THE CORRELATION BETWEEN TYMPANIC MEMBRANCE TEMPERATURE AND SPECIFIC REGION OF FACE TEMPERATURE WITH STATISTICAL CORRECTION

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Introduction

Many travelers travel through airports or ports as they progress toward an international society. At the same time, there is a growing possibility that many infectious diseases will travel between countries. In the case of the outbreaks of infection disease such as SARS in 2002/2003, a large number of pyrogenesis detectors were placed in order to prevent the spread of a fever in international airports and ports, which led to early screening of high-temperature patients. According to ISO reports, the inner canthus temperature is the most suitabl

Material and Methods

1) Participants: Data were collected from National Health Insurance Service (NHIS) Ilsan Hospital from August 2016 to November 2017. In total, 2155 patients were included in this study. The patients were informed about the procedures for all stages of the investigation and signed informed consent forms prior to enrolment in the study.

2) Experimental design: Patients who were not able to sit or open their eyes were excluded. Facial temperature was measured by the following methods. First, the beds were block light and heat from the outside. Second, place the temperature and hygrometer next to the bed, and position the IR camera at a distance of 1.5 meters from the patient, and then taken. Finally, left and right tympanic temperature was measured

3) Thermal image processing: In order to estimate the patient's temperature status from the thermal image, position the six regions of interest (ROI) of eyes (medial canthus, cornea, sclera between medial canthus and cornea, both eyes) and the ROI of the inter-brow and calculate the ROI average and standard deviation temperature for each 4x4 pixel size. Patient information included in the study were gender, age, presence of lens wear, height, weight, blood pressure and diagnosis, room temperature, humidity and time of measurement. For the identification of high-fever patients, we divided the ear temperature into 37.5 degrees and compared the existing statistical methods with support vector machine (SVM) in classification accuracy. In the support vector machine, a total of 70% were selected randomly for learning (training set), and the remaining 30% were classified to verify the efficiency of the model (validation set). The infrared camera received a calibration certificate from the institution, certified by the specification and KOLAS. The hygrometer and tympanic thermometer also received a calibration certificate. Data were calculated using calibrated measurements.

4) Statistical analysis: The numerical and categorical characteristics of the study population were expressed as mean±standard deviation and percentages, respectively. To quantitatively assess the performance of the seven spots correlation with core temperature, we calculated interclass correlation (ICC), root mean squared error (RMSE) and quantile root mean squared error (QRMSE). The closer the ICC value is to 1, the better the result, but the closer the RMSE and QRMSE are to 0, the better. In addition, we checked visual quality using by Bland-Altman plot and Taylor diagram. The scatter plots was analyzed to determine the linear relationship and the distributional identity between tympanic membrane and thermographic temperature. When the eardrum temperature exceeded 37.5 degrees, we observed monotone increase in facial temperature. Based on these results, we defined the patients with high fever and compared the logistic regression method and the SVM to distinguish high fever patients. All of graphics were created using R software for Windows version 3.0.2. All of statistical measurements were performed in SAS version 9.4.

Results

Baseline characteristics of the study population (total 656 patients) are listed in Table 1. The mean age at the time of thermography was 48.58 years-old. When age was categorized by below 10 years-old, there were 77 (11.74 %), 60 teenagers (9.15 %), 33 twenties (5.03 %), 35 thirties (5.34 %), 62 forties (9.45 %), 95 fifties (14.48 %), 136 seventies (20.73 %), 65 eighties or more (9.91 %), respectively. Within the population, 53.20 % of participants were male. Mean room temperature and humidity were 26.06°C and 42.61 %, respectively. The left side ear and facial temperature were measured by increasing the room temperature by 0.5°C and the humidity by 10%. Since the results on the left and right do not differ greatly, only the results on the left side are summarized in Table 1.

