Screening for Fever by Remote-sensing Infrared Thermographic Camera

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ABSTRACT

Background: Following the severe acute respiratory syndrome (SARS) outbreak, remote-sensing infrared thermography (IRT) has been advocated as a possible means of screening for fever in travelers at airports and border crossings, but its applicability has not been established. We therefore set out to evaluate (1) the feasibility of IRT imaging to identify subjects with fever, and (2) the optimal instrumental configuration and validity for such testing.

Methods: Over a 20-day inclusive period, 176 subjects (49 hospital inpatients without SARS or suspected SARS, 99 health clinic attendees and 28 healthy volunteers) were recruited. Remotely sensed IRT readings were obtained from various parts of the front and side of the face (at distances of 1.5 and 0.5m), and compared to concurrently determined body temperature measurements using conventional means (aural tympanic IRT and oral mercury thermometry). The resulting data were submitted to linear regression/correlation and sensitivity analyses. All recruits gave prior informed consent and our Faculty Institutional Review Board approved the protocol.

Results: Optimal correlations were found between conventionally measured body temperatures and IRT readings from (1) the front of the face at 1.5m with the mouth open (r =0.80), (2) the ear at 0.5m (r =0.79), and (3) the side of the face at 1.5m (r =0.76). Average IRT readings from the forehead and elsewhere were 1°C to 2°C lower and correlated less well. Ear IRT readings at 0.5m yielded the narrowest confidence intervals and could be used to predict conventional body temperature readings of ≤38 °C with a sensitivity and specificity of 83% and 88% respectively.

Conclusions: IRT readings from the side of the face, especially from the ear at 0.5m, yielded the most reliable, precise and consistent estimates of conventionally determined body temperatures. Our results have important implications for walk-through IRT scanning/screening systems at airports and border crossings, particularly as the point prevalence of fever in such subjects would be very low.

Recently, the global outbreak of severe acute respiratory syndrome (SARS) has necessitated the institution of rapid and noninvasive means of screening for people with fever, especially at airports and border crossing points. One of the proposed methods depends on remote-sensing infrared thermography (IRT), a technique already used to detect thermal anomalies associated with a number of inflammatory conditions. [1-3]

IRT makes use of the wavelength window of 8 to 15μm in the infrared radiation band. Based on the Stefan-Boltzmann Law, which gives a relationship between the emissive power and temperature, an infrared camera focuses the infrared energy emitted by an object on a detector and converts it into electronic signals for image processing. The emitting property of the object is described by its 'emissivity', a measure of how much radiation is emitted from the object, compared to that from a perfect black body. A perfect black body has an emissivity equal to 1.0, whereas a highly reflective body has a low emissivity. [4,5]

The radiation detected by the infrared camera consists of contributions from different sources: emission from the object, reflected radiation from the object, and emission from air and other objects between the camera and the object. The relative contributions from these three sources depend on the object's temperature and emissivity, transmittance through the air, the ambient temperature, and the distance between the measuring device and the object. For an IRT camera trained on a human at a distance of about 1m, approximately 86% of the detected radiation is emitted by that subject. Human skin has an emissivity that is quite close to that of a black body.

IRT has been applied in many areas of medical research pertaining to diagnosis, treatment decisions and monitoring. These include cancer detection, following myocardial perfusion during surgery, assessment of inflammatory/allergic conditions, and the management of headaches. [6-9] However, evaluation of IRT as a means of directly identifying patients with clinically accepted significantly elevated body temperature has been limited. Past studies for this purpose were mainly necessitated by difficulties encountered with conventional methods of measuring body temperature, such as in infants, [10] pigs, [11] elephants [12] and rabbits. [13,14] Research on humans [15-17] has demonstrated substantial variations in skin temperature, depending on the site sampled, and raises the prospect of obtaining an average value from IRT readings at multiple sites. Thus, if facial IRT is to be used for the screening of travelers with fever at airports, ports and border crossings, consideration must be given to the specific locations that should be targeted. The possible influences of other variables, including ambient temperature, use of surgical masks and exercise, also need to be addressed. Nevertheless, infrared systems commonly entailing single- reading thermoprobes directed at the forehead or full-face imaging are currently being used extensively in Hong Kong as a means of screening travelers.

We therefore set out to investigate (1) the reliability of using IRT imaging techniques to identify human subjects with elevated body temperature by comparison with conventional measures of body temperature, and (2) the optimal conditions for conducting such measurements. The latter included instrumental configurations such as location and size of area on the face to be targeted, as well as the influence of camera-object distance, ambient temperatures, prior exercise and the wearing of facemasks.

