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Original Article

Utility of thermal image scanning in screening for febrile patients in cold climates

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ABSTRACT

Background: Infrared thermography (IRT) for fever screening systems was introduced in not only general hospitals, but also orthopedic hospitals as a countermeasure against the spread of coronavirus disease 2019 (COVID-19). Despite the widespread use of IRT, various results have shown low and high efficacies, so the utility of IRT is controversial, especially in cold climates. The aims of this study were to investigate the utility of IRT in screening for fever in a cold climate and to devise suitable fever screening in orthopedic surgery for COVID-19.

Methods: A total of 390 orthopedic surgery patients were enrolled to the outdoor group and 210 hospital staff members were enrolled to the indoor group. Thermographic temperature at the front of the face in the outdoor group was immediately measured after entering our hospital from a cold outdoor environment. Measurements for the indoor group were made after staying in the hospital (environmental temperature, 28 °C) for at least 5 h. Body temperature was then measured using an axillary thermometer >15 min later in both groups.

Results: In the outdoor group, mean thermographic temperature was significantly lower than axillary temperature and IRT could not detect febrile patients with axillary temperatures >37.0 °C. Mean thermographic temperature was significantly lower in the outdoor group than in the indoor group. Sensitivity was 11.5% for the outdoor group, lower than that for the indoor group.

Conclusions: We verified that IRT was not accurate in a cold climate. IRT is inadequate as a screening method to accurately detect febrile individuals, so we believe that stricter countermeasures for second screening need to be employed to prevent nosocomial infections and disease clusters of COVID-19, even in orthopedic hospitals.

1. Introduction

Detection of fever has become an essential step in identifying patients who may have contracted coronavirus disease 2019 (COVID-19), to allow isolation before the disease can be transmitted to other patients or hospital staff. Compared to traditional thermometry methods, infrared thermography (IRT) has been gaining popularity because of its non-invasive nature and the ability to screen massive numbers of travelers or patients at entrances to facilities [1,2]. In terms of the spread of COVID-19, as a countermeasure to prevent spreading inside facilities, the use of IRT is increasing at airports, hospitals, restaurants and so on. Various studies have examined the role and efficacy of IRT in fever screening [3,4]. Despite the widespread use of IRT, results have been highly variable, with both low and high efficacies reported [5–9], so the utility of IRT remains controversial.

One factor influencing the accuracy of IRT is a cold ambient temperature. Dzien et al. showed that forehead infrared thermometers were not appropriate tools to screen for infectious diseases directly at building entrances in cold climates, because the values measured by IRT soon after entering a building are decreased [10]. However, few studies have reported comparisons between the body temperatures of individuals entering a building from a cold outdoor environment and those staying in a warm indoor

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environment. Whether IRT can accurately work at the entry point of large facilities in a cold climate remains unclear. COVID-19 is thought to be predisposed to spread in cold, dry climates, so IRT has to accurately detect body temperature in a cold environment. If thermographic temperatures from IRT systems differ from axillary temperatures, deployment of such systems will be more challenging in a cold climate.

The aims of this study were to investigate the utility of IRT as a method of body temperature measurement for screening in a cold climate and to devise suitable fever screening in an outpatient department of orthopedic surgery.

2. Materials and methods

Ethics approval for this prospective study was provided by the institutional review board of our institution. A total of 600 individuals participated in this study, and provided informed consent prior to enrolment. Measurements were taken at our hospital from October 26th, 2020 to January 31st, 2021. During this period, mean maximum air temperature was 3.7 °C and mean minimum air temperature was −0.8 °C. Air temperature changes for this period and diurnal variations in air temperature are shown in Fig. 1. Of the 600 participants, 390 were outpatients of the orthopedic surgery department with the exception of emergency cases (outdoor group), and 210 were hospital staff (indoor group). Body temperatures in the outdoor group were measured by IRT immediately after entering the hospital from a cold outdoor environment. Values for the indoor group were measured after staying in our hospital (environmental temperature, 28 °C) for at least 5 h. Demographic data are shown in Table 1. Participants stood at a marked location 2 m from the entrance, with the thermography lens positioned 1.5 m from the craniofacial region for measurements (Fig. 2). All participants were measured using IRT (DS-43S; AZON Co., Aichi, Japan) prior to measurement of axillary temperature. Infrared sensors were used to optically scan the surface of participants. Temperature distributions were recorded as two-dimensional thermal images, and scanning results were displayed as color images. Maximum temperature in the facial region was calculated and recorded. After an interval of >15 min, body temperatures were measured by axillary thermometer (MC-1600-W-HP; OMRON Corp., Kyoto, Japan) in both groups. We compared thermographic temperatures with axillary temperatures within the same group and also compared values between the outdoor and indoor groups. We also evaluated the correlation between thermographic and axillary temperatures and calculated the accuracy of IRT.