The average temperature of the medial canthus was similar to that of the ear among the various parts of the face temperature. Despite changes in room temperature, the ear temperature was

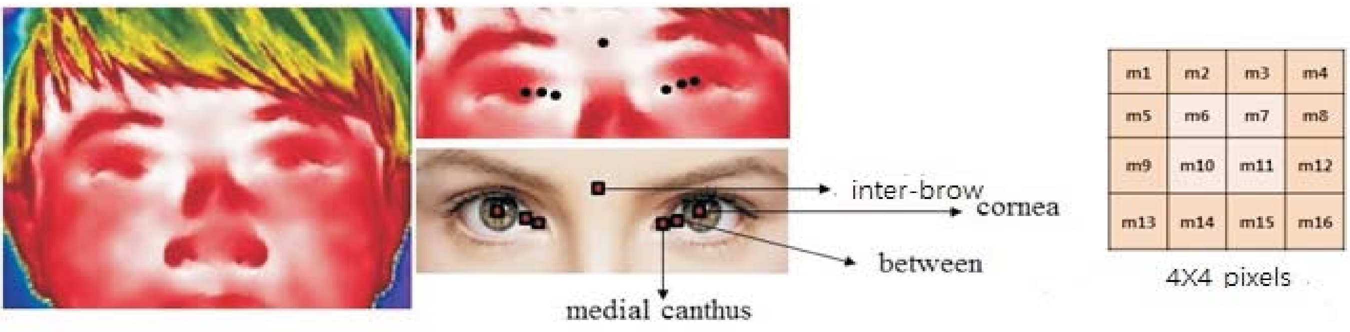


Figure 1
Seven ROIs of temperature measurement of the eye and face. The size of each ROI was 4X4 pixels.

maintained at 37.2°C. To quantitatively assess the performance of the temperature of seven ROIs, we calculated RMSE and QRMSE. The ICC, RMSE and QRMSE are defined as follows

$$ICC = \frac{1}{Ns^2}\sum_{n=1}^{N}(y_{pred} - \bar{y})(y_{true} - \bar{y})$$

$$RMSE = \sqrt{\sum \frac{(y_{pred} - y_{true})^2}{n}}$$

$$QRMSE = \sqrt{\sum \frac{(Rank_{(y_{pred})} - Rank_{(y_{true})})^2}{n}}$$

Where y_{pred} denote the mean temperature of 4 by 4 temperature pixels of each ROIs, and y_{true} denote eardrum temperature for each person, respectively. The $\bar{y}$ and s denote the common average and variance of y_{pred} and y_{true} respectively. Rank( ) denote the quantile of data. Table 2 shows the results of ICC, RMSE and QRMSE. As can be seen, the medial canthus produces better per-

Table 1
Baseline characteristics of the study population, and left side membrane and face temperature for each room conditions.

