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Original Article

Validity of the Use of Wrist and Forehead Temperatures in Screening the General Population for COVID-19: A Prospective Real-World Study

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Abstract

Background: We aimed to compare the accuracy of individuals' wrist and forehead temperatures with their tympanic temperature under different circumstances.

Methods: We performed a prospective observational study in a real-life population in Ningbo First Hospital in China. We consecutively recorded individuals' wrist and forehead temperatures in Celsius (°C) using a non-contact infrared thermometer (NCIT). We also measured individuals' tympanic temperature using a tympanic thermometer (IRTT) and defined fever as a tympanic temperature of ≥37.3 °C.

Results: We enrolled 528 participants, including 261 indoor and 267 outdoor participants. We grouped the outdoor participants into four groups according to their means of transportation to the hospital: by foot, by bicycle/electric vehicle, by car, or as a passenger in a car. Under different circumstances, the mean difference in the forehead measurement ranged from -1.72 to -0.56 °C across groups, and that in the wrist measurement ranged from -0.96 to -0.61°C. Both measurements had high fever screening abilities in indoor patients. (Wrist: AUC 0.790; 95% CI: 0.725-0.854, P<0.001; forehead: AUC 0.816; 95% CI: 0.757-0.876, P <0.001). The cut-off value of the wrist measurement for detecting a tympanic temperature of ≥37.3 °C was 36.2 °C, with 86.4% sensitivity and 67.0% specificity, and the best threshold for the forehead measurement was 36.2 °C, with 93.2% sensitivity and 60.0% specificity.

Conclusion: Wrist measurements are more stable than forehead measurements under different circumstances. Both measurements have favorable fever screening abilities in indoor patients. The cut-off values were both 36.2 °C.

Keywords: COVID-19; Wrist temperature; Noncontact infrared thermometer

Introduction

The outbreak of 2019 novel coronavirus COVID-19 (previously known as 2019-nCoV) has attracted attention worldwide due to the virus's ability to be transmitted easily and its associated risk of fatality (1, 2). Fever, fatigue and dry cough are common symptoms of COVID-19 patients (3, 4); 43.8% of the patients showed fever before admission, and it was commonly the first symptom (5). Therefore, it is important to perform temperature screening in the high-risk population for the early identification of COVID-19 infection and to thereby reduce the risk of cross-infection.

During the epidemic, infrared tympanic thermometers (IRTTs) and noncontact infrared thermometers (NCITs) are being used for temperature screening in the general population (6). These screening tools are quick for mass screening and allow fast triaging (7). However, we need to dispose of many plastic covers when we use IRTTs. This waste may increase the financial burden of societies when population screening is widely performed. Furthermore, indirect contact with infected individuals may increase the risk of cross-infection. NCITs meet the clinical requirements for mass screening in terms of detection efficiency, safety and cost-performance. In addition, they take less time to use than do IRTTs. The forehead is one of the key areas for thermography. However, individuals' forehead temperature is affected by physiological and environmental conditions (8). It should be measured in a relatively temperature-controlled environment. Individuals exposed to cold temperatures acclimate to the indoor temperature for at least 10 min before their body temperature is recorded (8). However, this process is not practical for mass screening in the winter during the outbreak of COVID-19.

The use of individuals' wrist temperature is under consideration in this outbreak. Before testing, individuals only need to roll up their sleeves to 10 cm above the palmar side of the wrist. Considering that this area is covered with clothing, individuals' wrist temperatures may remain stable. Wearable devices (WDs) on the wrist were used for temperature monitoring in clinical practice (9). It has not been determined whether wrist temperature can be used as accurate, safe and cost-effective screening way in this outbreak.

In this study, we explored the accuracy and advantages of wrist temperature measurements in a real-life population under different environments and conditions. We aimed to identify the thresholds for this key technique for the diagnosis of fever. The results from this study may help standardize both the applicability and performance of wrist thermometers, which are especially indispensable in the pandemic 2019-nCoV situation.

