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Temperature thresholds and screening of febrile people by non-contact measurement of the face using infrared thermography – A methodology proposal

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ABSTRACT

Recent outbreaks of infectious diseases such as Covid-19 that have fever as one of the symptoms drive the search for systems to track people with fever quickly and non-contact, also known as sanitary barriers. The use of non-contact infrared-based instruments, especially the infrared thermal imager, has widely spread. However, the screening process has presented low performance. This article addresses the choice of regions of interest on the human face for the analysis of the individual's fever, deals with the temperature thresholds used for this analysis, as well as the way to issue the recommendation to screen the person or not. The data collection and statistical analysis of temperatures of 198 volunteers allowed us to study and define the most appropriate face regions as targets for these barriers, as well as the temperature thresholds to be used for screening for each of these regions. Besides, the paper presents a probabilistic method based on the metrological quality of the sanitary barrier to the emission of recommendation for screening potentially febrile people. The developed method was tested in feverish and non-febrile volunteers, showing complete assertiveness in the tested cases.

1. Introduction

Recent outbreaks of infectious diseases, such as severe acute respiratory syndrome (SARS) in 2003, influenza A (H1N1) in 2009, Ebola virus disease (EVD) in 2014, which have fever as one of the symptoms, demand technological tools for screening of febrile people. Some situations require measuring instruments whose approaches occur without the need for physical contact, quickly, with reasonable reliability, and without the need for sterilization. The pandemic of Covid-19 (Corona-Virus – Disease-2019) has boosted the search for these systems to track possibly infected people, aiming to reduce the disease transmission. Faced with this scenario, management of places such as airports, shopping malls, schools, and others are implementing sanitary barriers to detect feverish people, preferably using non-contact infrared based instruments (NCIR-based), such as thermal imagers and pyrometers, to measure body temperature [1–11].

Temperature measurement in humans and animals for disease detection is usually performed by measuring core body temperature by rectal, vaginal, vascular or digestive tract via sensors [12], that is, invasively. However, NCIR-based instruments have been widely used in these febrile screening systems. Its working principle is based on the theory that every object with a temperature above absolute zero (0 K or −273.15°C) emits radiation that propagates in the infrared region of the electromagnetic spectrum. These instruments capture this infrared radiation and perform calculations that correlate this radiation to the surface temperature of the analyzed body [13]. In the case of the pyrometer, which is one of the most used types of infrared thermometers in sanitary barriers, there is only one detector responsible for capturing this radiation, so the measurement is performed at only one point on the surface of the analyzed body. On the other hand, thermal imagers have

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thousands of detectors responsible for capturing this radiation and the instrument's return, instead of a single temperature value, is a two-dimensional thermal image that graphically represents the different temperatures of the surface of the analyzed body [5–7,14].

However, several studies have pointed out that the screening of febrile people by temperature measurement using NCIR-based instruments has low reliability, with a high rate of false negative diagnoses [15–18]. Fever, whose characteristic is an elevation of the body's thermal threshold usually maintained around 37°C, triggers metabolic responses of heat production and conservation, for example, tremors and peripheral vasoconstriction. These responses help raise body temperature to a new threshold. After the fever is resolved or treated, the threshold returns to the initial point and the processes of heat loss, like peripheral vasodilation and sweating, begin. In the febrile response, thermoregulation is preserved usually at a higher temperature level [19,20]. The temperature threshold to determine whether a patient is in a feverish state varies among different authors. However, the most adopted thresholds for core body temperature are 37.5°C [21–23] and 38.0°C [24–26].

In a sanitary barrier, surface or peripheral temperatures of the human body are measured, instead of the core temperature. The peripheral concerns the temperatures of more external organs, such as the skin, muscles, and subcutaneous tissues, while the core temperature refers to internal body temperatures, such as the cranial, thoracic, and abdominal cavities [27–29]. While the hypothalamus regulates the core temperature, external influences, such as ambient temperature, air humidity and radiation affect the face temperature. In this case, the core temperature remains constant in healthy individuals, while the surface temperature may considerably vary. This fact can generate surface temperature measurements that do not effectively correspond to the core temperature [27,30].

