

# Screening of febrile cows using infrared thermography

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## Research article

**Keywords:** Infrared thermography, smart phone, health monitoring, fever, body regions, surface temperatures

**Posted Date:** December 10th, 2019

**DOI:** <https://doi.org/10.21203/rs.2.18411/v1>

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# Abstract

**Background** As dairy herds increase in size, close monitoring of health becomes a necessity, but this is expensive and labour-intensive. Early detection of febrile diseases is essential for economical and welfare reasons and to prevent the spread of disease. The goal of this study was therefore to evaluate a mobile, non-invasive technique for measuring the body temperature of cows that precludes the need for restraint of the animals. An infrared thermographic imaging camera installed on a smart phone was used to measure the surface temperature of cows. In experiment 1, a metal block heated to defined temperatures was used to obtain infrared thermographic measurements. The accuracy of measurements made at different distances from the block and at two different ambient temperatures was determined. In experiment 2, non-febrile cows in a tie-stall barn underwent infrared thermographic imaging, and the body regions with the highest correlations between thermographic and rectal temperature were identified. In experiment 3, thermographic measurements were made in febrile and neighbouring non-febrile cows.

**Results** In experiment 1, the thermographic and true temperatures of the block had the strongest relationships at 0.5 and 1.0 m ( $r = 0.98$ ). In addition to distance, the ambient temperature had a significant effect on the measurements. In experiment 2, the thermographic measurements at the muzzle ( $r = 0.28$ ), the eye ( $r = 0.37$ ) and the medial canthus ( $r = 0.27$ ) had the strongest relationships with the rectal temperature in non-febrile cows. After correcting the thermographic measurements with the mean difference between thermographic and rectal temperatures of the non-febrile cows, sensitivities of 88, 90 and 82%, respectively, were calculated for thermographic measurements at the muzzle, eye and medial canthus in febrile cows in experiment 3. The corresponding specificities were 6, 23 and 32%.

**Conclusions** Based on the low specificities of the infrared thermographic measurements, the thermographic imaging camera has limited usefulness for the mass screening of dairy cows for febrile conditions. Cattle falsely identified as febrile need to be separated, caught and re-examined, which causes unnecessary stress to the animal and increases labour input.

## Background

There has been a world-wide trend in the dairy industry toward larger herd sizes and a move away from tie-stall barns, which has seen the monitoring of health and wellbeing of individual cows become more demanding. Larger herds require more staff, often hired from outside, and because of financial constraints, for instance those caused by fluctuating milk prices, the care of cows may be left to less-experienced staff [1]. All these factors compel the producer to optimise and professionalise husbandry conditions. These changes have been paralleled by a significant increase in milk production during the last few decades, albeit with a concurrent increase in disease rates [1]. Automation of production and close disease monitoring may aid in overcoming these challenges. Methods that assist in the identification of individual diseased cows in large groups without the need for separation and restraint are essential for efficacious disease monitoring. Several technical approaches have been developed for this based on the detection of deviations in physiological parameters, including feed intake, rumination,

activity, milk conductivity and temperature and others. Determination of body temperature is a central component in the diagnosis of infection and measurement of rectal temperature is a reliable method. However, cows need to be restrained and handled, which is time-consuming and often hazardous in free-stalls or on pasture. Infrared thermography has been proposed as an alternative to rectal temperature measurement in a variety of animal species as well as in people [2–4]. This method allows non-invasive measurement of body temperature without the need for handling of the individual.

Infrared thermographic cameras determine the heat on a body surface by measuring the intensity of the infrared radiation emitted by the body and operate in wavelengths of 780 nm to 1 mm ( $10^6$  nm). The intensity of the radiation correlates with the surface temperature of the individual and is defined by the formula

$$W = \sigma \cdot T^4$$

where W is the intensity of radiation and  $\sigma$  is the Stefan-Boltzmann constant;  $5,67 \times 10^{-8} \text{ W}/(\text{m}^2 \cdot \text{K})$

The emissivity of a black body is 100%, whereas that of skin covered with hair ranges from 93 to 98% [5]. Environmental factors including wind speed and sunlight as well as intrinsic factors, such as stress, physical activity, age and the colour and density of the hair coat, also affect emissivity [6, 7].

The primary objectives of this study were two-fold. The first was to determine whether the exact measurement of the temperature in the body temperature range of a metal block is feasible using a portable thermal imaging camera. The second objective was to investigate whether this method is useful for the differentiation of febrile and non-febrile cows. A secondary objective was to identify the body regions best suited for infrared thermographic imaging.