Materials and Methods

Study population

This was a prospective observational study in a real-life population. We consecutively enrolled 571 participants at Ningbo First Hospital in China (Fig. 1). The exclusion criteria included (i) an age ≤ 18 yr (*n* = 6); (ii) a hearing aid or cerumen (*n* = 7); (iii) soft tissue infection or trauma (*n* =3); (iv) missing data of the wrist, forehead, and tympanic temperatures (*n* = 4); and (v) forehead temperature measurements considered "low" (*n* = 23). We finally enrolled 528 eligible participants for the final analysis, including 261 indoor and 267 outdoor participants. The 261 indoor patients were from the fever clinic and emergency department, and the 267 outdoor participants included patients and accompanying family members. The data of indoor patients were collected consecutively between Feb 14th and Feb 20th in 2020. The data of outdoor participants were collected on Feb 14th, 15th, and 17th in 2020. Temperature readings were taken by trained and experienced nurses. Each participant underwent measurements twice for the wrist, forehead, and tympanic temperatures. The temperatures were recorded as the mean wrist, forehead, and tympanic temperatures. Data regarding the participant's age, sex, mode of transportation, occupation, and temperature were recorded immediately by the nurse in preprinted files.

The study was approved by Ningbo First Hospital Ethics Committee. All participants were asked to answer questions verbally. They gave verbal informed consent to participate in this study. The study was registered at ClinicalTrials.gov with an identifier number: NCT04274621.

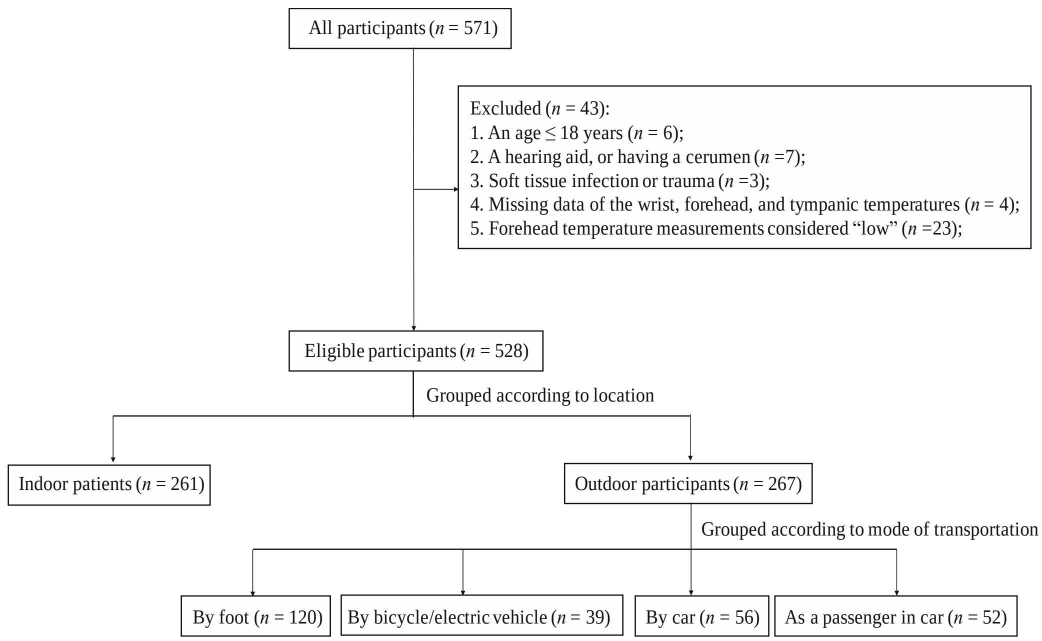

Fig. 1: Flowchart of the study

Assessment of the environment

Indoor patients at the fever clinic and emergency department included those who had been indoors for at least a few minutes. The outdoor participants were divided into four groups according to their means of transportation to the hospital: by foot, by bicycle/electric vehicle, by car, or as a passenger in a car.

Measurement of temperature

Individuals' tympanic temperature was measured using an IRTT (Braun ThermoScan PRO 6000). Wrist and forehead temperatures were measured using an NCIT. The range of the NCIT was 32.0-42.9 °C. The accuracy was ±0.2 °C. NCIT measurements were taken following the manufacturer's instructions on the mid-forehead and a region located 10 cm above the palmar side of the wrist. After pulling the pinna backward, the nurse inserted the IRTT into the external auditory meatus.