Results are shown as mean and 95% confidence interval. The paired t-test was used to test the significance of differences in mean values between two measurement methods in the same group. To test significant differences between the outdoor and indoor groups, Student's t-test was used. Categorical variables were analyzed using the chi-squared test, and Pearson's product-moment correlation between two continuous variables. Receiver operating characteristic (ROC) analysis was used to determine the validity of measurements by IRT. Area under the curve (AUC) was used to indicate the accuracy of measurements. All statistical analyses were performed using JMP Pro version 10.0 statistical software (SAS Institute, Cary, NC, USA).

Table 1
Characteristics of study group participants.

	Outdoor group	Indoor group	*P* value
Total no	390	210	
Sex			
Male	165	28	<0.01
Female	225	182	
Age (years)			
0–9	5	0	<0.01
10–19	8	1	
20–29	19	39	
30–39	13	29	
40–49	28	70	
50–59	46	60	
60–69	62	11	
70–79	127	0	
80–89	60	0	
>89	22	0	

3. Results

Age distributions for patients in the outpatient department of orthopedic surgery are shown in Table 1. Many patients from the outpatient department of orthopedic surgery were elderly, with 69% over 60 years old.

Mean body temperatures as measured by IRT and axillary thermometer in both groups are shown in Table 2. Mean thermographic temperature was significantly lower than axillary temperature in the outdoor group ($P < 0.01$), although mean temperatures measured by each method did not differ significantly in the indoor group ($P = 0.24$). Mean temperature as measured by IRT was significantly lower in the outdoor group than that in the indoor group ($P < 0.01$), although mean temperature as measured by axillary thermometer did not differ significantly between groups ($P = 0.08$) (Table 2). Differences in body temperature between IRT and axillary thermometer in the outdoor and indoor groups (calculated as axillary thermometer - IRT) were 0.36 °C and 0.03 °C, respectively; this value was significantly higher for the outdoor group than for the indoor group ($P < 0.01$) (Table 3). The proportion

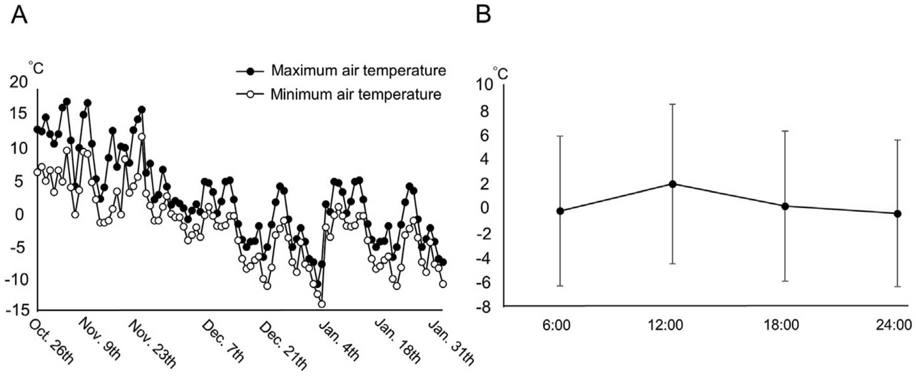

Fig. 1. **A)** Maximum and minimum air temperature changes. **B)** Diurnal variation in air temperature.

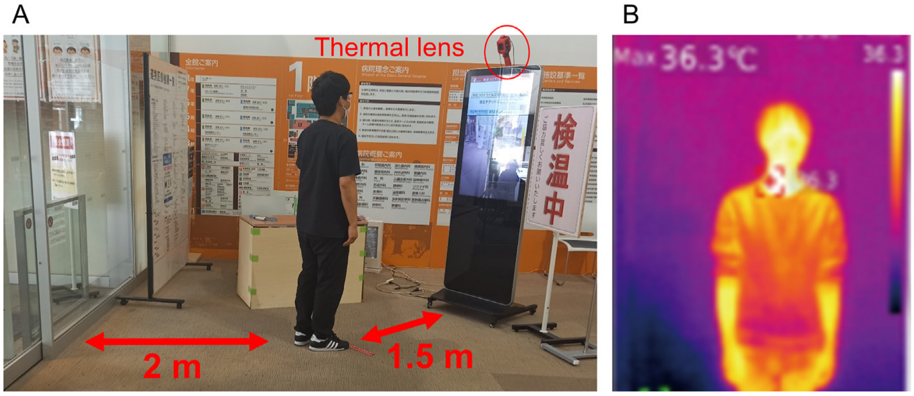

Fig. 2. **A)** Temperature measurement by infrared thermography. **B)** Infrared thermal image of the body.

