Mass Screening of Suspected Febrile Patients with Remote-sensing Infrared Thermography: Alarm Temperature and Optimal Distance

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Background/Purpose: Detection of fever has become an essential step in identifying patients who may have severe acute respiratory syndrome (SARS) or avian influenza. This study evaluated infrared thermography (IRT) and compared the influence of different imagers, ambient temperature discrepancy, and the distance between the subject and imager.

Methods: IRT-digital infrared thermal imaging (IRT-DITI), thermoguard, and ear drum IRT were used for visitors to Municipal Wang Fang Hospital, Taipei, Taiwan. The McNemar and χ^2 test, standard Pearson correlation, ANOVA, intraclass correlation coefficient (ICC), and receiver operating characteristic curve (ROC) analysis were used to calculate the alarm temperature for each imager.

Results: A total of 1032 subjects were recruited. Different distances and ambient temperature discrepancy had a significant influence on thermoguard, and lateral and frontal view DITI. By ICC analysis, a significant difference was found at 10 m distance between ear drum IRT and thermoguard ($r = 0.45$), lateral view DITI ($r = 0.37$), and frontal view DITI ($r = 0.44$). With ROC analysis, the optimal preset cut-off temperatures for the different imagers were: 36.05°C for thermoguard (area under the curve [AUC], 0.716), 36.25°C for lateral view DITI (AUC, 0.801), and 36.25°C for frontal view DITI (AUC, 0.812).

Conclusion: The temperature readings obtained by IRT may be used as a proxy for core temperature. An effective IRT system with a strict operating protocol can be rapidly implemented at the entrance of a hospital during SARS or avian influenza epidemics. [*J Formos Med Assoc* 2008;107(12):937–944]

Key Words: avian influenza, infrared thermography, intraclass correlation coefficient, receiver operating characteristic curve, severe acute respiratory syndrome

Since the first case of atypical pneumonia appeared in China in 2002, outbreaks of severe acute respiratory syndrome (SARS) have been reported in 29 countries.[1–3] In Taiwan, SARS outbreaks began in March 2003.[4,5] Fever is one of the most important diagnostic symptoms in patients with SARS and avian flu.[6–10] Detection of fever has become an essential step in identifying patients who may

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have contracted SARS for isolation and workup before they transmit the disease to other patients. Monitoring body temperature at hospitals, airports, and border crossing points is critical for preventing outbreaks and epidemics.[8,11,12] Recently, mass screening of all suspected febrile visitors at the entrance of every hospital building has become standard procedure.[8,11,12]

Oral and aural temperature measurements are accurate but are fairly invasive, time-consuming, labor-intensive and skill-dependent.[8] The ideal device for fever screening should be rapid, non-invasive and be able to accurately detect patients with fever. Infrared thermography (IRT) has the potential to serve as a tool for mass screening for fever.[8,11–14] Current IRT systems in use at various border checkpoints have not been scientifically validated, particularly with regard to the false-negative rate.[8] The unadjusted mode threshold temperature setting in a thermal imager needs to correct the difference between the skin and core body temperatures.[8] It often has to take into account the effects of environmental and ambient conditions, and the thermal imager's performance parameters.[8]

This study was designed to evaluate the sensitivity and specificity of each thermal imager and to compare the influence of different instruments, ambient temperature discrepancy, and the distance between the subject and the instrument.

Methods

A total of 1032 subjects were recruited from Wan Fang Medical Center, Taipei, Taiwan. The Institutional Review Board of Human Ethics, Taipei Medical University, approved the study protocols. Verbal informed consent was obtained from all the subjects.