The probe was held in the same position until a "beep" was heard. Temperature readings were taken by the same trained nurse in the following order: the forehead, forehead (the second time), left wrist, right wrist, left ear, and right ear. The data were recorded by another researcher in preprinted files. The tympanic membrane is close to the hypothalamus and the internal carotid artery (10). Thus, an individual's tympanic temperature is considered to directly reflect his or her core temperature (11) and was used as the gold standard in this study. These thermometers were stabilized before the measurements were taken. The calibration of the thermometers was checked by the Quality and Technology Supervision Bureau in Ningbo, China. They were calibrated according to the Calibration Specification of Infrared Thermometers for Measurement of Human Temperature (JJF1107-2003).

Statistical analysis

Power calculations were performed to determine the sample size needed. The following parameters were used: a power of 90%, an α-error level of 0.05, a standard deviation of 1 °C and a potential allowable error of 0.2 °C. Considering a 10% possibility of dropouts and otherwise missing data, it was determined that at least 293 subjects were needed for our study.

Continuous variables are expressed as the mean ± standard deviation (SD), and categorical data are expressed as the frequency and proportion. The agreement between the tympanic temperature and the wrist and forehead temperatures were analyzed by Bland–Altman analysis (12). The resulting plot shows three superimposed horizontal lines. The red dashed line highlights the mean bias among all paired measurements. The black dashed line marks the upper and lower 95% limits of agreement (LoA). A temperature deviation of 0.5 °C was considered clinically acceptable (13). A tympanic temperature of ≥ 37.3 °C was defined as the cut-off point for fever. Statistical analyses were conducted using R version 3.5.1 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Participants

In this prospective observational study, 528 participants were enrolled. Figure 1 summarizes the characteristics of the participants. The mean age was 46.7 ± 16.4 yr. 69.4% (*n* = 297) of the participants were males, and 78.2% (*n* = 413) were patients (Table 1). The mean forehead, wrist, and tympanic measurements were 35.6±1.2 °C, 35.7±0.8 °C, and 36.6±0.6 °C, respectively. There were 44 indoor patients with fever. The data of the outdoor participants were collected on Feb 14th, 15th, and 17th in 2020. The mean outdoor temperatures were 13 °C, 14 °C, and 7 °C on these days, respectively.

Table 1: Demographic characteristics of the participants

Variables	*Total (n = 528)*
Age (yr)	46.7 ± 16.4
Sex, male, n (%)	297 (69.4%)
Environment	
Indoor patients, n (%)	261 (49.4%)
By foot, n (%)	120 (22.7%)
By bicycle/electric vehicle, n (%)	39 (7.4%)
By car, n (%)	56 (10.6%)
As a passenger in car, n (%)	52 (9.8%)
Patients	
Yes, n (%)	413 (78.2%)
Forehead temperature, °C	35.6 ± 1.2
Wrist temperature, °C	35.7 ± 0.8
Tympanic temperature, °C	36.6 ± 0.6

Bland-Altman comparison among the participants in different environments

Table 2 shows the mean temperatures and Bland-Altman analysis results for the participants in different environments. Compared with the tympanic temperatures, used as the gold standard, the forehead measurement had a mean difference ranging from -1.72 to -0.56 °C, and the wrist measurement had a mean difference ranging from -0.96 to -0.61 °C. We observed smaller variability in the temperature measurements at the wrist than at the forehead.

Table 2: Bland-Altman comparison among the participants in different environments

Environment	*Method*	*Mean temperature (℃)*	*Bland-Altman comparison (℃)*		
			Mean difference	*95% prediction interval*	*Proportion of Differences within 0.5 °C*
Indoor patients	Tympanic	36.8	reference		
	Wrist	35.8	-0.96	(-2.70—0.77)	41.4%
	Forehead	36.2	-0.56	(-1.91—0.80)	57.1%
By foot	Tympanic	36.3	reference		
	Wrist	35.4	-0.86	(-2.05—0.34)	72.5%
	Forehead	34.6	-1.72	(-4.07—0.64)	22.5%
By bicycle/electric vehicle	Tympanic	36.0	reference		
	Wrist	35.5	-0.61	(-2.14—0.93)	56.4%
	Forehead	34.6	-1.49	(-3.82—0.84)	48.7%
By car	Tympanic	36.6	reference		
	Wrist	35.7	-0.93	(-1.43—-0.44)	91.1%
	Forehead	35.4	-0.92	(-1.47—-0.36)	85.7%
As a passenger in car	Tympanic	36.7	reference		
	Wrist	35.8	-0.85	(-1.54—-0.15)	94.2%
	Forehead	35.8	-1.13	(-2.41—0.16)	80.8%