Subjects and Methods

Subjects were recruited from Queen Mary Hospital, two health clinics, and the University of Hong Kong Sports Center (USC). Hospital inpatients as well as clinic attendees were recruited with the object of encountering at least some individuals with fever, and the USC provided a source of individuals in whom fever was unlikely. Written informed consent was obtained from all hospital inpatients (if necessary from their parents or guardians), and verbal informed consent was obtained from all others. Subjects were excluded from the study if they (1) had SARS or suspected SARS, or (2) were unable to cooperate with the IRT thermography team. In each location outside the hospital, eligible, consenting subjects were recruited consecutively. In the hospital setting, patients expected to be afebrile were interspersed with patients previously determined to have had fever, but the IRT operators were blinded to this information. The Institutional Review Board of the Faculty of Medicine, the University of Hong Kong, approved the study protocol.

Three different infrared cameras (models PM595, SC320C and S60), all manufactured by FLIR thermovision, were used in the study. All three cameras used a similar system, which is able to detect a temperature difference of 0.1°C and has a resolution defined by 320x 240 cells per image. Also, infrared camera distance from the subject and the ambient temperature were entered into the control program for each dataset as input parameters for calibration of the measured temperature. Throughout the study, an emissivity of 0.98 was used to compute skin temperature. [18-20]

Maximum IRT temperature values from the entire face (both front and side views) were determined. Since values can vary substantially over different parts of the face, maximum temperatures noted within a circular spot centered at various sites were also taken as representative temperatures for these locations. Each circumscribed area was equivalent to about 10% of the entire facial area. Thus, spot maximum IRT temperature readings for the following locations were logged: forehead, temples, nose, mouth, cheeks, and ear. In consenting subjects, IRT was undertaken both with and without a surgical mask and with and without an open mouth. The temperature of the ear (pinna) area was measured at distances of 1.5m and 0.5m from the camera; all other remote IRT was carried out at a distance of 1.5m. Concurrently, appropriately trained personnel determined aural (ear) temperature by tympanic IRT and, whenever feasible, oral temperature (using clinical mercury thermometers), but the values were not disclosed to the IRT camera operators until the respective IRT measurements were completed. The latter two temperature readings were taken to reflect core body temperature and will be referred to as such, as clinically they are widely accepted for this purpose. In 15 individuals, sets of IRT and core body temperature readings were obtained both before and within 5min after exercise (vigorous soccer). Postexercise readings were also obtained from 13 subjects within 2min after they had been jogging. The association with ambient temperature was assessed in attendees at a health clinic and in USC volunteers (prior to exercising), provided that their core body temperatures were <37.5°C.

To compare the relationship between IRT readings and corresponding core body temperature measurements, respective sets of data were subjected to standard Pearson correlation and normal linear regression analyses using Microsoft Excel 2000 and SPSS (version 10.0). The method for predicting core temperatures from IRT readings is explained in the footnote to Table 3.

Table 3. Linear Regression and Prediction of Core Temperature

		Remotely Sensed IRT				
		Regression Parameters vs. Core Temperature			*Predicted Core Temperature (95% CI)*	
Spot Location		***Aural***	***Oral***	***Maximum Reading (°C)***	***Aural °C***	***Oral °C***
Ear at 0.5m	α	9.5836	4.4511	37.0	37.3 (35.6-39.0)	37.0 (36.0-38.0)
	β	0.7347	0.8799	37.5	38.0 (36.3-39.7)	37.6 (36.6-38.5)
	s^2	0.402	0.194			
	R^2	0.565	0.625	38.0	38.7 (37.0-40.4)	38.1 (37.1-39.1)
	p	<.000	<.000			
Forehead	α	7.6092	17.0892	37.0	39.9 (36.9-42.9)	42.2 (38.2-46.2)
	β	0.7363	0.4720	37.5	40.6 (37.6-43.6)	43.2 (39.2-47.3)
	s^2	1.246	0.938			
	R^2	0.265	0.061	38.0	41.3 (38.3-44.2)	44.3 (40.3-48.3)
	p	<.000	.012			

The dependent variable y (e.g., ear 0.5-m IRT reading) was regressed on the independent variable *u* (aural/oral temperature) to give a fitted regression
equation of the form y=α+β*u*+´, where ´ is distributed *N*(0, s^2), and refers to a normal distribution (*N*) with a mean of zero (0) and s^2 is the resid
ual mean square of the fitted regression line. Given y (e.g., y=38), we can then invert the equation to give *u* as following a normal model with mean
(y-α)/β and variance $s^2/β^2$. In the table, the predicted values are *u*=(y-α)/β, and the 95% confidence intervals (CIs) are given by *u*±1.96 (*s*/β).

