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RESEARCH ARTICLE

Relationship Between Body Temperature Measured by Infrared Thermography and Rectal Temperature in Sheeps: Identifying Less-Invasive Alternative Sites to Rectal Measurement

Ferda TURGUT[1,a,✉], Latif Emrah YANMAZ[2,b], Sitkican OKUR[3,c], Ugur ERSÖZ[3,d], Mumin Gökhan ŞENOCAK[3,e], Ayşe GÖLGELİ BEDİR[3,f], Yakup KOCAMAN[4,g], Ömer Tarık ORHUN[5,h], Taner ARSLAN[3,i]

[1]Department of Surgery, Faculty of Veterinary Medicine, Cukurova University, Adana-TÜRKİYE
[2]Department of Surgery, Faculty of Veterinary Medicine, Burdur Mehmet Akif Ersoy University, Burdur-TÜRKİYE
[3]Department of Surgery, Faculty of Veterinary Medicine, Ataturk University, Erzurum-TÜRKİYE
[4]Department of Surgery, Faculty of Veterinary Medicine, Yozgat Bozok University, Yozgat-TÜRKİYE
[5]Department of Surgery, Faculty of Veterinary Medicine, Necmettin Erbakan University, Konya-TÜRKİYE

ORCID: [a]0000-0003-2956-7548, [b]0000-0001-5890-8271, [c]0000-0003-2620-897X, [d]0000-0002-1687-2327, [e]0000-0002-8855-8847, [f]0000-0002-9798-8638, [g]0000-0002-3580-7782, [h]0000-0003-4184-8879, [i]0009-0001-4222-3718

✉ Corresponding Author

Ferda TURGUT

Department of Surgery, Faculty of Veterinary Medicine, Cukurova University, Adana, TÜRKİYE

fturgut@cu.edu.tr

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Abstract

The measurement of body temperature is a crucial component of the clinical evaluation and provides the clinician with insights into the animal's health and homeostatic condition. This study included fourty healty female Ghezel sheep. The rectal temperature (RT) and axillary temperature (AT) were collected by digital thermometer. Ocular temperature (OT) and coronary band temperature (CBT) were assessed using infrared thermography (IRT). The Bland–Altman method was used to calculate the degree of agreement, with RT serving as the reference temperature. A total of 160 measurements were obtained from four distinct parts of the body. The mean differences and their 95% limits of agreement for the dfferences between RT−AT, RT−OT, and RT−CBT were 0.13°C (− 0.44°C – 0.70°C), 1.30°C (0.06°C – 2.53°C) and 15.30°C (1.93°C – 28.66°C), respectively. The AT, OT, and CBT values were within ±0.5°C of RT for 55.6%, 33%, and 11.1% of sheep, respectively. AT measurement may be more applicable and relevant as it provides temperature readings with an easily accessible device for clinicians and does not necessitate additional time for image interpretation and analysis findings.

Key Words: Axillary, coronary band, eye, infrared thermography, sheep

Koyunlarda Kızılötesi Termografi ile Ölçülen Vücut Sıcaklığı ve Rektal Sıcaklık Arasındaki İlişki: Rektal Ölçüme Alternatif, Daha Az İnvaziv Bölgelerin Belirlenmesi

Öz

Vücut sıcaklığının ölçümü, klinik değerlendirmenin önemli bir bileşenidir ve klinisyene hayvanın sağlığı ve homeostatik durumu hakkında fikir verir. Bu çalışmaya kırk sağlıklı dişi Ghezel koyunu dahil edilmiştir. Rektal sıcaklık (RT) ve koltuk altı sıcaklığı (AT) dijital termometre ile ölçülmüştür. Oküler sıcaklık (OT) ve koroner bant sıcaklığı (CBT), kızılötesi termografi (IRT) kullanılarak değerlendirilmiştir. Uyum derecesini hesaplamak için Bland-Altman yöntemi kullanılmış ve RT referans sıcaklık olarak kullanılmıştır. Vücudun dört farklı bölgesinden toplam 160 ölçüm alınmıştır. RT−AT, RT−OT ve RT−CBT arasındaki farklar için ortalama farklar ve %95 uyum sınırları sırasıyla 0.13°C (− 0.44°C – 0.70°C), 1.30°C (0.06°C – 2.53°C) ve 15.30°C (1.93°C – 28.66°C) olarak bulundu. AT, OT ve CBT değerleri sırasıyla koyunların %55.6'sında, %33'ünde ve %11.1'inde RT'nin ±0.5°C'si içindeydi. AT ölçümü, klinisyenler için kolay erişilebilir bir cihazla sıcaklık okumaları sağladığı ve görüntü yorumlama ve analiz bulguları için ek zaman gerektirmediği için daha uygulanabilir ve alakalı olabilir.