## Results

### Infrared thermographic temperature of the metal block

Multifactorial anova showed that the factors block temperature, distance between camera and block, and ambient temperature used in the model and interactions had a significant effect on the thermographic measurements (all  $p < 0.0001$ ). Taking into account the independent variables distance and ambient temperature, the following regression equation was obtained:

Block temperature =  $-3.84 + 2.00 \times \text{distance} - 0.54 \times \text{ambient temperature} + 1.39 \times \text{infrared thermographic temperature}$

The thermographic temperatures ( $n = 400$ , including all five temperature levels) differed significantly from the block temperatures at all five temperature levels ( $25^\circ \text{C}$ ,  $p < 0.05$ ; all others  $p < 0.0001$ ) regardless of distance and ambient temperature. There was a close correlation between thermographic temperature and block temperature at all ten distances regardless of ambient temperature (Tab. 1); the highest

correlation coefficient ( $r$ ) of 0.98 was calculated for the distances 0.5 and 1 m. The accuracy (mean deviation ()) of the thermographic temperature from the block temperature) and the precision of the thermographic measurements are shown in Fig. 3 as standard deviation ( $\pm$  SD) of the mean thermographic temperature. With the exceptions of the 25 °C block temperature at the distances of 1.5 to 3.5 m and the 40 °C block temperature at the distance of 0.5 m, there were significant deviations from the block temperature at all temperatures and distances. With respect to ambient temperature, at 14.7 °C all thermographic measurements from all distance-block temperature pairs differed significantly from the block temperature (all  $p < 0.05$ ), and at 23.8 °C, all measurements differed significantly from the block temperatures with the exception of the block temperature of 30 °C at 1.5 to 3 m, the block temperature of 35 °C at 1 m and the block temperature of 40 °C at 0.5 m (Fig. 1).

Table 1 Correlation coefficients ( $r$ ) for the relationship between true temperature and thermographic temperature of a metal block measured from different distances (\*  $p < 0.0001$ )

Distance (m)	$r$
0.5	0.98*
1	0.98*
1.5	0.93*
2	0.92*
2.5	0.91*
3	0.89*
3.5	0.90*
4	0.88*
4.5	0.86*
5	0.83*

## Infrared thermographic temperature in non-febrile cows

The measurements obtained at the eye (medial canthus and  $T_{\max}$ ), flank and tail region, muzzle, coronet and udder at 0.5 and 1.0 m differed significantly from the rectal temperature (all  $p < 0.05$ ).

Regression analysis for each location showed that distance did not have a significant effect on the model, and therefore the data for both distances were pooled for correlation analysis and other calculations. The highest correlations between infrared thermographic and rectal temperatures were calculated for  $T_{\max}$  at the eye ( $r = 0.37$ ), medial canthus ( $r = 0.27$ ) and muzzle ( $r = 0.28$ ) (Tab. 2).

Table 2: Regression analysis for the relationship between infrared thermographic temperatures and rectal temperatures at different body regions of non-febrile cows.

Localisation	Number of measurements	p-value	r	Slope Distance	Slope rectal temperature	Intercept
<b>Eye T<sub>max</sub></b>	1200	< 0.0001	0.37	-1.738	0.144	31.544
<b>Eye medial canthus</b>	1200	< 0.0001	0.27	-1.645	1.206	-10.304
<b>Muzzle</b>	1153	< 0.0001	0.28	-1.276	1.942	-40.383
<b>Coronet</b>	1142	< 0.0001	0.20	-0.882	-0.975	68.776
<b>Udder</b>	1180	< 0.01	0.11	-0.617	0.136	31.504
<b>Tail region</b>	1200	< 0.0001	0.25	-1.199	0.409	21.284
<b>Flank T<sub>max</sub></b>	1200	< 0.0001	0.18	-0.829	0.899	0.672

The mean differences between rectal and thermographic temperatures were smallest for the tail region ( $2.2 \pm 1.3$  °C), the udder ( $2.0 \pm 1.5$  °C) and the eye ( $2.5 \pm 1.2$  °C) (Fig. 2A). The mean differences were  $3.7 \pm 0.2$  °C for the medial canthus (Fig. 2B),  $5.3 \pm 1.9$  °C for the muzzle (Fig. 2C),  $3.8 \pm 1.6$  °C for the flank and  $7.5 \pm 1.7$  °C for the coronet.

The variation coefficient of the thermographic measurements was 1.4% at the eye (maximum difference 1.6 °C), 2.7% at the medial canthus (maximum difference 4.3 °C), 3.1% at the muzzle (maximum difference 4.1 °C), 1.6% at the coronet (maximum difference 1.6 °C), 1.0 % at the udder (maximum difference 1.4 °C), 1.8% at the tail region (maximum difference 2.3 °C) and 0.6% at the flank (maximum difference 1.0 °C).

## Infrared thermographic temperature in febrile and non-febrile cows

At the locations with the highest correlations between rectal and thermographic temperatures in non-febrile cows (eye, medial canthus and muzzle; Table 5), the mean measurements differed significantly between the two groups at 0.5 and 1.0 m (all  $p < 0.0001$ ). The independent factors (rectal temperature, ambient temperature, distance and interactions) only had an effect on the measurements at the medial canthus.

The ratio of febrile cows ( $\geq 39.3\text{ }^{\circ}\text{C}$ ) identified correctly as such was 23.6% for  $T_{\text{max}}$  measurements at the eye, 3.9% for measurements at the medial canthus and 2.1% for measurements at the muzzle. Because of the low ratios, the bias from the Bland-Altman plot calculations (Fig. 2) were added to the thermographic measurements of the febrile and non-febrile cows. There was a systematic difference between rectal and thermographic temperature measurements at all three locations. The inter-rater reliability for measurements at the medial canthus and at the entire eye was classified as slight agreement with a kappa of 0.15. There was no agreement between measurements at the muzzle with a kappa of 0.07.

