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The Value of Non-Contact Infrared Thermometer in Measuring Temperatures of Different Body Surfaces: A Clinical Diagnostic Study

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Abstract: Objectives: This study aimed to determine the optimal cutoff value for fever based on temperature measurements of different body surfaces using a non-contact infrared thermometer. Methods: A total of 229 participants were conveniently sampled for this clinical diagnostic study. Oral temperature was measured using a mercury thermometer, while the temperatures of the forehead, neck, and wrists were measured using a non-contact infrared thermometer. The differences and linear relationships between the temperature measurements of different body surfaces and oral temperature were analyzed using statistical methods. Receiver operating characteristic (ROC) curves were constructed to determine the optimal cutoff values for fever on the forehead, neck, and wrists. Results: The optimal cutoff values for fever on the neck, forehead, and wrists were 37.1°C, 36.9°C, and 36.8°C, respectively, as measured by the non-contact infrared thermometer. Conclusion: The non-contact infrared thermometer is a reliable tool for measuring body surface temperatures. The optimal cutoff values for fever using a non-contact infrared thermometer are 37.1°C for the neck, 36.9°C for the forehead, and 36.8°C for the wrists.

Keywords: Non-Contact Infrared Thermometer, Body Surface Temperature, Optimal Cutoff Value

1. Introduction

Body temperature is a vital sign that can indicate changes in the health status of the human body [1]. Fever is a common symptom of infectious diseases such as COVID-19, Middle East Respiratory Syndrome (MERS), H1N1 influenza, avian influenza, and Severe Acute Respiratory Syndrome (SARS) [2, 3, 4]. As COVID-19 is highly infectious and primarily transmitted through respiratory droplets and close contact, non-contact temperature measurement has become a widely used method to prevent cross-infection.

Non-contact temperature measurement has several advantages, including fast measurement (1-3s) and no need for physical contact with the human body during measurement [5]. However, there is a difference between the surface temperature measured by non-contact thermometers and the core temperature, and external environmental conditions and other factors can influence the accuracy of the measurements. Most research on non-contact infrared thermometers has focused on measuring forehead temperature, and research on measuring temperatures at other body parts, such as the neck and wrist, is limited.

Furthermore, most studies still use fever standards measured by mercury thermometers as the benchmark for accuracy, and there is no authoritative data defining fever temperature by measuring the temperature of different body parts. This clinical diagnostic study aimed to evaluate the performance and value of non-contact infrared thermometers in measuring body temperature by comparing measurements from the oral cavity, forehead, neck, and wrist of the study subjects using non-contact infrared thermometers and mercury thermometers. The study aimed to explore the optimal cutoff values for fever based on temperature measurements of different body surfaces.

2. Methods

2.1. Sample

The sample for this clinical diagnostic trial consisted of inpatients admitted to the hospital from September 1, 2021, to February 28, 2022. The inclusion criteria for the study were individuals between the ages of 3 and 90 years, clear consciousness and absence of cognitive impairment, and informed consent and voluntary participation. Exclusion criteria included oral disease, inability to breathe through the nose due to nasal surgery or other reasons, tracheotomy or intubation, neck vein catheterization or wounds affecting temperature measurement, upper limb arteriovenous fistula or hand injuries affecting temperature measurement, pregnancy, steroid treatment, and inability to cooperate with the study.

2.2. Sample Size Evaluation

The required sample size for this study was calculated using the formula for a diagnostic test based on literature review, which estimated the sensitivity of non-contact infrared thermometers for measuring forehead temperature as 88.7% and 89.9%. Sample size calculations were performed using SPSS 26.0 software, and the results showed that the minimum number of participants required for this study was 210, including 21 febrile patients and 189 non-febrile patients.

2.3. Study Design

This study is a clinical diagnostic trial that utilized a convenience sampling method. The study was conducted in the inpatient ward of a hospital. All temperature measurement tests were completed by members of the research team who received standardized training prior to the study to ensure the accuracy of the results. The research tools used included a general information questionnaire, an experimental data record form, and temperature measurement equipment, including a mercury thermometer and a non-contact infrared thermometer produced by Guangzhou Beierkang Medical Equipment Co., Ltd., model JXB-182, which was used for measuring temperature on the forehead, neck, and wrist of all study participants.