Two-sampled Student *t* -tests were conducted as deemed necessary. Relevant IRT parameters were also assessed from the perspective of sensitivity, specificity, and false-positive and false-negative rates, sensitivity being the proportion testing positive who have the target disorder (fever), and specificity being the proportion testing negative who do not have the target disorder.

Results

Analyses were performed on 198 sets of readings in 176 subjects consisting of 49 hospital inpatients, 99 clinic attendees, and 28 USC healthy volunteers. Fifteen of the last-mentioned also had postexercise IRT testing, and seven of the hospital inpatients were tested on two separate days. Table 1

Table 1. Mean±SEM of Remotely Sensed IRT Readings and Concurrently Measured Core Body Temperatures

	Mean Temperature Reading (°C ± SEM)				
	49 Hospital	*99 Clinic*	*28 Healthy Volunteers*		
Parameters	***Inpatients***	***Attendees***	***15 Preexercise***	***28 Postexercise***[a]	***All Readings***
Core temperature					
Aural[b]	37.2±0.2	36.6±0.1	36.7±0.1	37.9[c]±0.1	37.0±0.1
Oral	38.3±1.2	36.6±0.0	36.3±0.0	36.4±0.1	36.6±0.0
Face Max. IRT					
Front view					
Closed mouth with mask	36.8±0.3	35.3±0.1	NA	NA	35.8±0.1
Closed mouth and no mask	36.9±0.2	35.8±0.1	35.8±0.1	36.7[c]±0.1	36.3±0.1
Open mouth and no mask	37.3±0.2	36.7±0.1	36.2±0.1	36.6[c]±0.1	36.8[d]±0.1
Side view	36.6±0.2	35.7±0.1	36.1±0.1	37.2[c]±0.2	36.4[d]±0.1
Spot Max. IRT					
Front view					
Forehead	35.3±0.2	34.2±0.1	34.9±0.1	35.9[c]±0.2	34.8±0.1
Temples	35.5±0.1	34.4±0.1	34.9±0.1	36.0[c]±0.1	35.0±0.1
Nose	35.0±0.3	34.5±0.2	34.9±0.2	35.8[c]±0.2	34.9±0.1
Closed mouth	36.0±0.2	34.9±0.1	34.6±0.2	35.6[c]±0.2	35.2±0.1
Open mouth	37.2±0.2	36.5±0.1	36.2±0.1	36.0±0.2	36.5[d]±0.1
Cheeks	34.9±0.2	33.9±0.1	34.3±0.1	35.7[c]±0.1	34.5±0.1
Side view					
Temple	35.1±0.3	34.8±0.1	35.3±0.2	36.0[c]±0.1	35.3±0.1
Ear 1.5m	36.3±0.2	35.6±0.1	36.1±0.1	37.1[c]±0.2	36.3±0.1
Ear 0.5m	36.9±0.2	36.6±0.1	36.5±0.1	37.7[c]±0.1	36.9[d]±0.1

Differences between respective means for all available IRT readings and corresponding mean core aural temperatures were all statistically significant (p<.05 to <.001), except where otherwise indicated. The same was true of differences from mean oral temperatures.

[a]Including the 15 subjects recruited for preexercise measurements.

[b]Aural core body temperatures ≥38 ° C were recorded in 29 (15%) of these 198 datasets.

[c]Statistically significant (p<.05) difference from corresponding preexercise readings.

[d]Not statistically significant.

is a summary of remote IRT readings and corresponding core body temperatures (aural and oral) encountered in our investigation. The mean (range) age of the hospital inpatients was 51 (0.25-92) years and 20 were males. Corresponding values for the clinic attendees and healthy volunteers were 34 (2-70) and 52, and 39 (12-56) and 26 respectively. In our healthy USC volunteers, mean postexercise temperature readings were about 1°C higher (p<.05) than corresponding preexercise readings, with the exception of those for (1) oral core body temperature, and (2) spot IRT with the mouth open. Thus, whatever the reason for this anomaly, postexercise oral core temperature measurements from our volunteers and all of their corresponding remote IRT readings were omitted from the definitive regression/correlation analyses (Table 2).