Anahtar Kelimeler: Göz, kızılötesi termografi, koltuk altı, koroner bant, koyun

INTRODUCTION

The measurement of body temperature (BT) is a crucial component of the clinical examination, offering the physician insights into the animal's health and homeostatic condition (1). Sheep's body temperatures are a reflection of their physiological and health conditions and are strongly correlated with metabolism and important functions (2).

Core body temperature (CBT_{emp}) is the temperature of the body's internal organs (3). However, measuring CBT_{emp} in live sheep has long been a challenge (4). Temperatures taken from the pulmonary artery or esophagus via a catheter are the places to use to estimate CBT_{emp} (3). Although the pulmonary artery is considered the gold standard for CBT_{emp} measurement, in general practice CBT_{emp} is usually estimated by rectal temperature (RT) (5,6). Due to the agreement between RT and CBT_{emp}, RT is considered the reference for clinical assessment of CBT_{emp} in animal (5). Manual collection of RT is the most common method of measuring BT in practice due to the ease of measurement and low purchasing costs of rectal thermometers (7). However, the accuracy of rectal thermometers is affected by the competence of the person using them. This process is time-consuming and can cause rectal injuries (7). Animals may be stressed during the measurement and the readings may be abnormal (8). In addition, diseases can be transmitted with this rectal thermometer method when measuring the temperature of larger groups of animals (9).

Axillary temperature (AT) measurement has become popular in recent years due to its non-invasive ability and convenience. The standard method for taking AT is to position the digital thermometer's (DT) tip into the axilla between the skin of the thorax and forearm (10). It is particularly used when RT measurement is made more difficult by rectal lesions, cross-contamination, injuries, or animal temperament (11). AT measurement is an established technique with many human studies (12,13). It is used frequently in pediatrics because of the low level of cooperation required and the difficulty of RT measurements (12). Choudhury et al. (13) have shown in their human study that appropriately calibrated AT measurements can be used as a noninvasive alternative to esophageal temperature measurements in intensive care unit patients. A previous study reported that RT and AT measurements in sheep had similar means and a strong correlation (14).

Infrared thermography (IRT) is a method employed to determine the surface temperature of objects based on the electromagnetic radiation and wavelengths emitted in the infrared spectrum (15). This non-invasive approach measures surface temperature without direct contact with animals, hence reducing stress factors that adversely impact animal welfare and can induce behavioral changes (16,17). The variation in blood flow caused on by increased BT in stressful environmental circumstances is also visible in IRT (18). Therefore, IRT has been used to measure physiological parameters and stress in a variety of livestock species. These include the eye, fore-head, muzzle, rump, flank, hooves, vulva and udder temperatures (19). Eye temperature is the most reliable surrogate indication for CBT_{emp} in sheep due to its strong association and consistency with CBT_{emp} (2,20). Arfuso et al. (21) suggested that the best eye region for estimating changes in sheep's RT is the medial canthus. Bakker et al. (15) in a study comparing the accuracy of temperature readings taken from the lacrimal caruncle, medial canthus and eyeball in sheep, suggested that the lacrimal caruncle was the most reliable method. Coronary band temperature (CBT) is typically tested to identify illnesses in cattle since it is found on the tissues that transmit blood and nutrients through the dermis (22). A previous work in bovine suggests that the lowest temperature is observed in the hoof area and the highest temperature is observed in the coronary band (23). To our knowledge, there are no studies comparing OT and CBT measured by thermal camera AT and RT measured by DT in sheep. This study aimed to assess the precision of non-contact devices and digital thermometers in measuring body temperature in sheep at several places, including RT, AT, OT and CBT, and to explore the feasibility of implementing these systems in flock management.