2.4. Experimental Methods and Steps

Preparation of temperature measurement equipment included ensuring the thermometer was calibrated and disinfected, and the skin was cleaned and dried before temperature measurement was taken. Data collection involved measuring oral temperature with a mercury thermometer, followed by the non-contact infrared thermometer to collect temperature data on the forehead, neck, and wrist. Data was recorded on the experimental data record form.

Preparation of Temperature Measurement Equipment: (1) Mercury Thermometer: Before measurement, swing the mercury column of the thermometer to below 35°C, and then place it in a constant temperature water below 40°C that has been tested at the same time. After 3 seconds, take it out. Those with errors above 0.2°C or with broken glass tubes should not be used. Qualified thermometers should be soaked in a container with 75% alcohol solution for 30 minutes for disinfection, then rinsed with sterile water, dried with sterile gauze, and placed in a clean and dry thermometer box for later use. (2) Non-Contact Infrared Thermometer: In this study, the same non-contact infrared thermometer was used to measure the temperature of the forehead, neck, and wrist of all study subjects. To ensure the stability of the temperature measurement equipment throughout the entire study process and avoid measurement errors caused by using thermometers produced by different manufacturers, three thermometers of the same make, model, and batch were prepared before the study, one for patient temperature measurement and the other two for backup and control purposes. To ensure the reliability of the thermometer temperature measurement, the temperature of the thermometer used in this study was compared with the temperature of the other two backup thermometers before each temperature measurement. When the measurement error exceeded the maximum allowable error of the instrument by ≥0.3°C, an engineer was contacted to calibrate the thermometer. Check the integrity of the equipment before temperature measurement, ensure that the buttons are functioning properly, the battery is fully charged, the temperature measurement is stable, and perform cleaning and disinfection.

Preparation of Study Subjects: The researcher determined the study subjects based on the inclusion criteria, obtained their consent, signed an informed consent form, completed a general information questionnaire, instructed the study subjects on the temperature measurement steps, ensured that the skin at the measurement site was clean and dry, and instructed them to sit or lie down for temperature measurement.

Experimental Data Collection Steps: The researcher used a mercury thermometer to measure the oral temperature of the study subjects, and then used a non-contact infrared thermometer to sequentially collect the temperatures of the forehead, neck, and wrist of the study subjects, recording the temperature measurement results and other experimental data.

Temperature Measurement Methods: (1) Measurement of Oral Temperature: Use a mercury thermometer to collect the oral temperature of the study subjects. During temperature measurement, place the thermometer under the tongue, instruct the study subjects not to speak, keep their lips closed, and breathe through their nose to ensure the accuracy of the measurement results [6]. The measurement time is uniform and set at 5 minutes [7, 8]. After measurement, remove the thermometer, read the mercury column reading, and record the measurement result. (2) Measurement of Forehead, Neck, and Wrist Temperature: Use a non-contact infrared thermometer to collect the temperature of the forehead, left and right neck, and left and right wrist of the study subjects. The measurement position and method are uniform, and the measurement position of the forehead is the center of the forehead above the eyebrows; the measurement position of the neck is the left and right sides of the neck (the strongest pulsation of the carotid artery); the measurement position of the wrist is the radial side of the left and right wrists (the strongest pulsation of the radial artery). There should be no hair or clothing obstructing the measurement site during measurement. Keep a distance of 3-5cm between the thermometer and the measurement site, and keep the infrared detector vertical to the measurement site. The induction time for a single measurement is greater than 1 second, and the time interval between each measurement is 3-5 seconds. Measure the temperature at each site three times or more, and use the temperature with the highest frequency as the measurement result. The measurement results should be read and recorded by the experimental personnel, and double-checked to ensure accuracy.

2.5. Statistical Analysis

SPSS 26.0 software was used for statistical analysis of data, which included diagnostic test evaluation indicators such as sensitivity, specificity, and Receiver operating characteristic (ROC) curve analysis.