Table 2. Correlation Coefficients of IRT Readings with Aural and Oral Core Body Temperatures

	Correlation Coefficient r(n)	
IRT Parameters	***With Aural Temperature***	***With Oral Temperature[a]***
Face Max.		
Front view		
Closed mouth with mask	0.48** (98)	0.50** (62)
Closed mouth and no mask	0.51** (185)	0.59** (101)
Open mouth and no mask	0.45** (136)	0.80** (73)
Side view	0.76** (102)	0.71** (41)
Spot Max.		
Front view		
Forehead	0.51** (188)	0.25* (103)
Temples	0.52** (366)	0.22** (204)
Nose	0.50** (185)	0.21* (103)
Closed mouth	0.47** (170)	0.39** (102)
Open mouth	0.13 (161)	0.54** (94)
Cheeks	0.49** (370)	0.31** (206)
Side view		
Temple	0.47** (99)	0.54** (40)
Ear 1.5m	0.78** (110)	0.52** (49)

Table 2. Correlation Coefficients of IRT Readings with Aural and Oral Core Body Temperatures		
	Correlation Coefficient r(n)	
IRT Parameters	***With Aural Temperature***	***With Oral Temperature[a]***
Ear 0.5m	0.75** (116)	0.79** (45)

[a]After exclusion of postexercise data.

*p<.05; **p<.01.

From any given IRT reading, it was also possible to predict the core body temperature together with its 95% confidence interval by calibrating back from the respective linear regression equations (Table 3). The feasibility of identifying persons with fever (defined as core body temperature ≤38 ° C) was assessed by a sensitivity analysis based on spot IRT readings for the ear at 0.5m and the forehead at 1.5m. Corresponding sensitivity and specificity for the diagnosis of elevated core temperature together with false-positive and false-negative rates are shown in Table 4.

Table 4. Sensitivity Analysis for Diagnosis of Elevated Aural Core Body Temperature Using Two Different Cutoff Values for Ear 0.5-m and Forehead IRT Readings

	Spot Ear 0.5-m IRT Cutoff Temperatures		***Spot Forehead IRT Cutoff Temperatures***	
	≥37.5°C	***≥38°C***	***≥37.5°C***	***≥38°C***
Sensitivity	83%	67%	15%	4%
Specificity	88%	96%	98%	99%
False-positive rate	35%	20%	43%	50%
False-negative rate	5%	8%	13%	14%

In 24 of these 116 sets of measurements for ear IRT at 0.5m, an elevated aural core body tem perature ≥38 ° C (defined as fever) was recorded, giving a point prevalence of 21%. Similarly, in 27 of 188 instances involving forehead IRT measurements, fever was encountered, giving a point prevalence of 14%.

Respective temperature readings from the 15 volunteers studied preexercise in the USC (ambient temperature 27°C) were compared with readings obtained from attendees in one of the two health clinics (ambient temperature 21°C). In the latter facility, all mean front and side view values except IRT readings with the mouth open and the ear at 0.5m were 1°C to 4.3°C lower than the mean aural temperature (p<.001). In the USC, corresponding mean IRT values were only about 0.6°C to 2.5°C lower, although the differences still attained statistical significance (p<.001), and for readings from the forehead, temples and closed mouth, differences from respective health clinic values were also statistically significant (p<.05). The mean maximum front-face IRT reading was 0.5°C lower in subjects wearing as opposed to not wearing surgical facemasks ($p<.01$).

Discussion

Aural temperature (measured by tympanic IRT) is presently a preferred and widely accepted clinical means of estimating body temperatures in modern hospitals and is presumed to be an, albeit imperfect, reflection of core temperature. [21,22] Moreover, just as genuine core body temperature increases with exercise, [23] our postexercise findings revealed that aural temperature and most remotely sensed IRT readings were also significantly higher than at rest (Table 1). Only oral and mouth-open IRT readings did not increase, indicating that these did not faithfully parallel exercise-induced increases in core body temperature. The latter discrepancies could be related to postexercise panting, consequent evaporation of water from the mouth, and associated cooling due to latent heat of evaporation losses. Under these circumstances, we opted to accept aural temperature readings together with non-postexercise oral temperature readings as a reliable and simple means of estimating the true core body temperature.