Besides natural variations, surface temperatures are lower than the core temperature [3,31–34]. Thus, adopting core body temperature thresholds for the diagnosis of fever from surface temperature measurements is not an adequate procedure.

The gold standard for temperature measurement considers core temperature, which is commonly measured in the rectum, esophagus, or intestinal tract [30,35,36]. However, the aforementioned methods are invasive and not applicable in environments such as a sanitary barrier, whose aim is to identify possible febrile individuals quickly, reliably, and safely.

Some sanitary barriers that use NCIR-based instruments measure the maximum temperature on the person's face and compare it to a reference, issuing an eventual recommendation to separate the person for analysis of febrile status [37,38]. It turns out that the different surface parts of the head have different typical temperatures [39,40], therefore, a single temperature threshold criterion is not recommended for the analysis of possible fever. Sanitary barriers based on NCIR-based instruments have presented sensitivity from 44% to 75% [22,26].

For the surface of the human face, regions that present better conditions for the analysis of the person's fever are already known. Such areas have a greater correlation with the core temperature and less variability due to external influences. These regions of interest (ROIs) are the corner of the eye (inner eye), the ear cavity, and the forehead [34,40–43]. In sanitary barriers that aim to influence the flow of people as little as possible, it is not convenient to ask passers-by to stop and expose the ROIs. Thus, eventually hair, respiratory masks, glasses, or other shields to the propagation of infrared radiation may cover some ROI [44,45]. Therefore, it is important to have all ROIs in the NCIR-based instrument's field of view, so that, the measurement of the surface temperature of at least one ROI is possible.

This research experimentally evaluated suitable temperature thresholds for the different ROIs of sanitary barriers using NCIR-based instruments, as well as proposing a screening criterion for potentially febrile people based on the probability of their core temperature being above the thresholds traditionally applied.

2. Methodology

This work is a quantitative study of a descriptive nature, about which temperature values of regions of interest (ROIs) should be adopted as thresholds for screening potentially febrile people. It is applied research since it aims to generate knowledge to improve the performance of sanitary barriers.

The Research Ethics Committee of the Federal Institute of Espírito Santo, linked to the National Research Ethics Commission of the Ministry of Health of Brazil, approved this research under the Certificate of Presentation and Ethical Appreciation (CAAE) 33502120.2.0000.5072, opinion number 4.180.201, on 29 July 2020.

The volunteers who participated in this research were informed about the objectives, the scope of their participation, the confidential treatment of their data, and the consolidated statistically grouped method of disclosing data. The volunteers who participated in this research were informed about the objectives, the scope of their participation, the confidential treatment of their data, and the consolidated statistical grouped method of disclosing data. All participants provided written permission.

The inclusion criterion considered the volunteers 18 years old or older and the signature on the consent term of free participation without any burden or bonus for the volunteer or researchers, with the possibility of withdrawing from the study at any time.

This research complied with the ethical principles contained within the Declaration of Helsinki of the World Medical Association.

2.1. Materials and methods

Although recommendations for human thermography point to controlled conditions; such as atmospheric temperature and relative humidity, person atmosphere, thermal imager resolution and uncertainty; the sanitary barriers currently in use are intended to be quick, non-invasive, and affordable cost. More eminent thermal imager manufacturers have commercialized instruments with an uncertainty of 2% or 2°C [37,46,47], as well as recommending ordinary calibration procedures based on [48,49], despite the existence of specific calibration procedures for human thermography [38,43,50,51]. Thus, aiming to reproduce the conditions usually used, this research considered thermal imagers with characteristics similar to those marketed and recommended by large manufacturers for use in sanitary barriers and their calibration procedures.

Two thermal imaging cameras, Flir E60® and Testo 885®, were used to capture thermal images of each volunteer. Table 1 shows the model, resolution and precision of the instruments used [52,53].

Taking into account that in the literature, there is no consensus on the value of skin emissivity, and the authors adopt values between 0.95 and 0.99, in this study, the authors adopt the value of 0.98 of emissivity for parameterization of thermal imagers used [54–57].