Statistical analysis was performed using SPSS 26.0 software in this study. Diagnostic test evaluation indicators including sensitivity, specificity, positive predictive value, and negative predictive value were calculated. Sensitivity was calculated as true positive divided by the sum of true positive and false negative, while specificity was calculated as true negative divided by the sum of true negative and false positive. Positive predictive value was calculated as true positive divided by the sum of true positive and false positive, while negative predictive value was calculated as true negative divided by the sum of true negative and false negative.

Descriptive analysis was used to evaluate the general data. Mean ± standard deviation was used for normally distributed data, while median (interquartile range) was used for skewed data. One-way analysis and paired t-tests were conducted to compare temperature differences between the left and right neck and wrist. The paired sample Wilcoxon signed-rank test was used to compare pairwise temperatures between different body surface areas and oral temperature. General linear regression analysis was performed to examine the linear relationship between temperature measured at different body sites and oral temperature, with $P < 0.05$ indicating statistical significance.

Finally, ROC curves were utilized to determine the optimal temperature for defining fever at different body sites. Three ROC curves were constructed based on temperatures collected from the forehead, neck, and wrist. The Youden index was calculated by analyzing the sensitivity and specificity of each body surface position's temperature for each subject using the ROC curve, where the Youden index equals sensitivity plus specificity minus one. The optimal cutoff value for defining fever at different body sites was selected by determining the critical value corresponding to the maximum Youden index of the three curves.

3. Results

Basic Information of Study Participants A total of 229 individuals were included in this study, with a mean age of 46.58±23.26 years. The age range was from 3 to 90 years, with 114 males (49.8%) and 115 females (50.2%). Oral temperature measured by a mercury thermometer was used as the standard for comparison with the temperature measured at five different body surface sites (i.e., forehead, left and right sides of the neck, and left and right wrists) using a non-contact infrared thermometer. A total of 1374 temperature measurement points were recorded.

3.1. Comparison of Temperature Measurements at the Left and Right Sides of the Neck and Wrists

In this study, the temperature was measured at different sites on both sides of the neck and wrists. The average temperature of the left neck was 37.07±0.79°C, the right neck was 37.09±0.81°C, the left wrist was 36.74±0.63°C, and the right wrist was 36.73±0.61°C. The Wilcoxon signed-rank test showed that there was no statistically significant difference between the left and right sides of the neck ($Z=-1.075$, $P=0.282$) or between the left and right wrists ($Z=-0.84$, $P=0.401$). Therefore, the data from the left and right sides of the neck and wrists were combined to calculate the mean temperature for further statistical analysis.

3.2. Comparison of Temperature Measurements at Different Body Sites with Oral Temperature

The results of the Wilcoxon signed-rank test showed that there was a statistically significant difference ($P<0.05$) between the temperature measured at each body surface site and the oral temperature. The neck temperature was closest to the oral temperature, followed by the forehead and then the wrists, as shown in Table 1.

Table 1. *Comparison of Temperature Differences between Different Body Sites and Oral Temperature.*

Position	Average temperature	Minimum	Maximum	Z	P
Oral cavity	37.33	36.1	40.7	-	-
Neck	37.08	36.1	41.1	-9.27	0.000
Forehead	36.93	36.1	40.1	-15.02	0.000
Wrist	36.73	36.0	41.6	-16.49	0.000

3.3. Regression Analysis Results Between Temperature of Different Body Surface Locations and Oral Temperature

The linear regression analysis results showed that there was a linear relationship between the temperature of the forehead, neck, wrist, and oral temperature (P<0.05), and the linear regression equations were y=0.55x+16.421, y=0.701+24.327, y=0.386+20.815, respectively. The coefficients of determination were 0.746, 0.727, and 0.505, respectively, indicating that the oral temperature could explain 74.6%, 72.7%, and 50.5% of the variation in forehead, neck, and wrist temperature, respectively, as shown in Table 2.