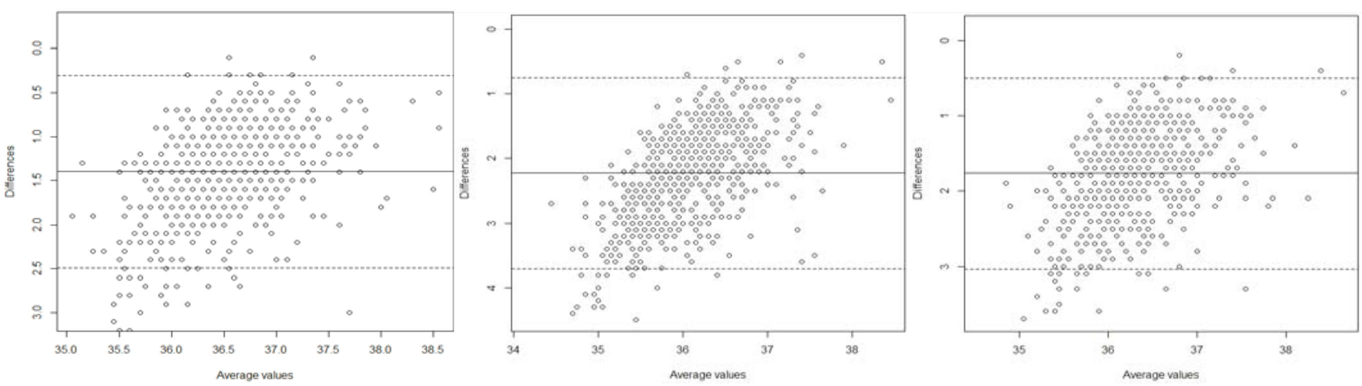
Sex	N(%)	Room Temperature (°C)	Ear	MC	Cornea	Between	Inter Brow
Male	1208(56%)	= 25	37.2 ± 0.5	35.7 ± 0.8	34.7 ±0.9	35.2 ±0.8	34.7 ± 0.9
Female	947(44%)	25.1~25.5	37.1 ± 0.4	35.7 ± 0.6	34.9 ± 0.8	35.4 ± 0.7	34.7 ± 0.7
Age (y)		25.6~26.0	37.2 ± 0.4	35.8 ± 0.7	35.0 ± 0.8	35.5 ± 0.7	34.9 ± 0.8
=9	244(11.3%)	26.1~26.5	37.2 ± 0.5	35.8 ± 0.7	35.0 ± 0.9	35.4 ± 0.8	34.9 ±0.8
10~19	184(8.5%)	26.6~27.0	37.2 ± 0.5	35.8 ± 0.8	35.1 ± 0.8	35.5 ± 0.8	35.0 ±0.7
20~29	92(4.3%)	27.1~27.5	37.2 ± 0.4	36.0 ± 0.5	35.3 ± 0.7	35.7 ± 0.6	35.2 ±0.7
30~39	82(3.8%)	> 27.5	37.3 ± 0.5	36.0 ± 0.7	35.1 ± 0.8	35.6 ± 0.8	35.1 ±0.7
40~49	204(9.5%)	Humidity (%)					
50~59	351(16.3%)	= 10.0	37.1±0.4	35.7 ± 0.6	34.7 ± 0.9	35.2 ± 0.7	34.9 ± 0.6
60~69	343(15.9%)	10.1~20.0	37.3±0.4	35.9 ± 0.8	35.0 ±0.9	35.5 ± 0.9	35.0 ± 0.5
70~79	460(21.4%)	20.1~30.0	37.1±0.5	35.7 ± 0.8	34.9 ± 0.9	35.4 ± 0.8	34.9 ± 0.8
0= 80	195(9.0%)	30.1~40.0	37.2±0.5	35.9 ± 0.6	34.9 ± 0.8	35.4 ±0.7	35.0 ± 0.7
		> 40.0	37.2±0.5	35.8 ± 0.7	35.1 ± 0.8	35.5 ±0.8	34.9 ±0.8

MC: Medial canthus
Ear: tympanic membrane
Between: ROI between medial cantus and cornea

Table 2 RMSE and QRMSE result of seven points for each tympanic temperature

		Total(N=2155)		
		ICC	RMSE	QRMSE
Left	Medial Canthus	0.3850	1.5047	1.4224
	Cornea	0.2567	2.3508	2.2675
	Between	0.3114	1.8837	1.7998
	Inter Brow	0.2685	2.3835	2.3134
Right	Medial Canthus	0.3496	1.5201	1.4371
	Cornea	0.2452	2.3532	2.2752
	Between	0.3033	1.8698	1.7915
	Inter Brow	0.2739	2.4005	2.3327

ICC : Interclass correlation
RMSE : root mean squared error
QRMSE : quantile root mean squared error



Medial canthus Cornea Between
Figure. 2 Bland-Altman plot for thermographic temperature of left eye with left ear temperature