The outdoor participants were divided into four groups: those who arrived at the hospital by foot, by bicycle/electric vehicle, by car, or as a passenger in a car. For those who walked, the limits of agreement were between -2.05 and 0.34 °C for the wrist and ear and between -4.07 and 0.64 °C for the forehead and ear (Fig. 2A, B). For those who rode bicycles or drove electric vehicles, the limits of agreement were between -2.14 and 0.93 °C for the wrist and ear and between -3.82 and 0.84 °C for the forehead and ear (Fig. 2C, D). For those transported by car, the limits of agreement were between -1.43 and -0.44 °C for the wrist and ear and between -1.47 and -0.36 °C for the forehead and ear (Fig. 2E, F). For those who were inside a car, the limits of agreement were between -1.54 and -0.15 °C for the wrist and ear and between -2.41 and 0.16 °C for the forehead and ear (Fig. 2G, H). The wrist temperature had a narrower 95% limits of agreement than the forehead temperature. The wrist measurements had a higher percentage of differences that were within ±0.5 °C than did the forehead measurements in these four groups.

For the indoor patients, the limits of agreement were between -2.70 and -0.77 °C for the wrist and ear and between -1.91 and 0.80 °C for the forehead and ear (Fig. 3). The forehead measurements had the most values that were within ± 0.5 °C (57.1%), followed by the wrist measurements (41.4%). We also explored the agreement between the left and right wrist measurements (Fig. 4). The mean bias was 0.00. The limits of agreement for the wrist and ear were between -0.74 and 0.74 °C. This result showed good agreement between the right and left wrist measurements.

Receiver operating characteristic (ROC) curves for the detection of fever

We generated ROC curves for the indoor patients for detecting tympanic temperatures of ≥37.3 °C. Figure 5 shows the comparison between the wrist and forehead measurements for the detection of fever. Both measurements had significant abilities to screen patients for fever (wrist: AUC 0.790; 95% CI: 0.725–0.854, P<0.001; forehead: AUC 0.816; 95% CI: 0.757–0.876, P<0.0001). The cut-off value for the wrist measurements for detecting tympanic temperatures of ≥37.3 °C was 36.2 °C, with 86.4% sensitivity and 67.0% specificity. The best threshold for the forehead measurements was also 36.2 °C, with 93.2% sensitivity and 60.0% specificity.