Table 2. *Results of Regression Analysis between Temperature Differences of Different Body Sites and Oral Temperature.*

Position	Correlation coefficient r	Regression coefficient	Constant term	Standard error	Z	P
Frontal part	0.746	0.550	16.421	0.021	20.568	0.000
Neck	0.727	0.701	24.327	0.029	10.128	0.000
Wrist	0.505	0.386	20.815	0.029	13.425	0.000

Determination of the optimal temperature for defining fever in different body surface locations

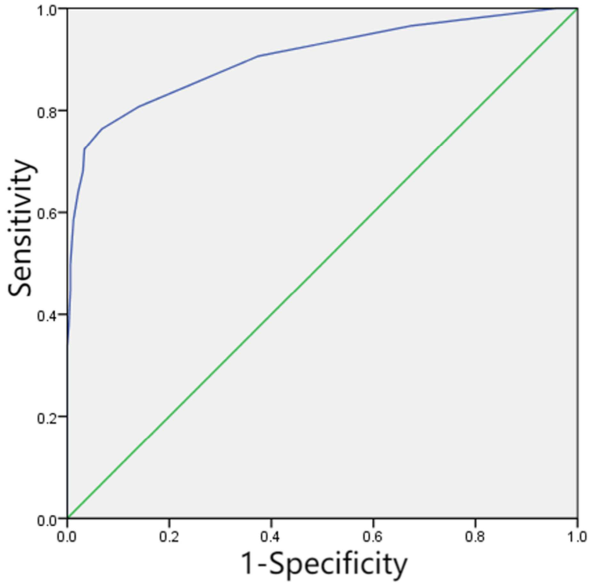

Figure 1. *ROC curve of measured temperature at forehead.*

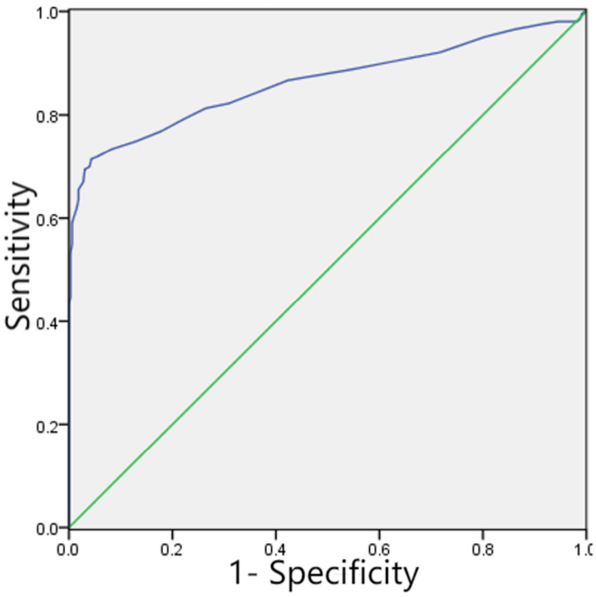

Figure 2. *ROC curve of measured temperature at neck.*

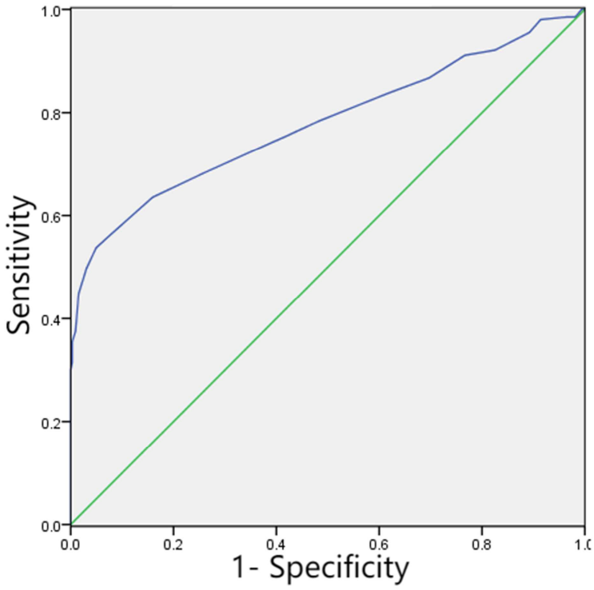

Figure 3. *ROC curve of measured temperature at Wrist.*

According to the study on determining the optimal temperature for defining fever in different body surface locations, three ROC curves were drawn based on the diagnostic study of temperature at three different body surface locations: forehead, neck, and wrist. The ROC curves were plotted using SE as the vertical axis and (1-SP) as the horizontal axis. Figure 1, Figure 2, and Figure 3 display the ROC curves. The area under the curve (AUC) was used to reflect the discriminative power of a diagnostic test. A diagnostic test with AUC≤0.5 has no diagnostic significance, while 0.5<AUC<0.7 indicates low diagnostic discriminative power. AUC values between 0.7 and 0.9 indicate moderate diagnostic discriminative power, and AUC≥0.9 indicates high diagnostic discriminative power.

The study found that the AUCs of the forehead, neck, and wrist temperature measurements compared with oral temperature measurements were 0.904, 0.863, and 0.778, respectively. The forehead temperature measurement had the highest AUC, while the wrist temperature measurement had the lowest AUC compared to oral temperature measurement. The diagnostic discriminative power of the forehead, neck, and wrist temperature measurements was good. Furthermore, all AUC data were within their respective 95% confidence intervals, indicating that most of the samples were consistent with the results in the data. Table 3 presents the AUC data.

Table 3. *Area under the ROC curve for temperature measurement on different body surfaces.*

Position	Area under the ROC curve	Significance	95% Confidence Interval
Forehead	0.904	0.000	0.875-0.933
Neck	0.863	0.000	0.826-0.900
Wrist	0.778	0.000	0.734-0.823