The measures calculated with the classification tests are summarised as confusion matrix in Table 3.

Table 3: Confusion matrix of measures in febrile and non-febrile cows after correction of the thermographic measurements with the bias of the means of the differences between the two groups.

	Medial Canthus of the Eye		Eye		Muzzle	
	With fever	Without fever	With fever	Without fever	With fever	Without fever
Predicted condition positive						
$\geq 39.3\text{ }^{\circ}\text{C}$ (n)	1045	623	1152	706	1155	865
Predicted condition negative						
$< 39.3\text{ }^{\circ}\text{C}$ (n)	235	297	128	214	160	55
Sensitivity	0.82		0.90		0.88	
(True positive rate)						
Specificity	0.32		0.23		0.06	
(True negative rate)						
Positive predictive value	0.63		0.62		0.57	
Negative predictive value	0.56		0.63		0.26	
Accuracy	0.61		0.62		0.54	
( $\Sigma$ True positive + $\Sigma$ True negative/ $\Sigma$ Total population)						

## Discussion

The first outbreaks of SARS approximately 20 years ago and of avian influenza infection in humans a few years later heightened the interest in techniques suitable for the detection of people affected with these conditions. The early identification of people with a fever is crucial for the prevention of the spread of endemic infectious diseases [2]. Stationary thermal imaging cameras have been used at airports and hospitals for mass screening of people. Infrared thermography has also been used in veterinary medicine for the early detection of febrile diseases by measuring increases in body surface temperature [8, 9]. However, these studies were conducted using stationary imaging equipment and therefore were limited to defined settings. Portable thermographic imaging cameras, on the other hand, should allow the easy and early detection of infected animals and thus the prevention of spread of disease in groups of animals considered to be at risk of an infectious disease outbreak. Whether portable thermographic imaging cameras are capable of providing data with sufficient accuracy has not been investigated to date in veterinary medicine. The present study showed high correlations between the true temperature of a metal block and its infrared thermographic measurements, but the correlations decreased with an increase in the distance between camera and object. The effect of distance between the infrared camera and an object similar to that used in the present study on thermographic measurements has been described [10]; the temperature deviation of up to 2 °C for a distance between object and camera of 0.5 to 3 m in that study was comparable to the deviation of 1.6 to 2 °C in our study at a block temperature range from 25 to 35 °C and an ambient temperature of 23.8 °C. We could also confirm previous observations that the measuring accuracy and thermographic readings decrease with increasing distance between camera and object [10]. The cameras used in a previous study [10] had a setting for distance, which partly compensated for the inaccuracies, but this was not a feature with our camera. This could explain the large temperature deviations of up to 9.5 °C at a measuring distance of 5 m. For use in a free-stall dairy barn, a camera with a distance setting would be desirable because a short measuring distance of 0.5 to 1.0 m, which was associated with a high correlation coefficient of 0.98 in the present study, is very difficult to achieve in a barn. The effect of distance became even more pronounced at the lower ambient temperature of 14.7 °C (Fig. 3); the deviation at block temperatures of 25 and 35 °C were 3.1 and 6.0 °C, respectively, and the variation for repeated measures increased, particularly at lower ambient temperatures. The latter observation was in agreement with findings by others, who also reported that infrared thermographic measurements decreased with decreasing ambient temperature or increasing wind speed [7, 10].

The thermographic measurements of non-febrile cows were limited to the distances of 0.5 and 1.0 m because these distances were associated with the highest correlations and smallest temperature deviations in the experiments involving the metal block. Similar to the block temperature measurements, the measurements at these two distances did not differ. In contrast, the anatomical location of the measurement had a significant effect. The temporal and frontal areas of the human face have been used for infrared thermographic imaging [2, 11]; measurements of the eye region had the strongest relationship with body temperature measured with an ear thermometer [11], and the medial canthus was found to be the best location [12]. In addition to regions of the head, other body areas including the flanks, back, claws, muzzle, gluteal region with anal and vulvar areas and caudal aspect of the udder have been used

for infrared thermographic temperature measurements and comparison with the rectal temperature in calves and adult cattle [4, 7, 10, 13]. As in human studies, the thermographic temperature obtained at the eyes had the strongest correlation with the thermometric temperature. Our findings confirmed these results, but  $T_{\max}$  of the entire eye, rather than the medial canthus, had the strongest correlation with the rectal temperature. Similar correlations were calculated for the muzzle. Because thermographic measurements of the muzzle are straightforward, this location would appear superior to the medial canthus for a quick screening of a group of animals; however, the Bland-Altman plots showed a relatively large systematic average error of  $-5.3\text{ }^{\circ}\text{C}$  for the muzzle. This systematic error was also apparent in the entire eye region and the medial canthus, and all three locations had thermographic measurements that were smaller than the rectal temperature. The deviations were greater than those observed in previous studies of cattle and horses; the mean deviation of the thermographic eye temperature from the rectal temperature was  $-1.7\text{ }^{\circ}\text{C}$  in Angus feedlot steers [10] and  $-1.6\text{ }^{\circ}\text{C}$  in febrile ponies [3]. The temperature deviations were  $-1.5\text{ }^{\circ}\text{C}$  for the side of the face and  $-3.1\text{ }^{\circ}\text{C}$  for the forehead of people [14]. These systematic underestimations of the true temperature can be easily corrected using the bias for the mean deviation of the thermographic temperature from the rectal temperature, but the variation of the measurements at all locations is problematic. The variation coefficient of rectal temperature measurements in cows is 0.2% and the maximum difference ranges from 0.1 to 0.5  $^{\circ}\text{C}$  [15], but the variation coefficient for the thermographic measurements of the present study were considerably larger and ranged from 0.6 to 3.1%. This clearly shows that infrared thermography is not only affected by external factors, such as distance between camera and object, ambient temperature, wind speed, sunlight and emissivity of the object, [10, 16] but is also subject to intrinsic inadequacies of the imaging equipment, which render accurate measurements impossible. Whether some of the variation in measurements was caused by the compact nature of the imaging equipment cannot be determined from our study. Regardless of the indication for infrared thermography, data on reliability and repeatability of measurements in veterinary medicine are sparse [17, 18].