In addition, to correct the systematic errors of the thermal imagers used in the study, the calibration procedure of these equipment was carried out from a calibrated black body as the true value, i.e., the physical object that is characterized by having an emissivity of 1.0, which means that it perfectly absorbs 100% incident thermal irradiation and radiates 100% own thermal radiation [38]. The adopted calibrated temperature range was compatible with the expected human temperatures, defined as (30 to 40)°C. Five calibration points were adopted, with double measurements, varying the blackbody temperature value up and down. This procedure was repeated 10 times [58].

Table 1
Measuring instruments used in the research.

Brand	Model	Resolution (°C)	Precision
Flir®	E-60®	0.1	2%
Testo®	885®	0.1	2%

Carrying out the calibration procedure and subsequent correction of the thermal imager's measurement tendency makes it possible to reproduce this methodology in any sanitary barriers. The systematic measurement errors were corrected, leaving only random errors, also known as uncertainty. Systematic errors were virtually the same as those found in previous calibrations performed in the previous two years. The expanded uncertainty to a 95% confidence level, or random error, was 0.3°C, also similar to previous calibrations. Even considering that the calibration only portrays the momentary condition of the measuring instrument, it is noted that the instruments demonstrate stability in this regard over time. Furthermore, the influence of the thermal imager uncertainty on the measurement result is much smaller than the influence of the emissivity uncertainty [59].

Considering the analysis of the surface temperature of the human face, at sanitary barriers where passers-by may have body parts covered by glasses, masks, hair, etc., which can act as a shield for the NCIR-based instrument, the authors adopted the three ROIs for this study: temporal and supratrochlear commissure (forehead), medial palpebral commissure (corner of the eye) and external auditory meatus (ear canal). Fig. 1 highlights these ROIs. In the experiment to capture the thermographic images, the adopted distance between thermal imagers and volunteers was of 1.5 m. This distance is feasible in sanitary barriers and adequate to the optical focus and angular resolution of the thermal imagers used. The procedure captured three images of each volunteer aiming to obtain data covering the different ROIs: frontal, left lateral and right lateral.

Source: elaborated by the authors.

The software used to manipulate these images provides the three temperatures of delimited area: average, maximum and minimum. Regions containing hair, clothing, or background scenes naturally experience lower temperatures. Therefore, to avoid these interferences, the chosen temperature value for each ROI was the maximum within its respective area. Based on these assumptions, it was possible to create a database with consistent information about volunteer temperatures.

In this work, the ROIs were manually delimited in each thermogram. However, this research team has already developed an automatic detection system of the defined ROIs based on computer vision, which has achieved above 95% of accuracy [60]. This software will be integrated with the other developed systems.

The study has as base information obtained from 198 non-febrile volunteers, aged 18 years or older, from August 2020 to January 2021, in the Metropolitan Region of Grande Vitória / ES, Brazil. Given the difficulty in recruiting volunteers during the Covid-19 pandemic due to the recommendations for isolation and social distancing established by the Ministry of Health of Brazil, this 198 volunteer amount is considered excellent for metrological and statistical purposes [61].

The method of estimating the probabilistic temperature characteristics of ROIs of non-febrile persons and classifying persons who have a temperature higher than these characteristics was adopted for the following reasons: infeasibility of recruiting a significant sample of feverish volunteers given the determinations of isolation of people during the COVID-19 pandemic, and of immediate administration of antipyretic drugs, minimizing fever; guidance from the Ministry for symptomatic patients to avoid going to health centers, except in cases of more severe symptoms; debilitated state of febrile patients who refused to volunteer for research. In two months of volunteer's recruitment only four people in feverish situation were identified. Given the scarcity of feverish volunteers, this lower sampling of febrile people was used to test the developed methodology. Cases of small availability of volunteers for the construction or evaluation of biomedical equipment have been recurrent and have not made the research unfeasible [62–64].