In order to define the optimal temperature for fever in different body locations, ROC curve analysis was employed. The upper and lower limits of fever for each temperature value were determined by selecting the critical values that corresponded to the three Youden index maximum cut-off points based on the sensitivity (SE) and specificity (SP) of each temperature value. Three ROC curves were generated, each representing a different body location.

Curve 1: The optimal cut-off value for fever was determined to be 36.9°C for the forehead temperature measured by non-contact infrared thermometer compared to oral temperature measured by mercury thermometer. The SE and SP values were 76.35% and 93.25%, respectively, resulting in a missed diagnosis rate of 23.65%. The Youden index was 0.696, and the positive predictive value (PPV) and negative predictive value (NPV) were 87.57% and 83.36%, respectively.

Curve 2: The optimal cut-off value for fever was determined to be 37.1°C for the neck temperature measured by non-contact infrared thermometer compared to oral temperature measured by mercury thermometer. The SE and SP values were 71.43% and 95.71%, respectively, resulting in a missed diagnosis rate of 28.57%. The Youden index was 0.671, and the PPV and NPV were 91.61% and 83.69%, respectively.

Curve 3: The optimal cut-off value for fever was determined to be 36.8°C for the wrist temperature measured by non-contact infrared thermometer compared to oral temperature measured by mercury thermometer. The SE and SP values were 53.69% and 95.09%, respectively, resulting in a missed diagnosis rate of 46.31%. The Youden index was 0.488, and the PPV and NPV were 90.99% and 74.60%, respectively.

Therefore, the optimal temperature for fever in different body locations measured by non-contact infrared thermometer are: neck 37.1°C, forehead 36.9°C, and wrist 36.8°C, as presented in Table 4.

Table 4. *Coordinate index under temperature measurement ROC curve of different body surface parts.*

Position	Best truncation value	Sensitivity (%)	Specificity (%)	Misdiagnosis rate (%)	Joden index	Positive predictive value (%)	Negative predictive value (%)
Forehead	37.1	71.43	95.71	28.57	0.671	91.61	83.69
Neck	36.9	76.35	93.25	23.65	0.696	87.57	86.36
Wrist	36.8	53.69	95.09	46.31	0.488	90.99	75.60

Using an oral temperature above 37.3°C as the standard for diagnosing fever in the forehead, neck, and wrist, missed diagnosis rates were calculated for 229 study patients, as shown in Table 5.