Unlike experimental studies in which determination of the exact thermographic temperature may be the focus of interest, in practice the identification of animals that deviate from the norm body temperature would be a common goal of mass screening of a group of animals [6]. Therefore, a cut-off was defined as the point when body temperature reached or surpassed  $39.3\text{ }^{\circ}\text{C}$  after correction with the bias. Analogous to mass screenings in airports and hospitals during the SARS outbreaks, it should be possible to identify, isolate and examine febrile animals by means of thermography. An increase in temperature in calves experimentally infected were detected up to a week before clinical scores or laboratory parameters indicated illness, and healthy and ill calves were reliably differentiated [4, 8]. However, repeated measurements were necessary to substantiate the increase in temperature. Sensitivity was 100%, and the positive predictive value was 80% [8, 9]. Depending on the body region, sensitivities between 82 and 90% and positive predictive values between 57 and 63% were calculated for thermographic measurements of febrile cows in the present study. However, this was contrasted by relatively low specificities (identification of non-febrile cows) ranging from 23 to 32% for measurements at the eye and only 6% for measurements at the muzzle. In comparison, the specificity (86.8%) and sensitivity (67.6%) for infrared



thermography at the eye in calves with bovine respiratory disease complex were considerably larger [9]. The low specificity calculated in the present study means that a considerable number of non-febrile cows would be falsely classified as febrile and unnecessarily isolated and re-examined with a rectal thermometer. However, in one mass screening study at a human hospital, a low specificity of 48.3 to 52.4% was tolerated to ensure a sensitivity of 100% [2]. Other mass screening studies in people had higher specificities of 71 to 86% but this was achieved at the cost of slightly lower sensitivities of 86 to 91% [19, 20]. The type of infrared thermographic camera had a pronounced effect on test efficiency [20]. The smart phone camera used in the present study had limited efficiency, which was evident primarily as large variations in measurements, which in turn caused poor agreement between rectal and thermographic measurements and low kappa values for measurements at the eye and very low values for measurements at the muzzle. Therefore, the muzzle does not appear to be useful for the detection of febrile cattle, whereas the eye, particularly the medial canthus, has a limited potential for this purpose. It is possible that a more sensitive infrared thermographic camera could generate better results similar to those achieved previously with a stationary device [8]. The advantages of a stationary camera include better control of external factors, such as sunlight, wind and fluctuating ambient temperatures, but the sites of examination are limited compared with a portable camera.

## Conclusion

The smart phone infrared thermographic imaging camera used in the present study has limited usefulness for the screening for febrile cattle; some febrile cows were missed and a considerable portion of non-febrile cows were falsely identified as febrile. This would necessitate unnecessary re-examination after possible stressful and labour-intensive separation from the group. Stationary infrared thermographic cameras with higher measuring accuracy are available and have been used successfully for mass screening of large groups of cattle. In addition to the quality of the camera, external factors, including the distance between camera and object, wind speed and lighting, affect the usefulness of infrared thermographic images.

## Methods

A FLIR ONE thermal imaging camera (2. Gen., Flir Systems, Wilsonville, OR, USA) was used for all measurements. The camera weighed 29 g and according to the manufacturer was able to measure the surface temperature of an object from  $-20$  to  $120$  °C with an accuracy of  $0.1$  °C at ambient temperatures of  $0$  to  $35$  °C. The camera operated at infrared wavelengths ranging from  $8$  to  $14$   $\mu$ m and with a pixel size of  $12$   $\mu$ m on the thermal sensor [21]. The camera featured automatic calibration for measurement of temperature at regular intervals using the default 'matte' setting for an emissivity of 95%, and was connected to a smart phone (iPhone 5, Apple, Cupertino, CA, USA) via a lightning connector. The FLIR ONE app was also installed on the smart phone for the storage of images. The images were analysed using the FLIR Tools program, and the temperatures were transferred to an Excel spreadsheet (Microsoft, Wallisellen, Switzerland). The ambient temperature and the rectal temperature of the cows measured

using an analogue thermometer (Scala Veterinärthermometer SC 12, SCALA Electronic, Stahnsdorf, Germany) were also recorded in the Excel spreadsheet.