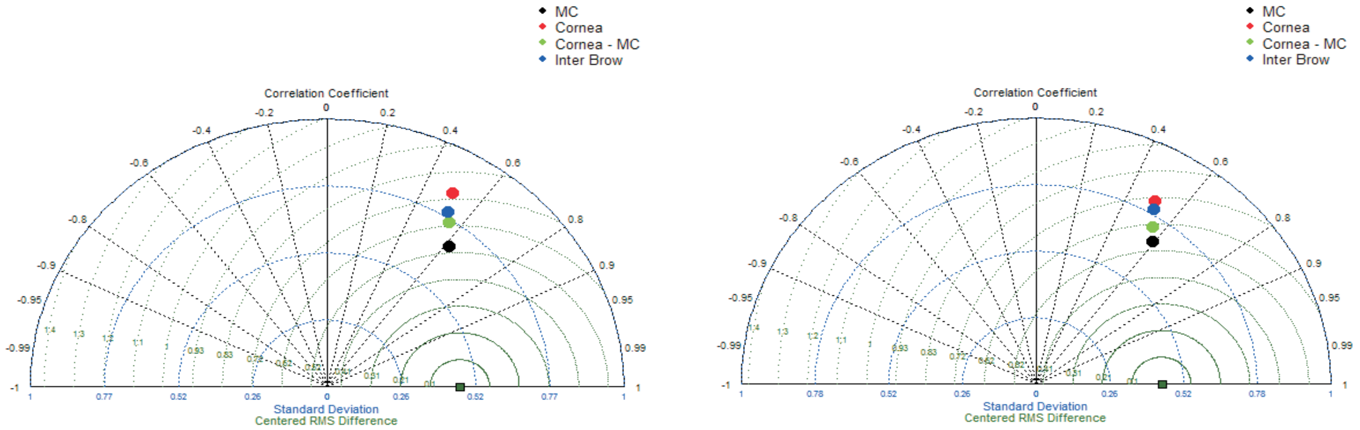
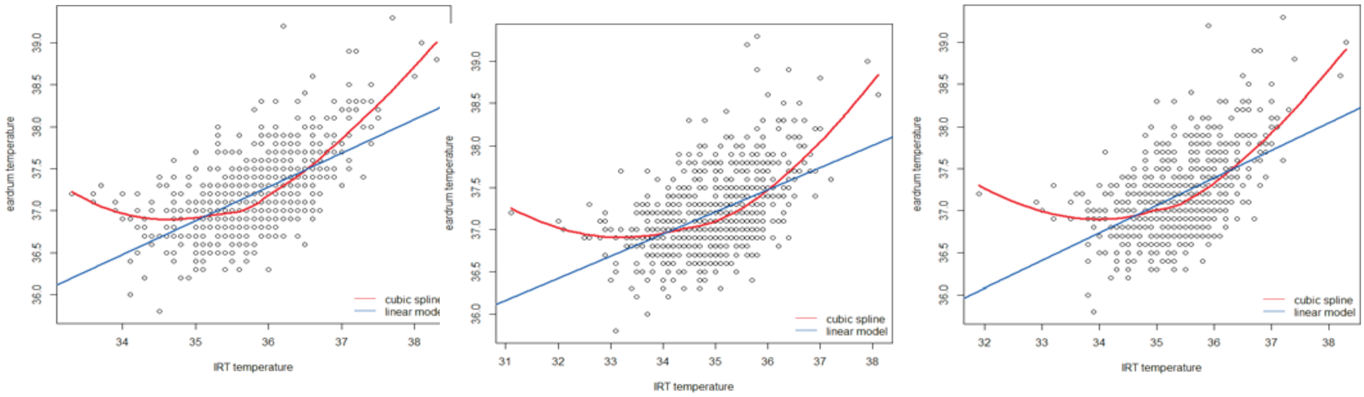


Figure 3 The Taylor diagram compare thermography observations and ear temperature for each side.