Table 5. *Missed diagnosis rates with 37.3°C as fever standard.*

Position	Number of missed diagnosis	Missed diagnosis rates (%)
Forehead	44	50.25
Neck	33	37.62
Wrist	66	75.86

4. Discussion

Non-contact infrared temperature measurement, also referred to as radiation temperature measurement (RTM) [9], operates on the principle that the human body emits electromagnetic waves, and its radiation energy strengthens with a rise in temperature. Infrared thermometers absorb this radiation energy from the forehead or other areas of the skin to determine the surface temperature without physical contact. Although variations in skin temperature could indicate changes in body temperature, several factors, including exercise, metabolism, and external heat sources, can affect skin temperature in everyday life. Hence, surface temperature measured by RTM cannot entirely represent body temperature [10].

Traditional temperature measurement typically uses a mercury thermometer to measure temperature in the axillary, oral, or rectal areas. Oral temperature measurement is considered more reliable than axillary temperature measurement as the closed body cavity formed by tightly closing the lips of the subject isolates the temperature inside the cavity from the external environment [11]. In comparison to rectal temperature measurement, oral temperature measurement is more convenient. This study, therefore, used oral temperature measured by a mercury thermometer as the "gold standard" [11] to assess the reliability of non-contact temperature measurement by comparing the temperatures obtained from different body surface areas using a non-contact infrared thermometer.

According to the results of the present study, the average temperatures of the neck, forehead, and wrist were lower than the oral temperature, with the neck temperature being the closest to the oral temperature, followed by the forehead and wrist temperatures. The neck temperature was, on average, 0.28°C lower than the oral temperature, the forehead temperature was 0.41°C lower than the oral temperature, and the wrist temperature was 0.62°C lower than the oral temperature. The oral temperature was considered the "gold standard" because the measured person closes their lips tightly, forming a closed body cavity, and the temperature inside the cavity is relatively constant and not affected by the external environment. Therefore, the oral temperature measurement result is closer to the core body temperature [12]. In contrast, the neck, forehead, and wrist are surface parts of the body that are easily affected by external interference and skin cooling, resulting in lower temperatures than the oral temperature. The neck is close to the heart and has abundant blood supply from the carotid artery, which insulates it from external factors, making its temperature closer to the body temperature. The forehead is more exposed to the external environment, which makes it more susceptible to external factors, resulting in a lower temperature than the oral temperature. The wrist is located at the end of the upper limb, away from the central body, resulting in its temperature being significantly lower than the oral temperature.

No literature was found on the comparison between non-contact infrared thermometry and oral temperature measurement. However, in several studies comparing forehead temperature with axillary temperature [13-17], statistically significant differences were found in some studies, while other studies found no significant difference [18-22]. There is limited research on the measurement of neck and wrist temperatures using non-contact infrared thermometry. One study found a difference in neck temperature between feverish patients and axillary temperature [16], while another study found a difference in forearm temperature and axillary temperature [22]. In summary, there is no unified conclusion in the research on the measurement of temperature in different surface parts of the body using non-contact infrared thermometry compared to mercury thermometry (citation).

This study examined the correlation between temperature measurements obtained by non-contact infrared thermometers on the forehead, neck, and wrist, and those obtained by mercury thermometers in the mouth. The correlation coefficient was calculated as a measure of the linear correlation between variables. The correlation coefficient is often represented by the letter "r", and a value greater than 0.8 is considered a strong correlation between variables A and B, while a value between 0.3 and 0.8 indicates a weak correlation, and a value below 0.3 indicates no correlation [23]. In this study, the correlation coefficients (r-values) between forehead, neck, and wrist temperatures and oral temperature were 0.738, 0.713, and 0.498, respectively. The results indicated a positive linear correlation between the temperatures measured at the different body sites and the oral temperature, meaning that as the oral temperature increased, the temperatures at the body surface also increased. However, the correlation coefficients between the three sites were all weak, with the forehead having the strongest correlation, followed by the neck and wrist. Literature review did not reveal any studies on the correlation between non-contact infrared thermometer measurements of body surface temperature and oral temperature. However, several studies on the correlation between non-contact infrared thermometer measurements of forehead and axillary temperatures have reported a significant positive correlation between the two [5, 24].