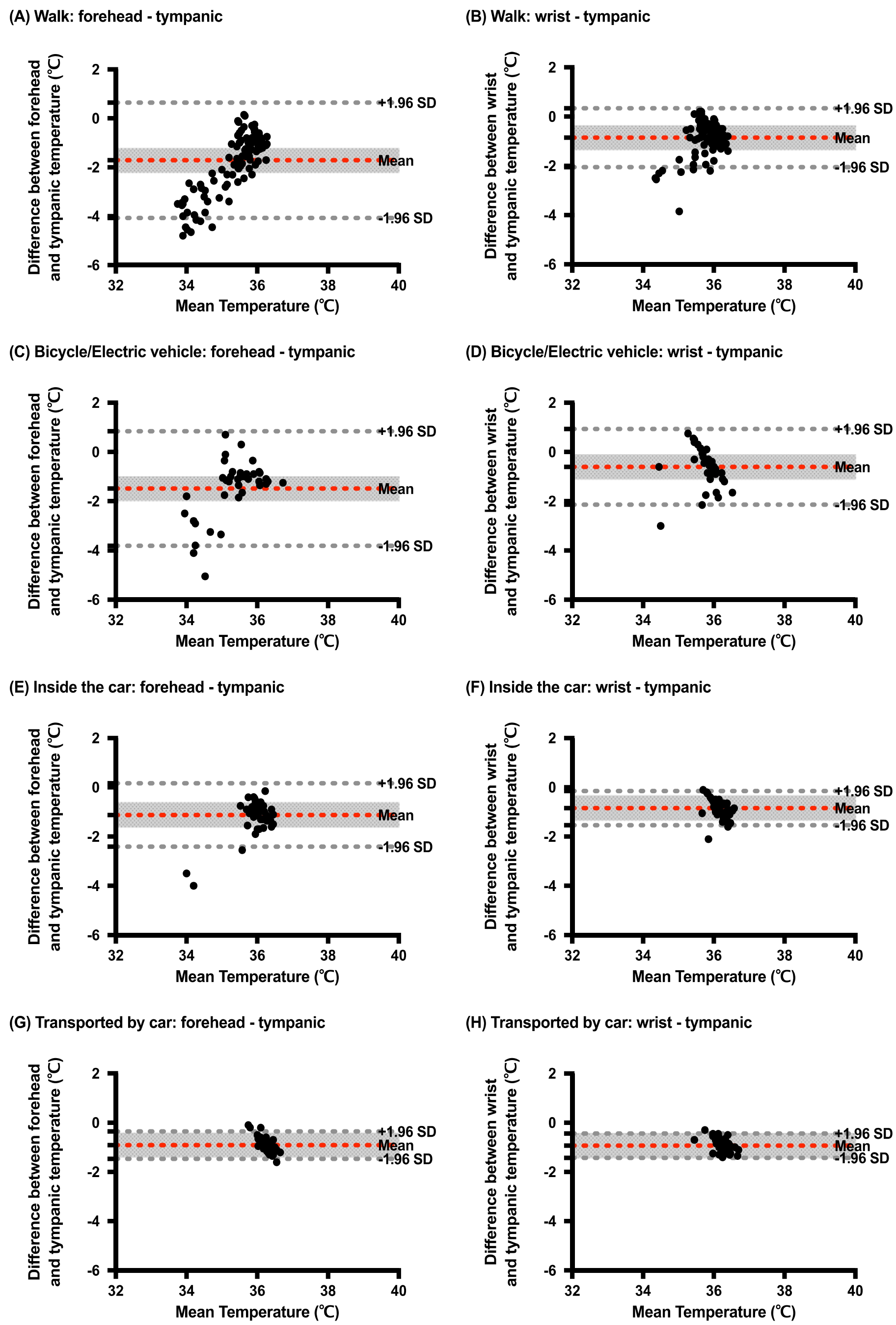

Fig. 2: Bland-Altman comparison between the tympanic temperature and wrist and forehead temperatures. The X axis corresponds to the mean temperature of each method. The Y axis corresponds to the difference between the tympanic temperature and wrist and forehead temperature. The red dashed line shows the mean bias. Black dashed lines show the 95% limits of agreement. (A), (B) the participants who walked; (C), (D) those who used bicycles/electric vehicles; (E), (F) those transported by car; and (G), (H) those who were inside a car