Instrumentation[15–20]
Digital infrared thermal imaging (DITI) (Spectrum 9000MB Medical Thermal Imaging System; Telesis Technologies Inc., Kaohsiung, Taiwan), thermoguard (Figure 1), and ear drum IRT were used to conduct mass screening of subjects who

entered the hospital and identify those with fever. The DITI system has two components: a sensor head and a PC imaging workstation. The DITI system can measure between 10°C and 40°C at 60 frames per second. The minimum change in temperature that can be detected is 0.07°C. The DITI system can measure the skin temperature of the face, especially the frontal and the temporal area, to screen febrile patients.[21,22] In Spectrum 9000MB *fever test mode*, the alarm sounds when thermographic temperature is > 37.5°C, as expected in a febrile patient. When a subject was found to have thermographic temperature > 37.5°C, the ear drum temperature was measured to confirm whether the patient had a fever (38°C). When the ear drum temperature was ≥ 38°C, the patient was immediately isolated for further examination.

The ear drum IRT, thermoguard and DITI screening station was set up away from the entrance of the hospital at distances of 0 m, 5 m, and 10 m. Temperature data at different distances and ambient temperatures were collected on 3 different days.

Statistical analysis
Ear drum IRT is the regular standard for fever screening, and corresponding core temperature measurements, sensitivity and specificity were calculated for thermoguard and DITI screening. The differences in fever screening between ear drum IRT, thermoguard and DITI were analyzed by McNemar and χ^2 tests.

To compare the relationship between IRT readings and corresponding core temperature measurements, respective sets of data were subjected to standard Pearson correlation and ANOVA using Microsoft Excel 2003 and SPSS version 11.0 (SPSS Inc., Chicago, IL, USA). Relevant IRT parameters were also assessed from the perspective of sensitivity, specificity, and false-positive and false-negative rates.[12]

Three-way, two-way and one-way ANOVA were used to analyze the interaction between method of detection, outdoor/indoor temperature discrepancy, and distance. If the collected temperature discrepancy was greater than two standard deviations,
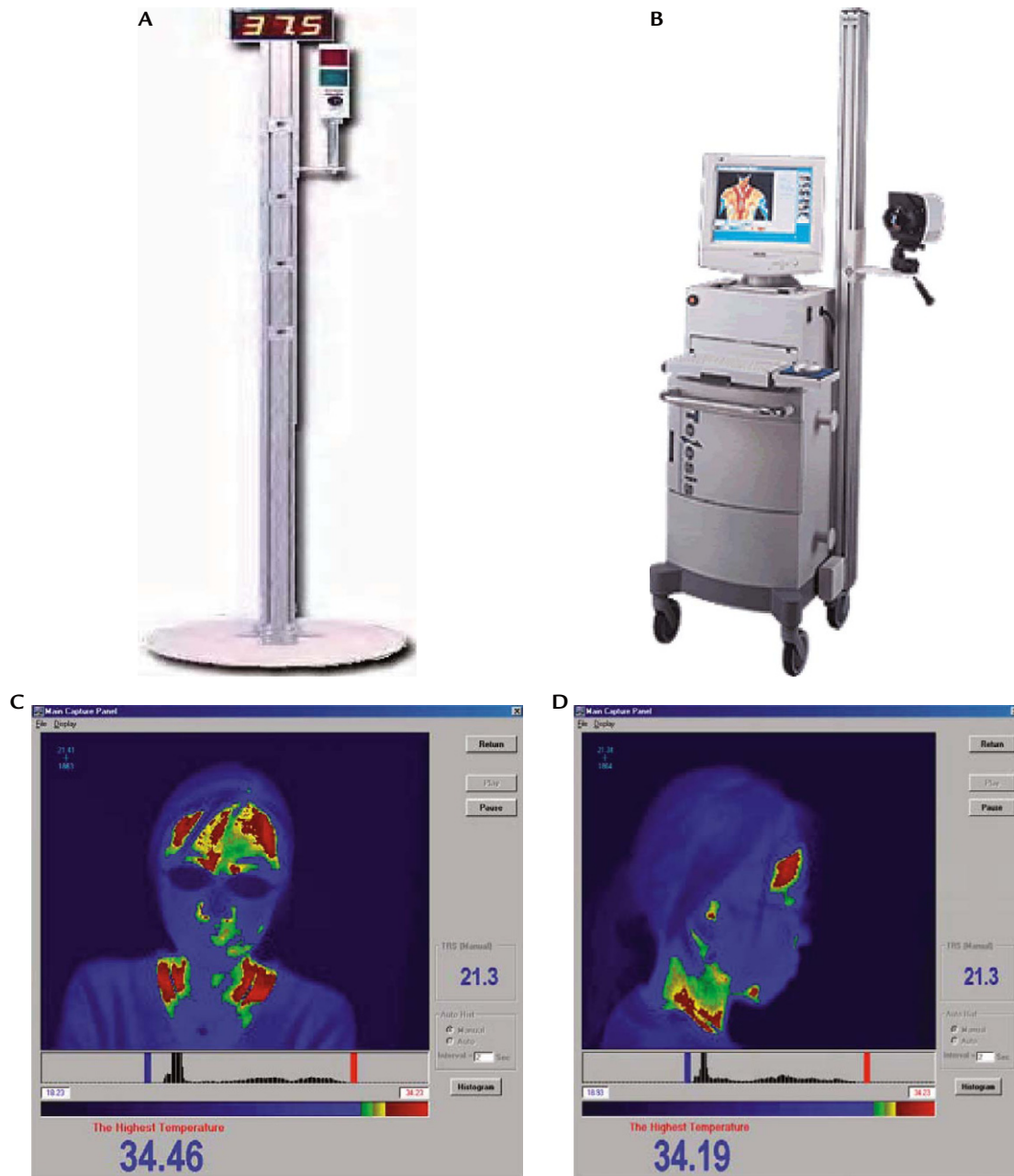
Figure 1. Instruments: (A) thermoguard; (B) infrared thermography (DITI); (C) frontal view DITI; (D) lateral view DITI.