Medial canthus Cornea Between

Figure 4 Scatter plot with linear regression and cubic spline for thermographic temperature of left eye with left ear temperature (x-axis : IRT temperature, y-axis : eardrum temperature)

Table 3 Accuracy, sensitivity, specificity, PPV and NPV of the SVM result in comparison with logistic regression

	Logistic		SVM	
	Training set	Validation set	Training set	Validation set
Accuracy(95%CI)	85.22(83.23-87.21)	81.11(78.55-83.67)	93.10(91.68-94.53)	85.00(82.67-87.33)
Sensitivity(95%CI)	75.26(69.13-81.40)	64.23(56.21-72.26)	62.10(55.21-69.00)	32.85(24.98-40.71)
Specificity(95%CI)	87.06(85.01-89.11)	84.14(81.55-86.73)	98.83(98.17-99.49)	94.36(92.72-96.00)
PPV(95%CI)	51.81(45.92-57.71)	42.11(35.41-48.80)	90.77(85.79-95.75)	51.14(40.69-61.58)
NPV(95%CI)	95.01(93.62-96.40)	92.91(90.99-94.82)	93.38(91.91-94.86)	88.67(86.49-90.85)

PPV : positive predictive values
NPV : negative predictive values
SVM : support vector machine

formance than cornea, between medial canthus and cornea and inter-brow in each side. Figure 3 and 4 show the similarity between temperature of IRT image and tympanic membrane for seven spots. The medial cantus performed well on left and right, high correlation and low RMS difference.

Scatter plot shows that rapid temperature change occurs at the eardrum temperature of 37.5°C. Among the statistical classification methods, the comparison of the classification probabilities by the support vector machine using the machine learning method and the classical method, logistic regression, showed that the results of the machine learning method showed high agreement with the accuracy.

Logistic regression analysis showed accuracy of 81% and machine learning result to be about 85% in validation set. In machine learning, sensitivity and specificity were 33% and 94%, respectively, and positive predictive values (PPV) and negative predictive values (NPV) were 51% and 88%, respectively.

Discussion

We measured seven ROIs of the facial IRT and estimated the similarity to the temperature of the eardrum. The results showed that the medial canthus of the eye was the closest to the tympanic membrane temperature with the same result as ISO. The inter-brow of the face was most different from the tympanic temperature. However, for travelers with eye disabilities or acute illness of the eye, it may be better to use inter-brow as an alternative ROI.

However, the tympanic temperature and the medial canthus temperature differed by more than about 2°, and the accuracy was problematic because the dispersion was relatively large. Therefore, it is difficult to use the facial temperature instead of the tympanic temperature. To solve all these problems, a study was conducted to isolate high-fever patients based on 37.5 degrees, to screen for the transmission of diseases in high-fever patients, and to improve the classification accuracy through machine learning. Because of the analysis, the accuracy increased slightly compared with the existing statistical model, but the sensitivity was relatively poor. Sufficient learning of data is needed to further enhance consistency and pre-processing of data is required. Therefore, we plan to use the medial canthus in future to formulate an estimation formula to estimate the tympanic temperature in addition to the formula that accurately classifies patients with high fever over 37.5 degrees.

Conclusion

The facial temperature was measured for patients admitted to the hospital for two years, and the relationship between the temperature and the tympanic membrane temperature was analyzed. We plan to apply a variety of machine learning methods to get a more accurate result, and we will recruit more data to improve results.

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References:

ISO/IEC. International vocabulary of metrology - Basic and general concepts and associated terms (VIM). 3rd eds, ISO/IEC GUIDE 99, 2007.

ISO/IEC. Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) in Uncertainty of measurement; ISO/IEC Guide 98-3, 2008.

Chandler C. The use of thermography inelevated bosy temperature screenig, Pan Am J Med Thermol.2015, 2: 58-62

Piani C, Haerter JO, Coppola E. Statistical bias correction for daily precipitating in regional climate models over Europe Theor Appl Climatol, 2010; 99(1-2), 187-192

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