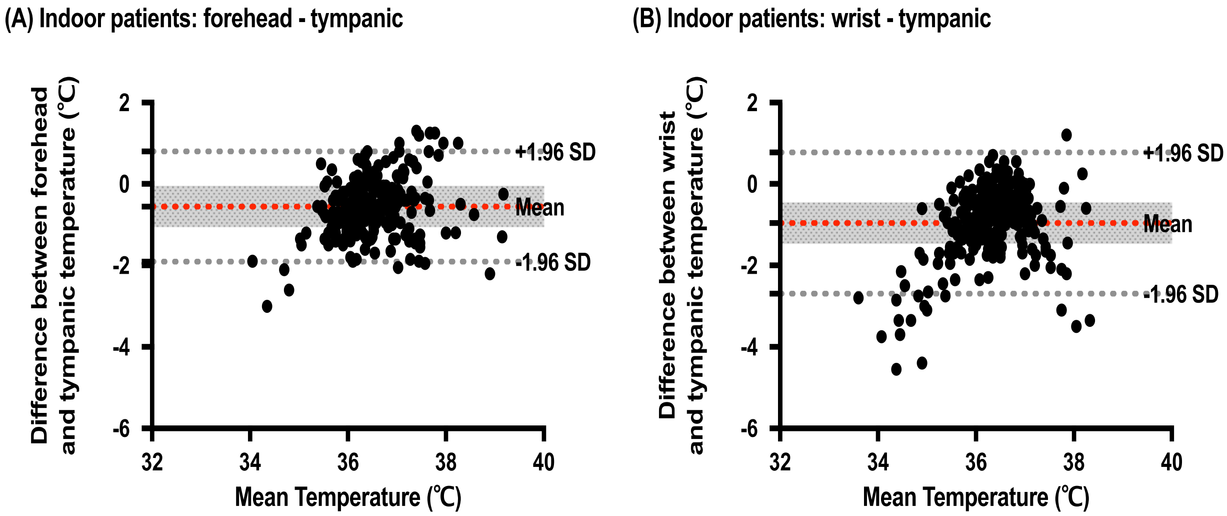

Fig. 3: Bland-Altman comparison between the tympanic temperature and wrist and forehead temperatures for indoor patients. The X axis corresponds to the mean temperature of the wrist and forehead and the ear. The Y axis corresponds to the difference between the tympanic temperature and wrist and forehead temperatures. The red dashed line shows the mean bias. The black dashed lines show the 95% limits of agreement

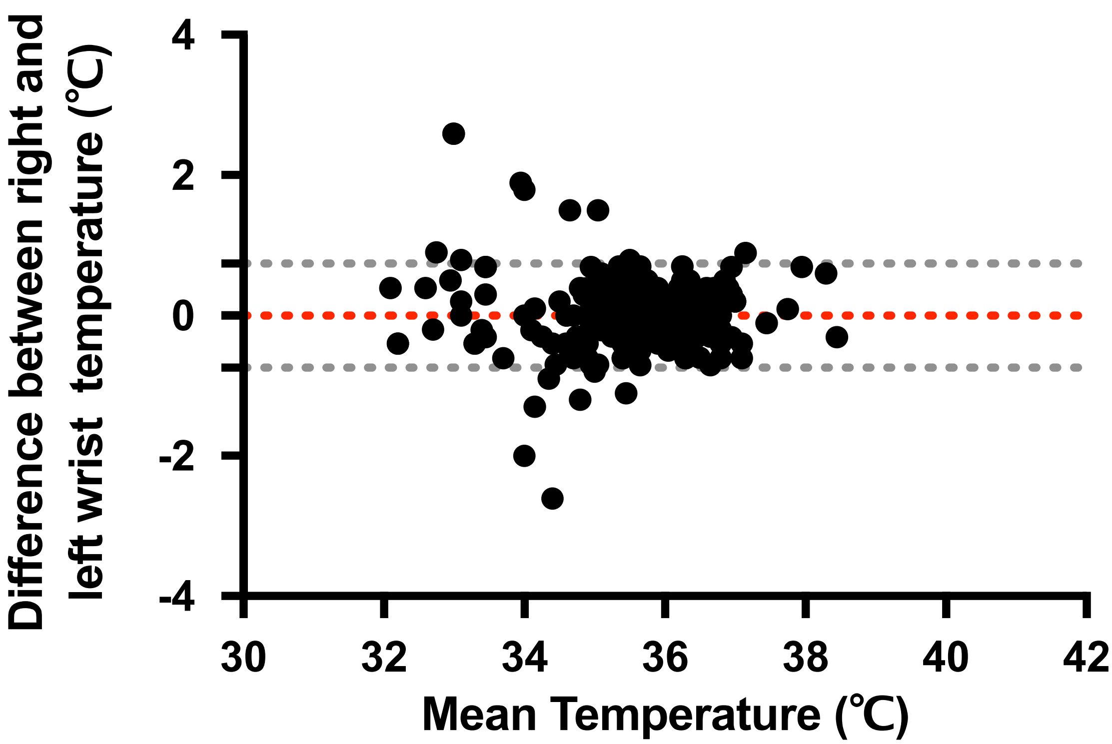

Fig. 4: Bland-Altman comparison for left and right wrist. X axis is the mean temperature of left and right wrist. Y axis is the difference of left and right wrist. Red dashed line showed mean bias. Black dashed lines showed 95% limits of agreement