it was treated as an outlier. After removing the outliers, intraclass correlation coefficient (ICC) and receiver operating characteristic curve (ROC) analyses were applied. The ROC is a plot of the true-positive versus false-positive results. It is a graphical means of assessing the ability of a screening test to discriminate between healthy and febrile persons.[8] We tried to set the alarm temperature in each testing modality according to the correlation of the ROC curve.

Results

A total of 1032 subjects were recruited. We calculated the sensitivity and specificity at different distances between ear drum and thermoguard (Tables 1 and 2). Sensitivity of ear drum and thermoguard at 0 m was 13%, specificity was 95%, and positive predictive value was 44%. At a distance of 5 m, the sensitivity of ear drum and thermoguard was 45%, specificity was 70% and positive predictive value

Table 1. Sensitivity, specificity and positive predictive value of different instruments at different distances

	Thermoguard	DITI lateral	DITI frontal
	0 m/5 m/10 m	0 m/5 m/10 m	0 m/5 m/10 m
Sensitivity (%)	13/45/57	32/40/24	15/29/23
Specificity (%)	95/70/85	89/77/93	95/87/94
Positive predictive value	44/29/39	47/33/36	50/40/41

Table 2. Sensitivity and specificity at different distances between ear drum and thermoguard, DITI frontal and DITI lateral views

		Ear drum		p
Thermoguard				
0 m	Normal	193	50	0.000
	Fever	10	8	
5 m	Normal	127	28	0.041
	Fever	54	23	
10 m	Normal	151	12	0.047
	Fever	25	16	
Lateral view				
0 m	Normal	184	21	0.020
	Fever	40	19	
5 m	Normal	137	39	0.336
	Fever	30	20	
10 m	Normal	171	12	0.121
	Fever	22	7	
Frontal view				
0 m	Normal	195	51	0.000
	Fever	9	9	
5 m	Normal	149	36	0.087
	Fever	22	15	
10 m	Normal	176	23	0.035
	Fever	10	7	

Thermoguard: fever diagnosed if body temperature >37°C; ear drum: fever diagnosed if body temperature >37.5°C.

was 29%. At a distance of 10 m, the sensitivity of ear drum and thermoguard was 57%, specificity was 85% and positive predictive value was 39%.