Among the various remote IRT temperature parameters that we assessed, the best agreement and correlations with core body temperatures were with: (1) the ear (pinna) at 0.5m and 1.5m from the camera; (2) the side face view; and (3) the front of the face with the mouth open. The reason for the pinna area being a good core temperature indicator perhaps lies in the geometric configuration of the external auditory canal. The latter blindly ending cavity behaves as an effective radiation trap, since it constitutes a relatively small and static air pocket almost entirely surrounded by heat-emitting skin. The good correlation between side face IRT readings and core body temperature was consistent with other reports. [10,24] The utility of this location may be explained by its proximity to the temporal artery under the thin skin of the temple region. Not surprisingly, wearing of surgical facemasks and opening the mouth also influenced front face readings, whereas ambient temperature appeared to influence front and side face readings to a similar extent. Front face maximal IRT readings with the mouth open are probably indirect reflections of the oral core body temperature, and may explain the good correlation. Nevertheless, screening for fever by the latter form of IRT could be regarded as being contrary to good infection control practice and nonesthetic.

By contrast, forehead and other maximum front face IRT estimates provided less dependable measures of core body temperature. In particular, confidence intervals for predicting core temperature from forehead IRT values were considerably wider than those for ear IRT at 0.5m (Table 3). Thus, our study points to the gross inadequacy of the screening methods currently used at border crossings and airports, as they depend on single-reading thermoprobes directed at the forehead. Thermoprobes positioned about 1m above the passenger's head are unlikely to detect maximum forehead temperatures reliably, and neither is the current full-face IRT imaging camera system likely to give accurate readings, particularly if passengers are moving. Moreover, it should be noted that currently deployed IRT camera distances for travelers at airports appear to be very variable and imprecise. These observations, taken together with our results, draw attention to the shortcomings of indiscriminate reliance on forehead IRT and indicate that the utility of currently implemented IRT systems at airports and border crossings is suspect.

In our sensitivity analysis for ear 0.5-m IRT readings (Table 4), using a cutoff value of ≤38 ° C (21% point prevalence), the corresponding false-negativity rate was 8%. Lowering the cutoff value to ≤37.5 ° C increases sensitivity by 16% (67% to 83%) and decreases specificity by 8% (96% to 88%), resulting in a false-negative rate decrease to 5%, and an increase in false-positive rate from 20% to 35%. Table 4 also shows that using the same cutoff value (37.5°C) for forehead IRT readings yields an unacceptably low sensitivity (only 15%), although the specificity would be high (98%). Since the prevalence of fever is likely to be much lower among travelers leaving or entering specific areas via airports or border crossings than the 21% encountered in our sample, a much higher proportion of subjects falsely testing positive and a much lower proportion falsely testing negative should be anticipated. For example, if 1 per 1,000 travelers being screened genuinely have fever (core body temperature ≤38 ° C), out of every 100,000 screened there would be 100 such individuals and the remaining 99,900 would be truly afebrile. Assuming that our IRT system is operated with a sensitivity of 83% (Table 4), 83 of the 100 affected subjects would be identified. Table 4 also indicates a corresponding specificity of 88%, and therefore 12% (100-88%) of the 99,900 travelers without fever (i.e., 11,988 subjects) would be falsely identified as febrile. Our system would consequently alert us to 144 (11,988/83) false-positive cases for every true positive detected. Implementation of such a remote-sensing IRT system implies that additional aural core body temperature checking (a much more laborious procedure) would be needed in 145 travelers to confirm one case of genuine fever. Thus, as opposed to conducting core body temperature measurements on the entire population of 100,000 travelers, approximately 12,000 (145x83) would require such testing, but 17 (100-83) patients with genuine fever would nevertheless be missed.

Thus, the main limitations to currently practiced remotely sensed infrared thermometry concern standardization (location to be targeted, camera-subject distance, ambient temperature, and influence of exercise). Ear IRT at 0.5m overcomes the resulting problems to a considerable extent. Other possible limitations of this study include the relatively small number of subjects with elevated core body temperature, and the fact that nearly all recruits were of Chinese ethnicity. Additional research is also warranted to address variations in emissivity, epidermic properties, skin complexion, sweating, the application of makeup and the imbibing of alcohol, food and drugs.

In conclusion, our findings suggest that temperature readings obtained by remote-sensing IRT can be used as a proxy for core body temperature. They also indicate that estimates based on the side view of the face and particularly the ear region at close range are the most reliable and precise. By contrast, the reliance of port and airport authorities on forehead IRT needs to be seriously questioned. Ambient temperature, prior exercise and wearing facemasks also affect IRT measurements. Appropriate selection and configuration of suitable remote-sensing IRT systems capable of continuous operation without significant instrumental drift will constitute a screening test only. For some subjects, access to more conventional thermometry will also be required.

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Declaration of Interests

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Street sellers in Hanoi, Vietnam. Submitted by Dr. Marc Shaw

FOOTNOTES

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