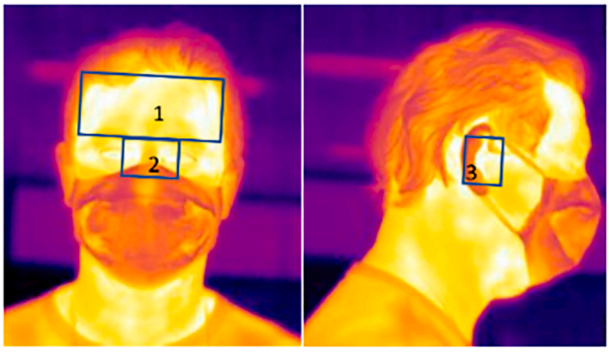

Fig. 1. Regions of interest (ROIs) for the research: 1 – temporal and supratrochlear commissure (forehead); 2 – medial palpebral commissure (corner of the eye); 3 – external auditory meatus (ear canal)

Although some authors claim that it is possible and others correlate ROI surface temperatures with core body temperature [32,39,65], this research team chose to analyze the temperature of each ROI separately, without correlating them with core body temperature, since the team intends to embed this method to other algorithms developed, as well as further procedures under development in a single device. This proposal eliminates a data processing stage, decreasing the combined uncertainty of the final result, as well as the computational effort. Furthermore, several studies have shown that temperature measurement in ROIs is suitable for screening febrile persons [26,33,38,39].

Table 2 lists the locations where experiments with volunteers were performed.

Screening systems for febrile people need agility, therefore, they do not investigate individual characteristics of passers-by. In addition, these systems must operate in different types of buildings, at any time and day of the week. This experiment tried to reproduce the same situation. Thus, the temperature measurements took place at different times and establishments, taking the temperature of male (87 volunteers) and female (111 volunteers) volunteers. In addition, human surface temperatures vary mainly as a function of the circadian cycle, external factors, and the person's previous resting condition [31,32,40,43]. Likewise in sanitary barriers, these factors were not controlled in this experiment.

Aiming to classify non-febrile and potentially febrile people, the temperature values obtained from the volunteers were used to determine a specific temperature threshold for each ROI. Thus, to calculate the probability of the passers-by being feverish, their ROIs' measured temperature and their respective uncertainties must be compared to the corresponding screening thresholds.

3. Results

Table 3 shows the mean of the maximum temperatures for each

Table 2
Volunteer approach and temperature measurement locations.

Establishment		City	Number of volunteers
Name	Type		
IFES – Campus Vitória	Teaching and Research Institution	Vitória/ES	20
Edifício Wimbledon	Residential Condominium	Vitória/ES	10
Thermovit Center	Physiotherapy's Clinic	Vitória/ES	8
Construtora PauloOctavio	Civil Construction Site	Vitória/ES	2
Igreja Sagrada Família	Church	Vitória/ES	53
Igreja Universal do Reino de Deus	Church	Vitória/ES	24
Igreja Batista da Lagoinha	Church	Vitória/ES	12
MasterPlace Mall	Mall	Vitória/ES	54
3 D Centro de Treinamento	Gymnastics Academy	Cariacica/ES	25
Total of volunteers			198

Table 3
ROI temperatures of the face of non-febrile volunteers.

ROI	Maximum temperatures of ROIs		
	Average	Standard deviation	Coefficient of variation
R-EAM	35.6°C	0.9°C	2.5%
L-EAM	35.6°C	0.8°C	2.3%
MPC	35.2°C	0.9°C	2.6%
Forehead	34.4°C	1.1°C	3.2%

region of interest on the face of the 198 non-febrile volunteers: right external auditory meatus (R-EAM), left external auditory meatus (L-EAM), forehead, and medial palpebral commissure (MPC). The coefficient of variation enables a comparison between groups with different mean values [66].

The R-EAM, L-EAM and MPC regions have a lower coefficient of variation when compared to the forehead. Therefore, they are more suitable ROIs since, with less variation, it is possible to establish a more accurate temperature threshold to separate febrile from non-febrile people. However, in actual sanitary barrier, it is not rare that only the forehead can be visible, naked, and accessible to the thermal imager's field of view. Since it is common to use half-face masks, long hair over the ears, furry ears and glasses. Thus, despite having inferior performance in terms of confidence interval, the forehead cannot be ruled out as a ROI.