- Infrared thermographic imaging of a metal block

A silver-coloured metal block measuring 3 x 3 x 8 cm, positioned on a heating plate, was used to determine the accuracy of the thermal measurements and the effect of ambient temperature and distance between the camera and object on the recordings. A heating plate (minitube HT 200, minitube, Tiefenbach, Germany) served to heat the block to the experimental temperatures, which were verified with a temperature probe (TFA Dostmann, Wertheim, Germany) inserted into a 1.5-cm hole in the middle of the block. This probe recorded the ambient temperature at the same time. The temperature of the block and the ambient temperature were also monitored with other thermometers (Geratherm, analogue mercury-free thermometer, Geschwenda, Germany; window thermometer, TFA Dostmann, Wertheim, Germany).

All measurements were made at ambient temperatures of 14.7 and 23.8 °C, and the initial measuring distance between the camera and the block was 0.5 m. The distance was then increased by increments of 0.5 m to a maximum of 5 m. Likewise, the initial temperature measured in the metal block was 25 °C. The block temperature was then increased by increments of 5 °C to a maximum of 45 °C (Fig. 3). For each block temperature, measurements were made from each of the ten distances at both ambient temperatures, resulting in 20 measurements for each distance (total n = 400).

- Infrared thermographic imaging in non-febrile cows

Cows (n = 30) referred to the Department for Farm Animals of the Vetsuisse-Faculty, University of Zurich, for non-febrile disorders were used for this experiment. Breeds included Braunvieh, Brown Swiss and Holstein Friesian, and they were housed in a tie-stall barn with straw bedding and an ambient temperature of 16 °C. The ration consisted of hay, grass silage and concentrate, which was adjusted according to milk production. Lactating cows were milked twice daily. As part of the daily clinical examination of the patients, the rectal temperature was measured every morning before milking using a digital thermometer with a range of 32.0 to 43.9 °C and a measurement time of 15 to 20 seconds (SC 12, SCALA Electronic Stahnsdorf, Germany).

The following regions of the body were selected for the measurements: left or right eye, muzzle, the coronet of one claw, caudal aspect of the udder, tail region and left and right flanks. In the analysis a ROI was defined for each of these anatomical locations and their maximum temperatures ( $T_{\max}$ ) were measured (Fig. 4). In addition to the maximum temperature of the eye, the temperature at the medial canthus was measured because this anatomical site has been identified as the best location for infrared thermography in animals and people [10, 11]. The two distances between the camera and the metal block with the highest correlations between the actual block temperature and the infrared thermographic temperature were used for measurements in the cows, and 20 measurements were made at both distances.

- Infrared thermographic imaging in febrile and non-febrile cows

Febrile (n = 34) and non-febrile cows (n = 23) referred to the Clinic were used to determine whether these two groups of cows can be differentiated using thermographic imaging. Husbandry conditions were the same as in the previous experiment. The non-febrile cow standing closest to a febrile cow was used as a control. Only one non-febrile control cow was examined on a given day even when multiple febrile cows were examined. Thermographic imaging was carried out at the same time as rectal temperature measurement, and at the two distances defined for the previous experiment. The two anatomical regions with the highest correlations between infrared thermographic temperature and rectal temperature in the previous experiment were selected for the measurements. Twenty measurements were made at each location at two different distances.

## Statistical analysis

The statistical program STATA (StataCorp LLC, College Station, TX, USA) was used for calculations. One-sample *t*-tests and multifactorial ANOVA were used and Spearman correlations and regressions were calculated to analyse the effects of distance and ambient temperature on the thermographic measurements of the metal block, and to examine the correlations between the experimental and thermographic temperatures of the metal block and the correlations between the rectal temperature and the thermographic temperatures at the seven body regions in the febrile and non-febrile cows. The reproducibility of the infrared thermographic measurements was examined by calculating the variation coefficient using mean and standard deviation from 20 serial measurements made in one cow. The measurements were made at distances of 0.5 and 1 m between the thermal imaging camera and the selected body regions.

The data were subjected to Spearman's rank correlation analysis and Bland-Altman plots were generated using the statistical program STATEL (ad Science, Paris, France) and Excel (Microsoft, Wallisellen, Switzerland). The resulting bias was added to the measured values of the febrile and the corresponding non-febrile cows to offset the bias of the thermal imaging camera. A rectal temperature 39.3 °C was defined as classifier for a febrile cow and used to classify the measurements. Based on this classification, the associations between the measurements obtained by thermal imaging and rectal thermometer were determined using the McNemar test, and several quality criteria of the classification were calculated: Cohan's kappa, sensitivity (true positive rate), specificity (true negative rate), positive predictive value, negative predictive value and accuracy ( $\Sigma$  true positive +  $\Sigma$  true negative/ $\Sigma$  total population).

## Declarations

## Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## **Ethics approval and consent to participate**

Since no manipulations were carried out on the animals for the data collection, an animal experiment approval was unnecessary according to national regulations. With the admission of the animals to the clinic, the owners give their written consent that the animals may be used for scientific tests, as long as these are not animal studies according to national regulations.

## **Consent for publication**

Not applicable.

## **Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## **Competing interests**

The authors declare that they have no competing interests.

## **Funding**

This research did not receive any specific funding.