The estimated sensitivity and specificity at different distances for ear drum and DITI are also shown in Tables 1 and 2. At a distance of 0 m, the sensitivity of ear drum and DITI in lateral view was 32%, specificity was 89% and positive predictive value was 47%. At a distance of 5 m, the

sensitivity of ear drum and DITI was 40%, specificity was 77% and positive predictive value was 33%. At a distance of 10 m, the sensitivity of ear drum and DITI was 24%, specificity was 93% and positive predictive value was 36%.

Finally, at a distance of 0 m, the sensitivity of ear drum and DITI in frontal view was 15%, specificity was 95% and positive predictive value was 50%. At a distance of 5 m, the sensitivity of ear drum and DITI was 29%, specificity was 87% and positive predictive value was 40%. At a distance of 10 m, the sensitivity of ear drum and DITI was 23%, specificity was 94% and positive predictive value was 41%.

ANOVA
Using three-way ANOVA analysis, the interaction among components of distance, outdoor/indoor temperature discrepancy, and method of detection was found to be significantly different. This means that the dependent component (body temperature) was affected by the interaction of three independent components. The interaction between two components (distance and modality, temperature difference and modality) was also significantly different.

Two-way ANOVA of modality and distance
The interaction between two components (modality and distance) analyzed by two-way ANOVA was significantly different ($F = 2.796$, $p = 0.003$). One-way ANOVA revealed that the influence of different distances on thermoguard ($F = 33.591$, $p = 0.000$), lateral view DITI ($F = 14.414$, $p = 0.000$), and frontal view DITI ($F = 16.642$, $p = 0.000$) were all significantly different (Table 3). *Post hoc* analysis revealed that distances set at 0 m and 5 m for thermoguard

Table 3. ANOVA of distances and instruments

Instruments	Sum of square	df	Mean square	F	p
Thermoguard				33.591	0.000
Between groups	0.023	2	0.012		
Within groups	0.304	882	0.000		
Total	0.327	884			
Lateral view				14.414	0.000
Between groups	0.011	2	0.005		
Within groups	0.322	882	0.000		
Total	0.332	884			
Frontal view				16.642	0.000
Between groups	0.012	2	0.006		
Within groups	0.305	882	0.000		
Total	0.316	884			

df = degrees of freedom.

Table 4. ANOVA of temperature gradients and instruments

Instruments	Sum of square	df	Mean square	F	p
Thermoguard				4.161	0.002
Between groups	0.006	4	0.002		
Within groups	0.321	880	0.000		
Total	0.327	884			
Lateral view				15.551	0.000
Between groups	0.022	4	0.005		
Within groups	0.310	880	0.000		
Total	0.332	884			
Frontal view				3.836	0.004
Between groups	0.005	4	0.001		
Within groups	0.311	880	0.000		
Total	0.316	884			

df = degrees of freedom.

and frontal view DITI were significantly different, as were distances of 5 m and 10 m for lateral view DITI.

Two-way ANOVA of modality and outdoor/indoor temperature discrepancy

The interaction between two components (modality and outdoor/indoor temperature discrepancy) analyzed by two-way ANOVA was significantly different ($F = 4.112$, $p = 0.002$). This demonstrated that interaction of two independent components had an influence on the dependent component.