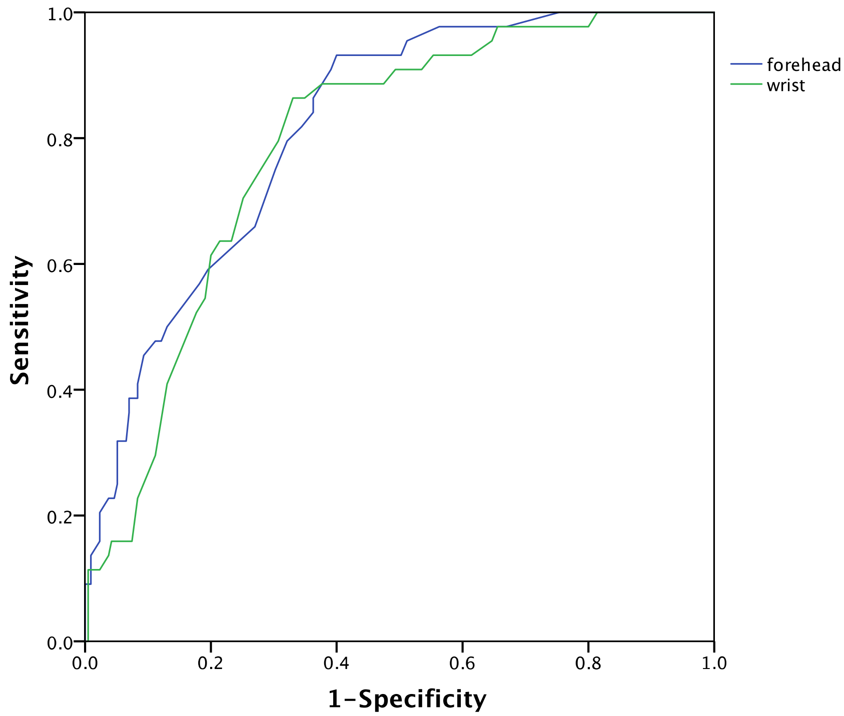

Fig. 5: The receiver operating characteristic (ROC) curves for the detection of fever

Discussion

In this prospective real-world study, we found that wrist temperature measurements are more stable than forehead measurements taken using NCITs under different circumstances in outdoor participants. Both measurements had significant abilities to screen indoor patients for fever. The cut-off values for the wrist and forehead temperatures were both 36.2 °C. They showed good sensitivity. These results may assist in fever screening in the population, especially during the outbreak of COVID-19. To the best of our knowledge, this study was the first to explore the reliability and validity of wrist and forehead temperature measurements in mass screening.

Axillary and rectal temperatures are considered the gold standards in clinical practice (14, 15). However, these measurements are impractical for large-scale screening. Time-efficient and minimally invasive tools are needed. IRTTs and NCITs are being applied in the general population during the epidemic. Many plastic covers have been disposed of, which may increase the financial burden. In China, each disposable plastic cover costs 1–2 RMB (approximately 0.2 dollars). In addition, indirect contact increases the risk of cross-infection. Forehead temperature measurements have been used for widespread population screening using NCITs. However, they can be affected by a person's physiological and environmental conditions (8, 16). The forehead temperature of 23 participants was considered "low" in our study. All measurements were taken on the same day (Feb 17th, 2020) with an outdoor temperature of 7 °C. Thus, we chose the wrist temperature as an alternative, especially in the winter, when mass screening is needed. Wrist measurements correspond to a peripheral temperature recorded at 10 cm above the palmar side of the wrist. We expected the wrist measurements recorded to be lower than the tympanic measurements. However, the wrist area was covered by clothing all day. It was influenced by environmental conditions less than the forehead. Our study showed that the wrist measurements were more stable for participants under different circumstances than the forehead measurements. Measurement stability is important for mass screenings in the open air during the outbreak of COVID-19. The ROC curves showed that wrist and forehead measurements had significantly higher abilities to screen patients for fever. The cut-off value of both measurements was 36.2 °C. The results can be applied in clinical practice and standardize both the applicability and performance of the thermometers.

The strengths of this study include its large sample size and prospective design in a real-world setting. There are several limitations. First, it is difficult to quantify physiological and environmental conditions. Second, only one brand of thermometer was used in this study. It is uncertain whether the results can be generalized to all brands of thermometers on the market.

Conclusion

Wrist measurements are more stable for participants under different circumstances than forehead measurements. Both measurements had significantly high fever screening abilities for indoor patients, and the cut-off value of both measurements for fever was 36.2 °C. Additional studies are needed to explore the validity and accuracy of wrist temperature measurements.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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