The *Z*-Test was carried out to verify statistically whether it is possible to say, whether the ROIs have significantly different temperatures when compared to each other. Table 4 displays the comparison among the ROIs and the corresponding *p*-value. The ROI taken as a reference is arranged vertically, and the ROIs whose temperature is compared to the reference ROI are laid out horizontally. If the *p*-value is lower than 0.05, the evaluated ROI has a temperature significantly greater than the reference ROI, with a confidence level of 95%.

We can verify that the temperatures of both ear canals (R-EAM and L-EAM) are predominantly higher than the temperatures of the other ROIs. The temperature of the left ear canal tends to be higher than that of the right ear canal, however, this trend cannot be certified, given the statistical conditions established. Notice that the eye corner temperature (MPC) is higher than the forehead temperature. In conclusion the typical surface temperatures of the different ROIs adopted for the human face are significantly different from each other, even though the temperature of each ROI is correlated with the core body temperature, agreed as unique. Therefore, the criterion based on a single temperature threshold value for all ROIs is not recommended for screening potential febrile people.

3.1. Temperature thresholds for screening febrile people

Since the different established ROIs have different typical temperatures for non-febrile people, it is necessary to adopt different threshold temperatures for screening potentially febrile people.

Establishing a temperature threshold to separate febrile from non-febrile people entails running the risk of classifying some non-febrile people as febrile and vice-versa.

Considering the coefficients of variation of the experimental results presented in Table 3 and international metrological recommendations [48], the 95% confidence level was adopted, which means that there is the risk of classifying 5% of non-febrile people as febrile is admitted.

The statistical tool used to interpret the temperatures of non-febrile people was the one-tailed Student's *t*-test, with a confidence level already established at 95% one-tailed. For the number of samples in this study, $n = 198$, the t-statistic value $t_{STUDENT}$ is 1.645 [66]. To determine the threshold temperature for screening febrile people, the equation Eq. 1 was used [66]:

$$T_{SCREENING} = T_{AVERAGE} + SD.t_{STUDENT} \quad (1)$$

Where $T_{SCREENING}$ is the threshold temperature for suspected febrile state; $T_{AVERAGE}$ is the typical average temperature of the ROI as per the Table 3; SD is the standard deviation of typical ROI temperature as Table 3 shows; $t_{STUDENT}$ is the t-statistic for the desired one-tailed confidence level.

Table 5 shows the proposed threshold temperatures for screening febrile persons for each ROI.

Notice that for all the ROIs studied, the proposed fever threshold temperature is lower than the value adopted when measuring the human body's core temperature, 37.5°C or 38.0°C.

Fig. 2 shows the normal distribution of the temperature for the R-EAM, the adopted threshold of 37.1°C. The shaded area, in black color, corresponds to the assumed risk of a 5% chance of classifying a non-febrile individual as febrile.

3.2. Screening method for febrile people

When measuring the temperature of a passerby by an NCIR-based instrument, the value obtained has an associated standard uncertainty, relative to the instruments and measurement methods used, typically on the order of (1.6 to 1.9)°C, considering the state-of-the-art knowledge of human skin emissivity, and thermal imager "precision" of the order of (1 to 2)°C [67]. The thermal imager calibration procedures adopted in this research, and mentioned in Section 2.1, indicate a "precision" of the order of 0.3°C for the considered temperature measurement range. This same magnitude order as also adopted for the standard uncertainty of the measurement. Therefore, it is the responsibility of the users to estimate the standard uncertainty to be associated with their measurement system [48].

Thus, the temperature measurement of one or more ROIs of a passerby, which consists of its base value associated with a standard uncertainty, should be compared to the temperature thresholds of febrile people presented in the Table 5. This means that the probability of a person has a fever corresponds to the probability that the passerby's temperature is higher than the proposed temperature threshold. And this can be calculated based on the temperature measured in the ROI, its base value, and standard uncertainty.