Table 2
Mean thermographic and axillary temperatures.

	Thermographic temperature (95%CI)	Axillary temperature (95%CI)	*P* value
Outdoor group	36.15 (36.12–36.18)	36.51 (36.47–36.55)	<0.01
Indoor group	36.42 (36.39–36.45)	36.45 (36.40–36.50)	0.24
P value	<0.01	0.08	

CI, confidence interval.

Table 3
Mean difference in thermographic and axillary temperatures.

Difference	Outdoor group (95%CI)	Indoor group (95%CI)	*P* value
Mean (°C)	0.36 (0.31–0.41)	0.03 (−0.02–0.08)	<0.01
>0.5	165	30	<0.01
−0.5–0.5	209	155	
<−0.5	16	24	

Difference = axillary temperature−thermographic temperature.
CI, confidence interval.

of people with a >0.5 °C difference in body temperature between measurements was significantly higher in the outdoor group (165/390, 42%) than in the indoor group (30/210, 14%; $P < 0.01$) (Table 3).

Fig. 3 shows linear relationships between IRT and axillary temperatures. Temperatures from IRT and axillary thermometer showed poor correlations in both groups, with correlation coefficients of −0.008 and 0.154 in the outdoor and indoor groups, respectively.

IRT in the outdoor group failed to identify most cases. The outdoor group showed low sensitivity of IRT (11.5%), but even the indoor group did not show particularly good sensitivity (54.8%; $P < 0.01$). Twenty-one subjects in the outdoor group displayed axillary temperatures ≥37.0 °C (range, 37.0–37.7 °C). However, IRT failed to detect febrile patients with temperatures ≥37.0 °C. Subjects in the outdoor group were divided into subgroups using a threshold of 37.0 °C, and comparisons of thermographic and axillary temperatures are shown in Table 4. No subjects in the indoor group showed temperatures ≥37.0 °C detected by both IRT and axillary thermometer. Mean axillary temperature was 36.5 °C in both groups, so ROC curves for temperatures measured by IRT in both groups were made with axillary temperatures >36.5 °C taken as positive. ROC curves are shown in Fig. 4 (cutoff value, outdoor group: 36.10 °C, indoor group: 36.50 °C). AUCs for the outdoor and indoor groups were 0.528 and 0.568, respectively. Accuracy was low in both groups.

4. Discussion

Thermographic methods are non-invasive and allow rapid measurement of body temperatures [11]. Various studies have investigated the roles of IRT in fever screening at airports [4], hospitals [3] and commercial facilities [12]. IRTs have been introduced not only in general hospitals, but also in orthopedic hospitals

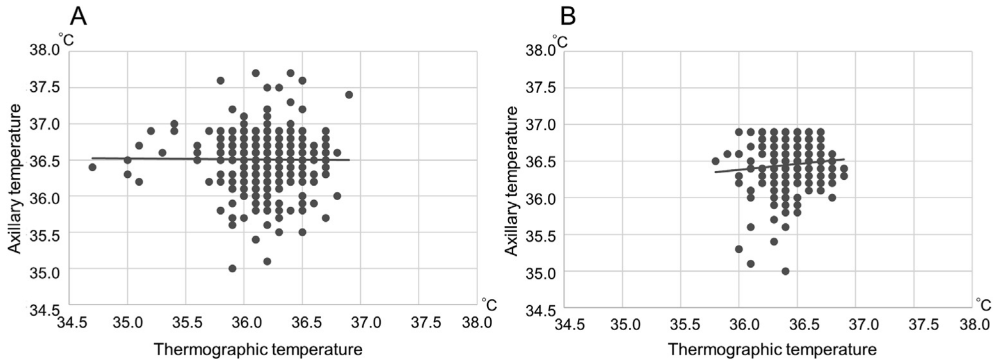

Fig. 3. Scatter plots of infrared thermographic temperature readings against axillary temperature readings. **A)** Outdoor group. **B)** Indoor group.

Table 4
Mean thermographic and axillary temperatures of subjects in the ≥37.0 °C and <37.0 °C subgroups of the outdoor group.

	Thermographic temperature (95%CI)	Axillary temperature (95%CI)	*P* value
≥37.0 °C group	36.20 (36.17–36.24)	37.29 (37.26–37.32)	<0.01
<37.0 °C group	36.15 (36.12–36.18)	36.47 (36.43–36.50)	<0.01
P value	0.37	<0.01	

CI, confidence interval.