## **Authors' contributions**

FK and UB designed the experiments; FK performed the experiments and analyses; FK, UB and MH analyzed the results; FK and UB wrote the manuscript. This research is a part of a Master thesis conducted by FK. All authors have read and approved the manuscript.

## **Abbreviations**

*Bias*:Means of the differences

*SARS*:severe acute respiratory syndrome

*ROI*:region of interest

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## Figures

Figure 1

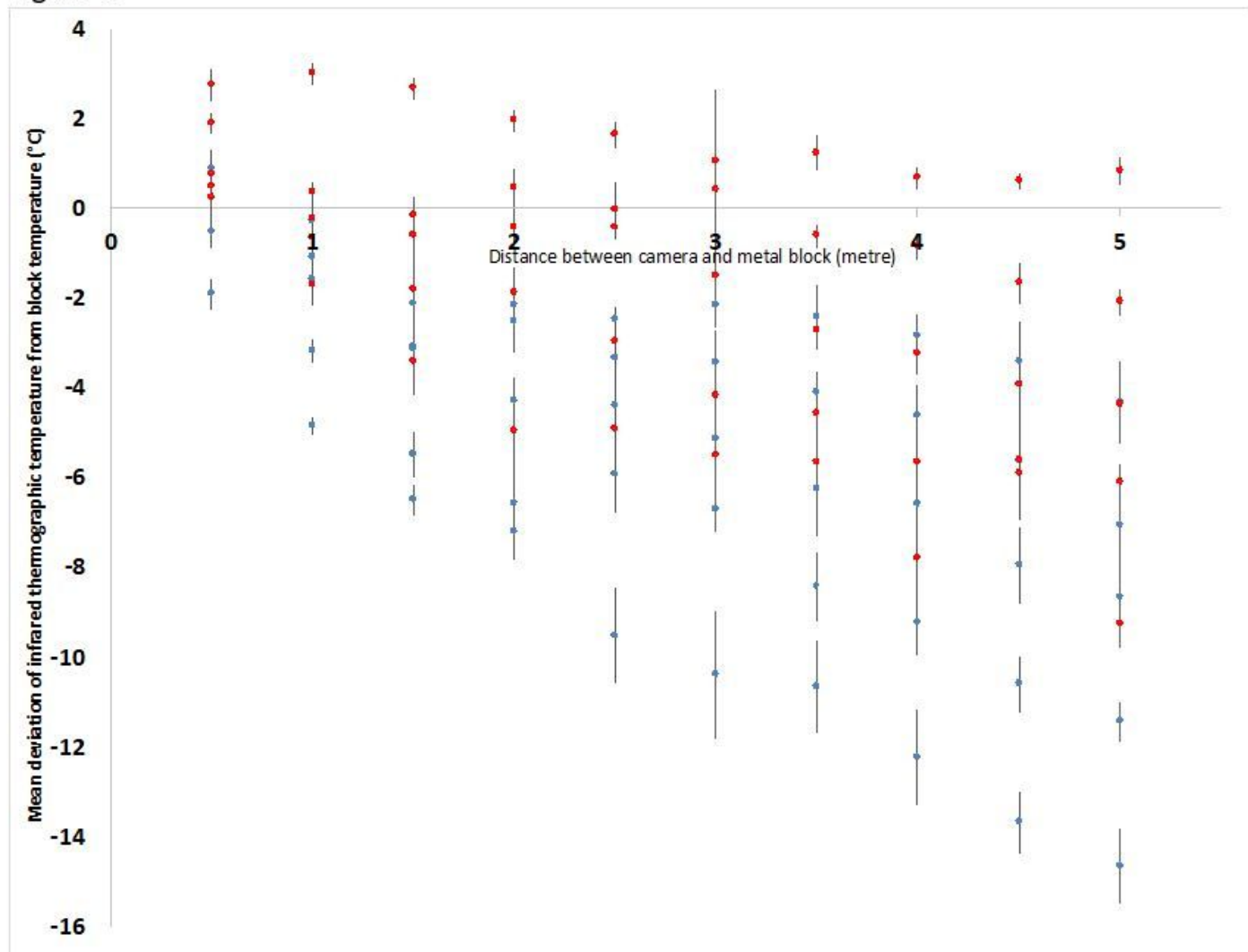
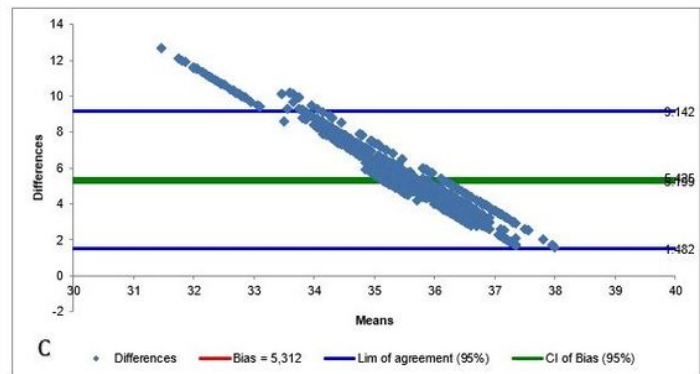
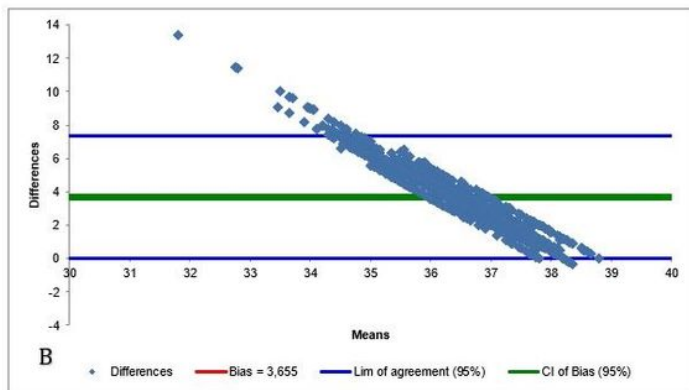
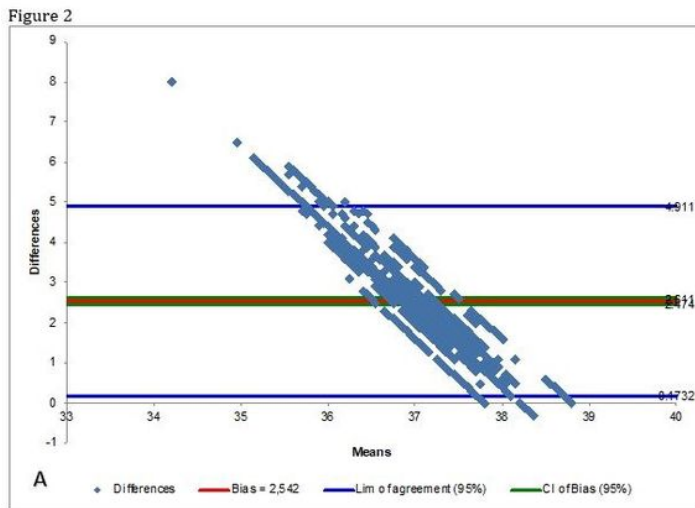