As an example, the proposed method will be applied to two hypothetical sanitary barriers, one based on a 0.5°C uncertainty thermal imager, and another one of 1.0°C. Six hypothetical passers-by will be analyzed whose ROI MPC temperatures would be (35.5; 36.0; 36.5; 37.0; 37.5; and 38.0°C). The method consists of, for each passerby, for each sanitary barrier, plotting its temperature probability curve, in a similar way to Fig. 2, identifying the temperature threshold for a feverish state in this curve, and calculating the probability of the passerby's temperature being above this threshold, which is represented by the black hatched area in Fig. 2.

The results in Table 6 show that when the sanitary barrier has greater

Table 4
Comparison of temperatures in different regions using the *Z*-Test.

REFERENCE ROI	ROI COMPARED TO REFERENCE ROI		
	L-EAM	R-EAM	MPC
R-EAM	0.162	–	–
MPC	5.14×10^{-18}	1.42×10^{-13}	–
Forehead	1.10×10^{-104}	9.20×10^{-89}	1.07×10^{-33}

Table 5
Temperatures for screening possibly febrile people.

ROI	Fever temperature threshold
R-EAM	37.1°C
L-EAM	36.9°C
MPC	36.7°C
Forehead	36.2°C

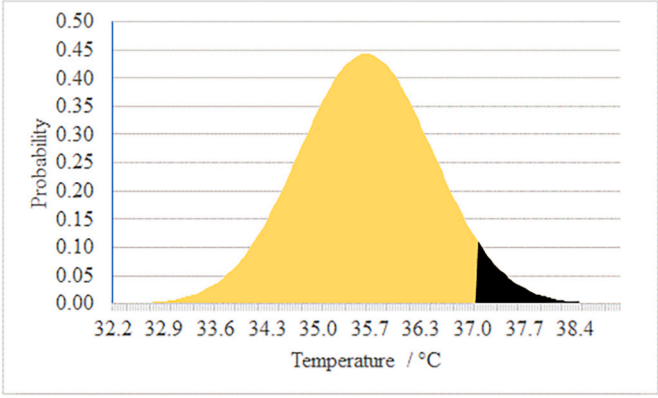

Fig. 2. Temperature distribution for the right external auditory meatus – R-EAM (mean = 35.6°C; standard deviation = 0.9°C; temperature threshold for feverish state = 37.1°C).
Source: Elaborated by the authors.

Table 6
Example of calculating the probability of fever with temperature measured at the Medial Palpebral Commissure (MPC), whose fever threshold is 36.7°C.

Measured temperature	Standard uncertainty of the used sanitary barrier	
	0.5°C	1.0°C
35.5°C	0.8%	11.5%
36.0°C	8.1%	24.2%
36.5°C	34.5%	42.1%
37.0°C	72.6%	61.8%
37.5°C	94.5%	78.8%
38.0°C	99.5%	90.3%

measurement uncertainty, it tends to issue a diagnosis of greater probability of fever when the person's temperature is lower than the screening threshold temperature. On the other hand, when the person's temperature is above the threshold temperature, the less accurate barrier tends to give diagnoses whose fever probability is lower than 100%. Hence the importance of minimizing the measurement uncertainty of the sanitary barrier.

Notice that in addition to properly estimating the threshold temperature for screening febrile people, as a function of each ROI, it is also necessary to establish a screening criterion by the barrier as a function of the probability of a febrile state. Thus, the criterion to be established by the barrier operator must minimally consider the measurement uncertainty of its barrier, the flow of people, the type of screening environment, and the capacity to attend and treat screened people.

Fig. 3 illustrates the case of measured temperature of 37.0°C in MPC. Figure (a) shows the situation for the sanitary barrier of standard uncertainty of 0.5°C, and Figure (b) for the 1.0°C case. The hatched areas, in black color, indicate the probability of fever, 72.6%, and 61.8%, respectively. It is noted that, for the case of uncertainty of 0.5°C, the probability distribution of the temperature of the individual is closer to the mean, since the quality of measurement is better, bringing a diagnosis with a higher probability of febrile state.