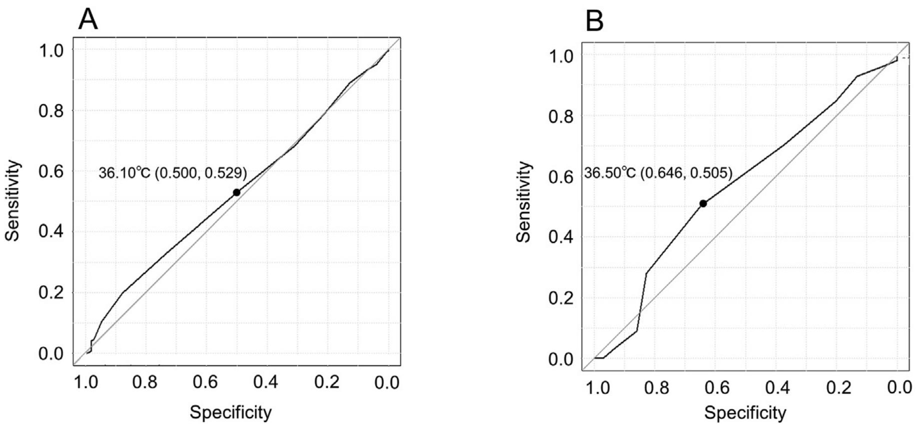

Fig. 4. ROC curve of infrared thermographic temperatures to detect temperatures over 36.5 °C. **A)** Outdoor group. **B)** Indoor group.

as countermeasures against the spread of COVID-19 at an unprecedentedly rapid pace. However, caution has been expressed regarding the use of IRT due to confounders such as ambient temperature [10,13]. This study was conducted to evaluate current fever screening technology in the context of cold outdoor temperatures.

In our study, in the outdoor group, mean temperature as measured by IRT was significantly lower than axillary temperature and IRT failed to detect any febrile patients over 37.0 °C. Mean temperature from IRT was significantly lower in the outdoor group than in the indoor group, and values from IRT and axillary thermometer in the indoor group showed no significant difference. The difference between thermographic and axillary temperatures in the outdoor group was significantly higher than that in the indoor group. From these results, measurement of body temperature using IRT is not considered entirely correct, so missed febrile patients may enter hospitals, particularly under a cold environment. A few reports have shown that a low ambient temperature can influence measurements from IRT. Dzien et al. showed that forehead infrared temperature control is not an appropriate tool to screen for infectious diseases directly at building entrances during cold seasons, with temperature at the entrance about 3.4 °C lower than that 1 h later [10]. Suzuki et al. showed that the median value from IRT at a room temperature of 12.6 °C was about 3.5 °C lower than that in a room at 20.0 °C [14]. One reason for the lower thermographic temperature in a cold environment is considered to be low skin temperature because of exposure to the cold outdoor environment. At any rate, accurate detection of body temperature in outpatients coming from outdoors using IRT at the hospital entrance is very difficult in cold climates.

Previous reports have shown that the area measured by IRT influences accuracy. Chan et al. showed that the face area targeted influences both measurement temperature and accuracy. Mean temperatures of the frontal and lateral face measured by IRT were 33.8 °C and 35.4 °C, respectively, and sensitivities of the frontal and lateral face for a threshold temperature of 36.5 °C were 14% and 57%, respectively [15]. Berksoy et al. showed that forehead temperature on IRT was unreliable compared with neck temperature, and 11.4% of febrile subjects were missed by forehead measurement [16]. We measured frontal face temperature by IRT. As many patients walk into the outpatient department of orthopedic surgery in our hospital, there is not enough time to carefully select an area of the face to measure. We therefore need to consider alternative solutions to accurately and quickly measure body temperature, such as measuring neck temperature using a handheld IRT.