By two-way ANOVA, there was a significant difference in the influence of ambient temperature discrepancy on thermoguard ($F = 4.161$, $p = 0.002$), lateral view DITI ($F = 15.551$, $p = 0.000$), and frontal view DITI ($F = 3.836$, $p = 0.004$) (Table 4). *Post hoc* analysis revealed that significant differences were found in thermoguard (each in 1–2°C and 2–3°C, 1–2°C and 4–5°C), lateral view DITI (each in 0–1°C and 1–2°C, 2–3°C, 4–5°C; 2–3°C and 1–2°C, 3–4°C, 3–4°C and 4–5°C), and frontal view DITI (each in 0–1°C and 1–2°C, 2–3°C, 4–5°C).
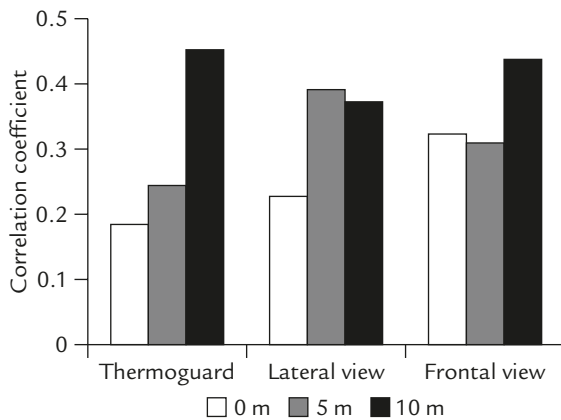
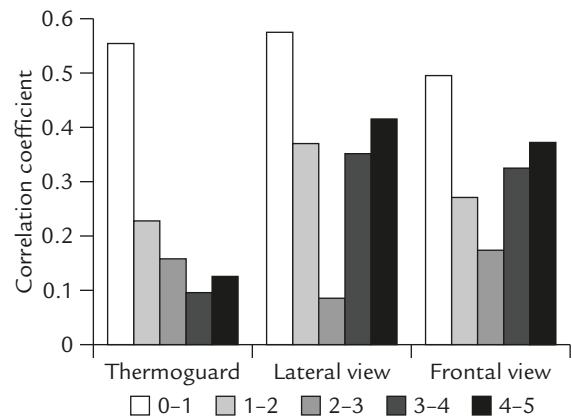Figure 2. Intraclass correlation coefficient between distances and instruments.

Figure 3. Intraclass correlation coefficient between ambient temperature gradients and instruments.

Table 5. Receiver operating characteristic curve (ROC) analysis of different instruments

Instruments	ROC	p	Alert temp	Sensitivity	Specificity	PPV	NPV
Thermoguard	0.716	0.01	36.05	1	0.42	1.72	0
Lateral view	0.801	0.021	36.25	1	0.483	1.93	0
Frontal view	0.812	0.008	36.25	1	0.524	2.1	0

PPV = positive predictive value; NPV = negative predictive value.

ICC

ICC analysis of the relationship between different distances and instruments revealed a significant difference at 10 m between ear drum IRT and thermoguard ($r = 0.45$, medium correlation), lateral view DITI ($r = 0.37$, medium correlation), and frontal view DITI ($r = 0.44$, medium correlation). At 5 m distance, there was a significant difference between ear drum IRT and thermoguard ($r = 0.24$, small correlation), lateral view DITI ($r = 0.39$, medium correlation), and frontal view DITI ($r = 0.31$, medium correlation). A significant difference was also found at a distance of 0 m between ear drum IRT and thermoguard ($r = 0.18$, small correlation), lateral view DITI ($r = 0.23$, small correlation), and frontal view DITI ($r = 0.32$, medium correlation) (Figure 2).

By ICC analysis, the relationship between the different ambient temperatures and instruments was significantly different in 0–1°C between ear drum IRT and thermoguard ($r = 0.55$, large correlation), lateral view DITI ($r = 0.57$, large correlation), and frontal view DITI ($r = 0.49$, large correlation) (Figure 3).

ROC

With ROC analysis, it was hoped that an optimum threshold temperature for the thermal imager can be found.[8] ROC analysis showed that the optimum threshold temperature was 36.05°C for thermoguard (area under the curve [AUC], 0.716, $p = 0.01$), 36.25°C for lateral view DITI (AUC, 0.801, $p = 0.021$), and 36.25°C for frontal view DITI (AUC, 0.812, $p = 0.008$) (Table 5).

Discussion

Fever is a major symptom in patients with SARS, and presents early in virtually all patients.[23] As reported at the first global conference on SARS at the World Health Organization headquarters in Geneva in 2003, only patients with fever can transmit SARS to others.[24] Although Pitman et al reported that airport entry screening is unlikely to be effective in preventing or delaying an epidemic of SARS or influenza,[25] airport entry screening has been advocated. Screening tests for fever at the entrance of hospitals is mandatory in some

countries.[8,11,12] Due to the large volume of visitors who enter a hospital each day, a less time-consuming and reliable method to screen body temperature is needed. In this study, we used the DITI system with a high resolution to screen large numbers of visitors in an efficient, non-contact and noninvasive manner.