3.3. Test of the proposed method

The proposed model for sanitary barrier was tested with four febrile volunteers and five non-febrile volunteers in the Emergency Health Care of Praia do Suá, Vitória / ES, Brazil, from July to August 2021.

Some factors were responsible for not obtaining a greater number of volunteers, for example, administration of antipyretics to reduce and control fever, not volunteering in the face of the person's debilitated state, and sanitary restrictions on interaction with feverish people.

A health professional previously diagnosed all nine volunteers as febrile or non-febrile, by axillary temperature measurement with a contact thermometer, following the Manchester Triage System (MTS) [68].

The adopted temperature thresholds are described in the Table 5. The standard uncertainty of the temperature measurement has been estimated at 0.3°C. The test results are condensed in the Table 7, which shows the temperatures of the ROIs of each volunteer and their probability of a feverish state according to the proposed.

Notice that for all volunteers previously diagnosed as non-febrile, the proposed sanitary barrier indicated a probability of fever between 0.0 and 1.3%. Considering the low number of test measurements, only four volunteers, this is an expected result since the confidence level adopted was 95%.

During the image capture of feverish volunteers, there were situations in which the ROI was not in direct view of the measuring instrument (thermal imager). In these cases, the angle of sight between the thermal imager and the normal to the inspected surface was not zero, and the measurements were not accurate. Usually, these cases present results lower than the expected values [69]. Such situations eventually occur in sanitary barriers since the passerby can walk with their head positioned in different directions. This situation corroborates the decision to have several ROIs to support the diagnosis, maximizing the

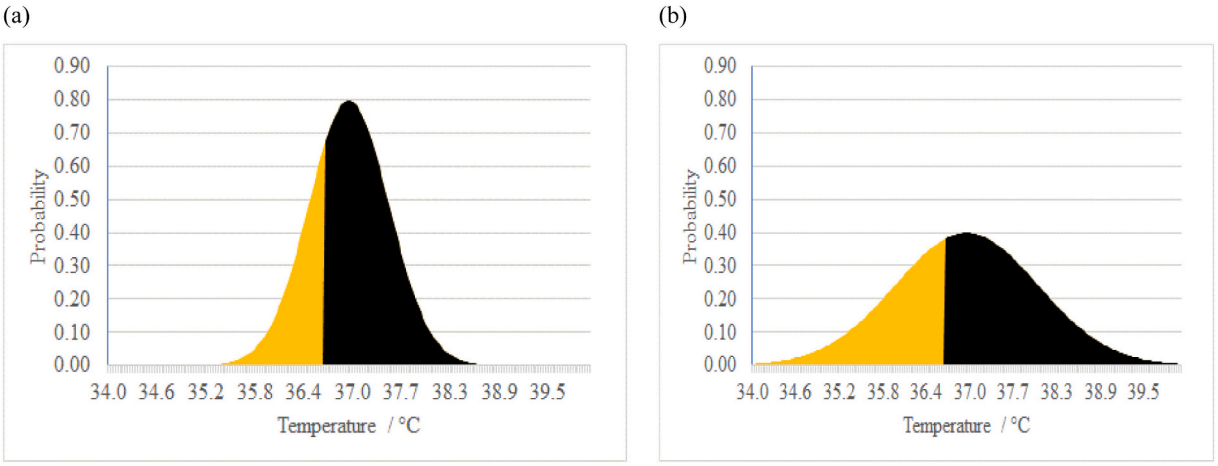

Fig. 3. Probability of a feverish state with a measured temperature of 37.0°C on the medial palpebral commissure (MPC), using a standard uncertainty thermal imager of 0.5°C (a) and 1.0°C (b).
(Source: Elaborated by the authors.)

Table 7
Test of the proposed methodology with feverish and non-febrile volunteers.