Mercury thermometers have traditionally been regarded as the "gold standard" for measuring body temperature due to their accuracy and reliability. However, they are not well-suited for screening body temperature during infectious disease outbreaks due to the long measurement time and the risk of cross-infection from contact measurements. In contrast, non-contact infrared thermometers are simple, quick, and reduce the risk of cross-infection. However, their temperature measurements can be influenced by environmental factors, and may differ from core temperature. Using the old standard for fever diagnosis to evaluate the measurement results of non-contact infrared thermometers could result in a high rate of missed diagnoses. Therefore, the aim of this study was to improve the accuracy of fever screening in patients by determining optimal cutoff values for temperature measurements of different body sites using non-contact infrared thermometers through experiments.

Fever is defined as an elevated body temperature above the normal range, with a diagnosis of fever made when the temperature in the armpit is above 37.0°C or in the mouth is above 37.3°C [25]. Currently, there are no established standards for using non-contact infrared thermometers to diagnose fever. In clinical practice or previous research, the standards for diagnosing fever using axillary or oral temperature have been used as the standard for diagnosing fever using non-contact infrared thermometers to measure the temperature of the body surface, resulting in a higher rate of missed diagnoses.

In the present study, 229 patients were screened using non-contact infrared thermometers to measure body temperature at the forehead, neck, and wrist, with a diagnosis of fever based on a temperature exceeding 37.3°C as the criterion. The results revealed a missed diagnosis rate of 37.62% (76 individuals) for neck temperature, 50.25% (102 individuals) for forehead temperature, and 75.86% (154 individuals) for wrist temperature. These findings demonstrate that using a temperature threshold of 37.3°C to diagnose fever when employing non-contact infrared thermometers for temperature measurement may result in a high rate of missed diagnosis, leading to delayed detection and inadequate treatment of fever patients, which may result in adverse outcomes.

The "Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia" recommends seeking medical attention when body temperature exceeds 37.3°C [26], but it does not specify the method of temperature measurement. If non-contact infrared thermometers are used, relying on this standard may lead to a high risk of missed diagnosis, and suspected or infected patients may not be identified in a timely manner, resulting in the spread of the virus and significant social harm. Therefore, it is crucial to establish appropriate fever warning values for measuring temperature at different body sites using non-contact infrared thermometers.

According to a study conducted by a medical researcher, non-contact infrared thermometers can be improved for screening fever patients and reducing missed diagnoses. The study employed diagnostic research to analyze ROC curves of temperature measurements from various body surface areas using a non-contact infrared thermometer. The results revealed that the best cutoff values for defining fever were 37.1°C for the neck, 36.9°C for the forehead, and 36.8°C for the wrist, compared to oral temperature measured by a mercury thermometer. The use of warning values of 37.1°C for the neck, 36.9°C for the forehead, and 36.8°C for the wrist for screening fever patients significantly decreased the missed diagnosis rate. The missed diagnosis rates for the neck, forehead, and wrist reduced by 16.67%, 28.41%, and 28.78%, respectively, when compared to using 37.3°C as the fever standard. A preliminary criterion of 37.0°C was found for judging fever by Liu Caihong et al [17]. when using an infrared forehead thermometer for temperature measurement, which is close to the best cutoff value of 36.9°C for the forehead temperature measurement in this study.

Non-contact infrared thermometers can be utilized as a tool for preliminary temperature screening, but attention should be paid to temperature judgment during use. The standard of 37.3°C is not suitable as a general criterion for fever diagnosis. According to the study's findings, when the temperature of the neck, forehead, and wrist reaches 37.1°C, 36.9°C, and 36.8°C, respectively, fever should be preliminarily judged. In addition, more accurate temperature measuring devices like ear thermometers and mercury thermometers should be used for temperature verification. During the epidemic prevention and control period, a warning value of 36.8°C can be utilized as the cutoff for forehead, neck, and wrist temperatures to reduce missed diagnosis of fever patients and detect fever patients as much as possible.

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