In our study, the outdoor group showed lower sensitivity of IRT (11.5%) than the indoor group (54.8%). Twenty-one subjects in the outdoor group displayed axillary temperatures ≥37.0 °C, but IRT failed to detect febrile patients with axially temperatures ≥37.0 °C. The AUC for the outdoor group was low (0.528). From these results, IRT measurement is more inaccurate under cold outdoor conditions, so the risk of COVID-19 outbreaks in hospitals may be increased. Previous studies examining the efficacy of IRTs in detecting fever have shown sensitivities for fever detection ranging from 4% to 89.6% [3,8,17–19], so the accuracy of IRT remains controversial. We considered that measurement by IRT as a method of screening for fever was insufficient, particularly in a cold environment, although our measurement method may have problems in cold climates. Thermographic temperatures of the outpatient group were measured immediately after entering the hospital. Thermographic temperatures are susceptible to changes in ambient temperatures, so thermographic temperatures measured immediately on entry to the hospital tend to be low. Because IRT measures skin temperatures rather than core temperatures, thermographic temperatures right after entering the hospital are unsuitable in cold climates. Our result showed that the mean difference in thermographic and axillary temperatures (axillary temperature - thermographic temperature) for the outdoor group was 0.36 °C. From this result, numbers of missed febrile patients with axillary temperatures ≥37.0 °C may be decreased by remeasuring thermographic temperatures of patients with first measured thermographic temperatures ≥36.6 °C after staying in the hospital for some time. As another problem with our measurement method, our IRT measured the thermographic temperature of the face. The face located outside is likely to be influenced by outside temperatures, so measurement of thermographic temperatures of sites masked by clothes (such as the neck or wrist) using a handheld IRT may be suitable in cold environments. Axillary and epitympanic temperature measurements are considered more reliable, although close contact with febrile patients carries a risk of infection. These methods are thus also unsuitable in mass screening for fever, so we believe that IRT has to be used in screening to detect febrile patients because of the advantages of rapid, non-contact testing. In such situations, new-generation IRT with acceptable sensitivity could be employed for mass screening of febrile patients. As suggested previously, in addition to body temperature, heart rate and respiratory rate are two crucial vital signs that need to be monitored [20,21]. Matsui et al. employed a laser Doppler flowmeter to obtain heart rate, a 10-GHz microwave reader to detect respiratory rate, and thermography to measure skin temperature [20]. They achieved 88% sensitivity and 89% specificity [20]. Sun et al. showed that inclusion of information on heart rate and respiratory rate enhanced sensitivity by 18.8% using a complementary metal oxide semiconductor camera, which remotely senses heart rate and respiratory rate, compared to the use of temperature alone [21]. Such devices may thus provide useful tools for the screening of febrile patients.

The present study has several limitations. First, high fever may have been masked by oral administration of pain relief medications. Several major pain killers, such as non-steroidal anti-inflammatory drug and acetaminophen, show antipyretic effects. In the department of orthopedic surgery, because many returning patients have received such agents on previous visits, body temperature may have been somewhat decreased. Second, no participants in this study showed body temperatures >38.0 °C as measured by axillary thermometer, so the efficacy in cases of high fever could not be elucidated. In fact, accurate triage of high fever patients, mainly >38.0 °C, from afebrile patients is desirable. Chan et al. showed that the sensitivity of IRT is lower with high threshold temperatures [15]. In our study, subjects with axillary thermometer $\geq$37.0 °C were missed by IRT. Based on this result, higher fever is unlikely to be detected by IRT. In the future, we need to collect data on patients with high fever to investigate the utility of IRT in screening for febrile patients with temperatures >38.0 °C. Third, we could not conduct comparisons between the IRT device used in this study and other IRT devices. The IRT device in this study should be located indoors and measurement should be performed in the environment from 10 to 35 °C according to the instruction. So, the entrance of our hospital may be too cold for this device in winter. Higher accuracy may have been achieved using other IRTs. Fourth, temperatures in the indoor and outdoor groups were not measured under identical conditions. Because we considered the temperature as measured by IRT at the hospital entrance is important for the triage of febrile patients, thermographic temperature was measured immediately on entry to the hospital. If the accuracy of our IRT will be investigated, participants will be measured by IRT after staying in the hospital for some time. Future investigations should clarify thermographic temperatures for outdoor groups at various times after arrival in the hospital. Finally, factors relevant to the accuracy of IRT other than environmental temperature were not considered. For example, younger people are known to show a higher correlation between thermographic and axillary temperatures than the elderly [15]. We need further studies to elucidate the efficacy of IRT in screening febrile individuals after accounting for other confounders that can influence the accuracy of IRT. We believe that elucidation of the accuracy and utility of IRT needs to be clarified in all seasons.

We conclude that thermographic temperature was significantly lower than axillary temperature, that the correlation between thermographic and axillary temperatures was weak and that the sensitivity of IRT screening is lower in cold environments. IRT has the advantages of a non-invasive nature and the ability to screen large numbers of individuals rapidly. IRT may still have utility under conditions such as warm weather or measurement after staying in the hospital for some time. Further investigation is needed to clarify the optimal conditions for using IRT in fever screening.

Declaration of competing interest

None.

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