Figure 1

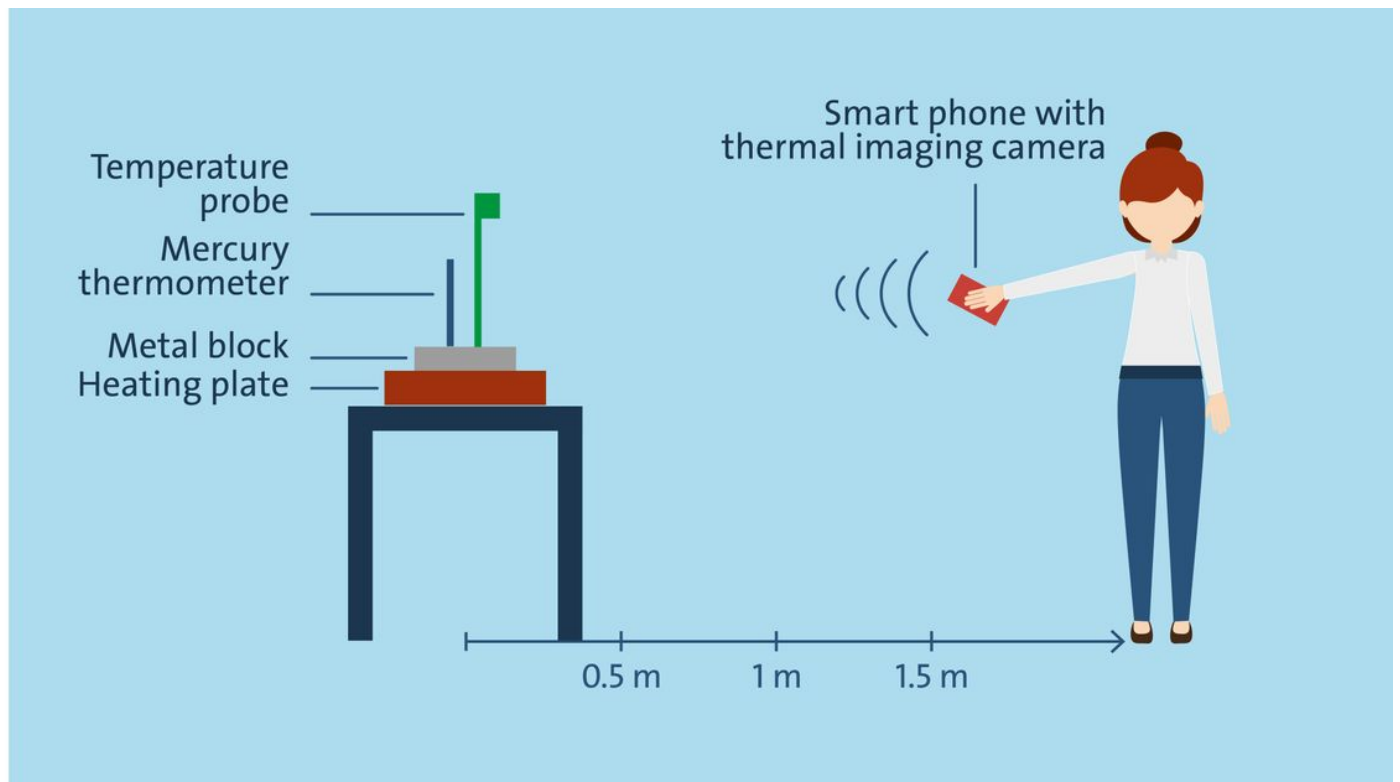
Mean deviations ( $\bar{x} \pm \text{SD}$ ) of the infrared thermographic temperatures from the five block temperatures taken from ten different distances between camera and metal block. Deviations recorded at the ambient temperature of 14.7 °C are shown in blue and those recorded at the ambient temperature of 23.8 °C are shown in red.