MATERIAL AND METHODS

Animals

This study was conducted in July and August 2023 at the Atatürk University Veterinary Faculty Animal Hospital in Erzurum, Türkiye (39° 54’ 35” N, 41° 16’ 32” E). In this region, July and August are summer months, and the average air temperature, relative humidity and precipitation between 2018 and 2023 are 5.8°C, 30.3% and 35.9 mm, respectively. Fourty female Ghezel sheep, aged 24±6 months and weighing 55.9±7.6 kg, were utilized. The sheep were randomly selected from the Food and Livestock Application and Research Center of Atatürk University and were investigated examined for non-pregnancy. The sheep were acclimated to indoor conditions for two weeks before the measurements were started. All animals were housed in the same group pen under the same environmental (18–21 °C, 30–50 % relative humidity), nutritional and management conditions. They were fed an ad libitum mixed diet (50% pellets, 25% oat straw and 25% alfalfa meal) and were supplemented with fresh water ad libitum.

Temperature Measurements

For each animal, OT, CBT, AT, and RT were measured simultaneously. Each measurement system's data acquisition was handled by a single operator. Approximately 150 seconds were needed to obtain all measurements. Before the experiment, the accuracy of the DT was verified in a temperature-controlled water bath using a reference thermometer. The RT was measured by inserting a digital rectal thermometer (Kruuse Digital Thermometer; Jørgen Kruuse, Denmark) 3 cm into the rectum until the terminal beep was audible. AT measurement procedures were performed as previously described (14). As the sheep stood, a AT measurement was collected from the left axilla with the forelimb held close to the torso, the probe was positioned as dorsally as feasible, approaching from the caudal portion of the axilla (Figure 1). The time between the DT being placed in the area and the temperature measurement result varying between 30-45 seconds. OT and CBT were measured with an IRT (IR Flexcam S; Infrared Solutions Incorporated, Plymouth, MN, USA). The images were captured at a distance of 1 m from the animal (24). IRT was focused on the left lacrimal caruncle region to measure the OT (Figure 2). Finally, CBT measurements were taken from the dorsal surface of the hooves, vertically (Figure 2). Each procedure took 5 seconds.



Figure 1. Thermometer position for axillary temperature measurement.

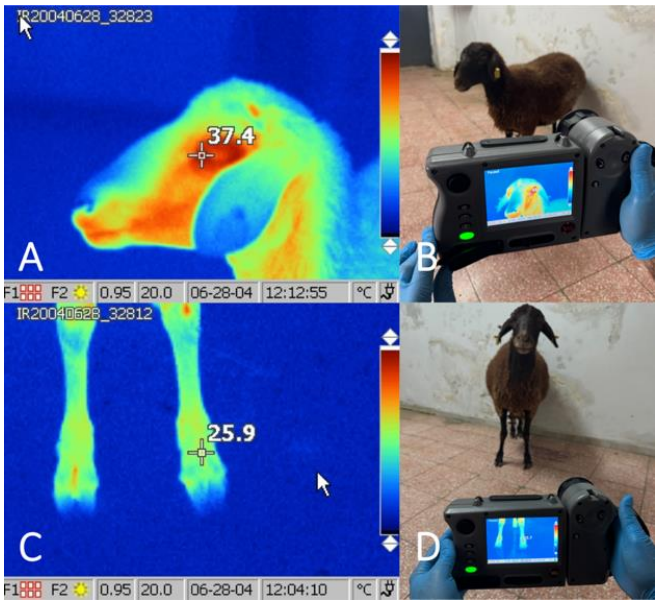


Figure 2. Thermal image (left) and digital photo (right) of the left eye (A,B) and hooves (C,D) of the sheep captured in this study with a IR Flexcam S; thermal camera (A,B: lacrimal caruncle, C,D: coronary band).

Statistical Analysis

All statistical analyses were performed using MedCalc Statistical Software (version 20.111, MedCalc Software Ltd., Ostend, Belgium). The agreement between RT and other temperature measurement methods, including OT, AT, and CBT, was evaluated using the Bland-Altman method (25). The arithmetic mean of differences, 95% confidence intervals (CIs), and limits of agreement (LoA) were calculated to evaluate systematic bias and variability. A regression analysis of the differences was conducted to assess proportional bias, with a significance level set at P<0.05. The percentage of data points within a ±0.5°C range around the mean difference was also computed to determine the clinical acceptability of each method in comparison to RT.

