1 Demographic properties of the patients

	Values (*n* = 48)
Age (years)	43.04 (23–87)
Gender	
Male	13 (27.08%)
Female	35 (72.91%)
Dominant side	
Right	46 (95.83%)
Left	2 (4.16%)
Affected side	
Right	30 (62.5%)
Left	18 (37.5%)
Symptom duration (months)	13.6 ± 10.3
NCV Stage	
Mild	18 (37.5%)
Moderate	30 (62.5%)

NCV: nerve conduction velocities

Results

A total of 96 hands from 48 patients were evaluated. Of 48 patients, 35 were female, and 13 were male (mean age 43.04, range 23–87 years). CTS stage based on NCS, 18 were mild, and 30 were moderate. There were 46 right- and two left-handed patients (Table 1). The active hands were affected in 32 patients (*66.6%*). The mean temperature difference (tΔ) at the ROI in the palm ($t\Delta^{palm}$), first ($t\Delta^{1}$), second ($t\Delta^{2}$), and third fingers ($t\Delta^{3}$) between the control and study groups were 0.341, 0.395, − 0.053, 0.216 relatively and were statistically significant ($p < 0.05$). NCV values and stages correlated with the $t\Delta^{3}$ ($p = 0.002$). The inter-observer reliability was high ($ICC = 0.858$) in detecting elevated temperature indicating possible nerve

compression. In addition there was no statistically significant temperature difference between the mild and moderate stages ($p = 0,827$).

Discussion

Our study proves that surface temperature variations in the palm and third finger correlate with electrophysiological studies diagnosing carpal tunnel syndrome. Local areas of hyperthermia are related to increased blood flow, while regions of hypothermia indicate reduced blood flow. Thermography can monitor the temperature of various body regions, which will increase with high blood flow; images gathered by thermography can be used to visualise blood flow to a specific anatomical structure.

Blood flow throughout the body is regulated by the nervous and endocrine systems in response to internal and external stimuli. The sympathetic nervous system belongs to the central nervous system, partially responsible for maintaining the body's homeostasis, regulating body temperature, and blood flow patterns [9]. The sympathetic nervous system synapses with the peripheral nervous system at the ventral roots of the spinal cord, and the interconnections transmit the sympathetic nervous system's effects throughout the body. Patients with median nerve compression demonstrate apparent motor and sensory fibre impairment, and autonomic nerves may also be disturbed [10, 11]. Physical examination and NCV both evaluate the degree of motor and sensory function loss. A substantial number of patients with CTS may experience symptoms due to the sympathetic dysfunction [1, 12, 13].

Infrared thermography is a technique that determines the infrared electromagnetic energy released from the skin surface related to the body temperature. This permits assessing the temperature changes associated with the vascular flow [14]. It is known that sympathetic denervation may lead to paralytic vasodilatation [10]. A historical study by Aminoff showed that a defect in sympathetic outflow to the index finger is visible via digital plethysmography in CTS patients [15]. Unlike that study, ours assessed statistically different temperature values at the third finger and palm.

When we analysed the thermal images, we found that smartphone-assisted IRT may be an additional easy, noninvasive, cheap, and rapid screening tool for CTS diagnosis. CTS diagnosis is based on medical history, symptoms, and clinical examination and confirmed by NCV [16]. Stevens criteria [7] divides CTS into three groups by the nerve conduction velocities: mild, with prolonged median sensory latency and normal distal motor latency; moderate, with prolonged median sensory latency and prolonged distal motor latency; and severe, with both long median sensory and distal motor latency which is characterised by either absent sensory nerve action potentials and low amplitude or absent thenar muscle action potentials. As in the other entrapment neuropathies, myelinated fibres are primarily affected, but in chronic or extremely severe situations, thin sympathetic nerve fibres are also affected [17]. Since autonomic nerve fibres are also involved in long-term disease, we excluded patients with severe NCV findings since, at the late period of CTS, the temperature of the affected hand may decrease instead of increase.

As did Ming and colleagues earlier [9, 18, 19], we evaluated only the volar side of both hands. However, some authors have shown the sensitivity of IRT on the dorsum of the hand to be higher [5, 20, 21]. We think that measuring both sides make the assessment more complex and unsuited for daily practice. Furthermore, though most researchers have compared study patients with healthy controls [5, 20, 21], we think that the difference between the two will be more significant than the detected temperature value since the sensitivity of these devices is not very high. In this way, comparing the temperatures with the healthy side may help us on the way to diagnosis.

Analysing thermographic images is challenging and time-consuming because an accurate assessment demands precision in determining regions of interest. However, standard software providing a detailed analysis of the images and an automated diagnosis of CTS has been developed [2]; our secondary aim was to achieve a fast and easy diagnosis using this software, which is accessible, user-friendly, and has sufficient features for comparisons.

The most significant limitation of our study was to include patients with mild and moderate NCV stages. If we include only mild stages, thermal changes may be more evident in the early periods of inflammation. We believe that thermographic analysis is more beneficial for detecting early compression because adaptation and heat compensation may develop in those symptomatic in the long term.

Conclusion

We believe that due to their ease of use, smartphone-assisted thermal cameras can be a helpful tool in daily practice to diagnose mild-to-moderate carpal tunnel syndrome. Additional studies are needed to investigate the benefits of these devices in diagnosing and following up on other orthopaedic diseases.

Abbreviations

IRT	Infrared thermography
NCS	Nerve Conduction Study
CTS	Carpal tunnel syndrome
ROI	Region of interest
qDASH	The quick disabilities of the arm, shoulder and hand score

VAS Visual analog scale
SG Study Group
CG Control Group

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Author contributions
KT, HÇ have designed the study and wrote the paper. TE, OGM has collected the data and analyzed.

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Availability of data and materials
Study data and materials are available with the authors.

Declarations

Ethics approval and consent to participate
The study was conducted by the department of Orthopedics and Traumatology at Istinye University Medical Care and Research Hospital with the approval of the ethics committee in accordance with the Declaration of Helsinki. Written informed consent was obtained from all patients prior to study participation. (IRB no: 2/2021.K-11).

Consent for publication
Authors have obtained written informed consent from all study subjects for study as well as publication and these documents are available with the authors.

Competing interests
The authors declare that they have no competing interest.

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