**Figure 2**

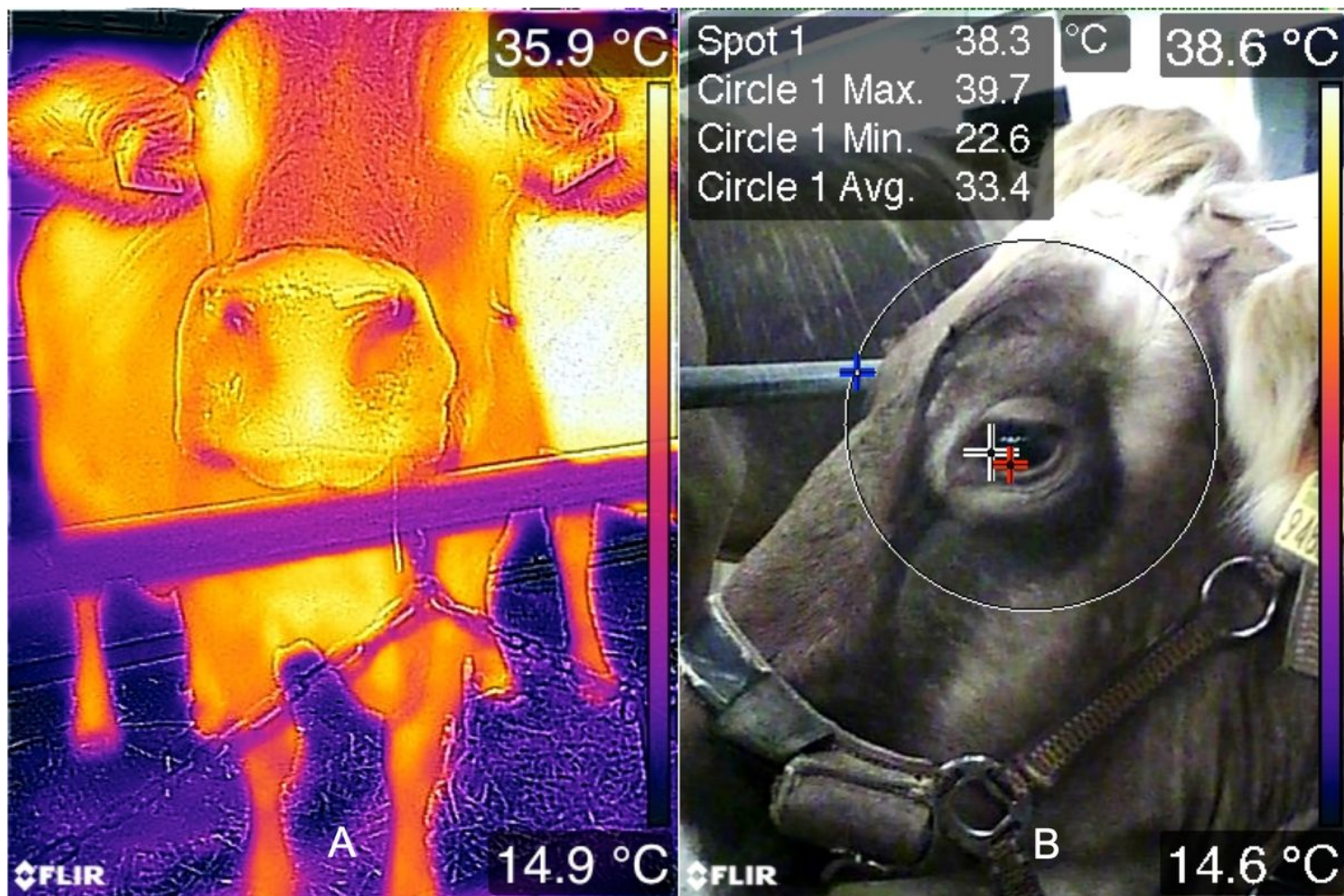
Bland-Altman plots for the differences in body temperature measured by rectal thermometer and infrared thermography at the eye (A), medial canthus (B) and muzzle (C) in non-febrile cows. Bias, mean of the difference; limits of agreement,  $\pm 1.96 \times$  standard deviation of the difference; CI of bias, 95% confidence interval of the bias





**Figure 3**

Measurement of the surface temperature of a metal block from different distances using a smart phone with a thermal imaging camera



**Figure 4**

A Thermogram focussing on the muzzle of a cow from a distance of 0.5 m. The temperatures of 14.9 and 35.9 °C are the minimum and maximum thermographic temperatures measured in the image. B Image of thermographic measurement at the medial canthus. The circle identifies the measurement region of interest, within which the minimum (blue cross) and maximum (red cross) thermographic temperatures were determined. The white cross marks the medial canthus.