Ng et al reported that human skin surface temperature is correlated with core body temperature to a certain extent.[8] This is also consistent with our study (Tables 1–4). It is risky to use a fixed physiological site offset to correlate both temperatures for the threshold temperature setting as the skin surface changes at different ambient temperatures (Table 4) and in different environments (Tables 1–3). The ambient temperature discrepancy at any gradient significantly affected the measurements. A significant difference was found by ICC analysis between temperature gradient and the different instruments (Figure 3). ICC analysis between different distances and instruments revealed a significant difference, especially at a distance of 10 m from the hospital entrance (Figure 2).

At a distance of 10 m, the sensitivity of ear drum and frontal view DITI was 23%, specificity was 94% and positive predictive value was 41% (Table 1). Although at a distance of 0 m, the nearest contact measuring, the three instruments all achieved better results, the p value for frontal view DITI at 10 m ($p = 0.035$) was the most significant among all instruments at either 5 m or 10 m distance (Tables 2–4). In a mass-screening survey, a long distance is required for a crowd of people. Therefore, we suggest that frontal view DITI at a distance of 10 m is the best condition for the screening test.

The DITI system may produce false-negative detection and have decreased sensitivity in fever screening if the febrile patient is sweating. We set the temperature for thermographic fever screening at 37.5°C, lower than the fever criteria for SARS (≥ 38°C). This would have ensured that all fever patients (> 38°C) were detected by the DITI system. To review the sensitivity and specificity of the DITI measurement, we counted all false-negative cases with body temperature < 38°C.

The thermal scanner temperature threshold should be determined by the environmental factors, the physiological site offset, and the performance characteristics of the thermal imager to achieve the most accurate and reliable screening method.[8] ROC was used to analyze the data collected from the thermal imager and to determine the optimal preset cut-off temperature for the thermal imager as the upper limit for normal healthy temperature. Anyone whose skin surface temperature exceeds this temperature is suspected to have fever.[8] From ROC analysis, we found that the most reliable alarm threshold for the different modalities was 37.5°C for ear drum IRT, 36.05°C for thermoguard, 36.25°C for lateral view DITI, and 36.25°C for frontal view DITI. An alarm temperature set at 36.25°C will be the most reliable threshold for DITI. However, the selected threshold temperature of 36.25°C revealed a low specificity in lateral view DITI (specificity 48.3%, sensitivity 100%) and in frontal view DITI (specificity 52.4%, sensitivity 100%) (Table 5). The low specificity may exaggerate the number of fever patients screened in such an acute lethal epidemic and assist with the strict isolation of infected individuals. Any tested temperature that exceeds this level will trigger the alarm, and an ear drum IRT can be used to verify whether the person has fever.

The main limitations to currently practiced, remotely sensed, infrared thermometry are targeted location, camera-subject distance, and ambient temperature gradient. The targeted areas varied from traditional ear drum, and the lateral or frontal view of the face as tested by different instruments (IRT, DITI, thermoguard). Following regression analysis, readings from variable targeted areas reached the same reliability. IRT set at 10 m from the entrance of the hospital could overcome the resulting problems caused by distance and temperature gradient; this was consistent with the study of Chan.[12] Other limitations of this study include the relatively small number of febrile subjects (only 36 in a total of 1032 visitors), and the number of subjects in the outdoor/indoor temperature discrepancy subgroups were uneven.

This study suggests that temperature readings obtained by remote-sensing IRT could be used as a proxy for core temperature. The optimal distance for IRT is at 10 m from the entrance. The preset threshold cut-off alarm temperature should be set at 37.5°C for ear drum IRT, 36.25°C for lateral view DITI, 36.25°C for frontal view DITI, and 36.05°C for thermoguard. To prepare for future SARS or avian influenza epidemics, an effective IRT system with a strict operating protocol to detect febrile individuals needs be rapidly implemented at hospital entrances.

Acknowledgments

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