Previous diagnosis	Region of interest							
	R-EAM		L-EAM		MPC		Forehead	
	T/°C	Prob	T/°C	Prob	T/°C	Prob	T/°C	Prob
Non-febrile	34.3	0.0%	33.3	0.0%	33.9	0.0%	33.5	0.0%
	33.7	0.0%	34.5	0.0%	34.5	0.0%	33.4	0.0%
	33.8	0.0%	34.9	0.0%	34.6	0.0%	34.1	0.0%
	34.5	0.0%	34.5	0.0%	34.4	0.0%	33.8	0.0%
	35.8	0.0%	35.7	0.0%	36.0	1.3%	34.9	0.0%
Febrile	36.9	(*)20.3%	37.4	94.0%	36.9	69.3%	36.6	93.1%
	38.7	100%	39.3	100%	39.3	100%	39.0	100%
	37.3	70.6%	37.9	99.9%	37.1	88.3%	35.9	(*)18.0%
	37.4	81.2%	37.6	98.7%	37.1	88.3%	36.4	78.8%

Prob: Probability of having a fever. (*): Situation without direct sight between thermal imager and ROI.

possibility that at least one of the ROIs is in direct view of the thermal imager. These events are highlighted with (*) in Table 7. It is worth mentioning that, among the feverish probability recorded in Table 7, all febrile volunteers presented their respective highest values equal to or greater than 94.0%.

4. Conclusions

From the analysis of our database with the surface temperatures of the adopted ROIs, temporal and supratrochlear commissure (forehead), medial palpebral commissure (MPC), and right and left external auditory meatus (R- and L-EAM), the results corroborate the following conclusions:

The ROIs present temperatures different from each other, and a single temperature threshold criterion cannot be adopted for screening febrile persons. This work experimentally analyzed and proposed different criteria for these different regions.

The regions that present the smallest temperature variation among non-febrile individuals are the ears canals (R- and L-EAM). However, these ROIs are not always in direct view of the thermal imager, which can lead to measurement with temperature results considerably lower than the true values. Thus, in an efficient sanitary barrier, without stopping, and adequate positioning of the NCIR-based instrument, it is important to detect and measure the temperature in the greatest amount of ROIs possible, avoiding false-negative diagnoses of febrile state. Therefore, all ROIs must be considered, including those that naturally have lower metrological performance.

The measurement uncertainty of the sanitary barrier influences the screening of febrile people proposed in this work, which is based on an indication of the probability that the person has a fever. Thus, the operator of the sanitary barrier must be aware of the quality of their equipment and estimate their measurement uncertainty, so that they can screen potentially febrile people based mainly on these two parameters.

This work proposed a method of screening febrile people with new approaches: distinct screening temperature thresholds for each ROI; separate temperature measurement at each ROI in the NCIR-based instrument's field of view; consider the quality of the temperature measurement instrumentation, i.e., metrological uncertainty; concluding with the assessment of the probability of the individual being febrile. In this way, several of the limitations and difficulties listed in the scientific literature are mitigated.

Superficial temperature measurement of human beings for screening of febrile persons is feasible through NCIR-based sensors, rather than invasive sensors, under metrological reliability, provided that parameters for analyzing the results are adequate. These parameters should not be the same as those used for measuring core body temperature.

Patient consent

The Research Ethics Committee of the Federal Institute of Espírito Santo, linked to the National Research Ethics Commission of the Ministry of Health of Brazil, approved this research under the Certificate of Presentation and Ethical Appreciation (CAAE) 33502120.2.0000.5072, opinion number 4.180.201, on 29 July 2020.

The volunteers who participated in this research were informed about the objectives, the scope of their participation, the confidential treatment of their data, and the consolidated statistically grouped method of disclosing data. The volunteers who participated in this research were informed about the objectives, the scope of their participation, the confidential treatment of their data, and the consolidated statistical grouped method of disclosing data. All participants provided written permission.

The inclusion criterion considered the volunteers 18 years old or older and the signature on the consent term of free participation without any burden or bonus for the volunteer or researchers, with the possibility of withdrawing from the study at any time.

This research complied with the ethical principles contained within the Declaration of Helsinki of the World Medical Association.

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Authorship

All authors attest that they meet the current ICMJE criteria for Authorship.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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