RESULTS

The animals did not lose or gain weight during the experimental period. Five temperature readings were decided to be unsuccessful and hence eliminated from the study. Three of these were due to sheep mobility during rectal temperature measurement and two due to the inability to perform thermal imaging measurements. A total of 160 temperature measurements were collected, including RT, AT, OT, and CBT measurements. For four sheep (two for OT and two for CBT), the first attempt failed due to incorrect focus, and a second attempt was made to collect the measurements.

The Bland–Altman analysis comparing RT and OT revealed a mean difference of 1.30°C (95% CI: 1.10 to 1.50, P<0.0001). The limits of agreement (LoA) ranged from 0.06°C to 2.53°C. Regression analysis produced a slope of 0.54 (P=0.0079). A total of 33.3% of data points were within ±0.5°C of the mean difference (0.80°C to 1.80°C) (Figure 3, Table 1).

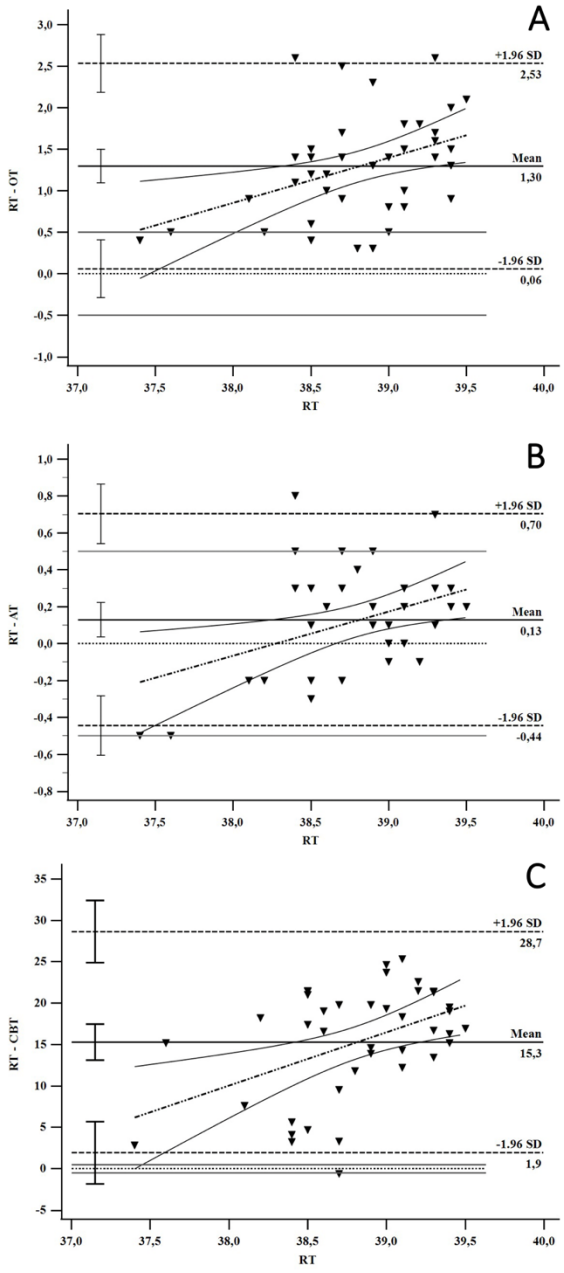


Figure 3. Ocular temperature (OT; A), axillar temperature (AT; B), and coronary band temperature (CBT; C) of 40 healthy sheep are plotted against rectal temperature (RT) using Bland-Altman bounds of agreement. The mean temperature difference is shown by the solid black line, while the dotted grey lines represent its 95% confidence interval. The accuracy of these estimations is shown by error bars. A predetermined clinical limit of agreement of ±0.5°C deviations is represented by the solid, thick gray horizontal lines. The difference of zero is shown by the dotted horizontal line. The regression line's slope for the linear relationship between temperature difference and mean, together with its 95% confidence interval (grey), is represented by the dashed-dot sloping grey line.

Table 1. Bland–Altman analysis compares body temperature (°C) measured at various locations with RT and evaluates the regression of the temperature difference (Y) on the mean temperature (X) to quantify variations in bias

Parameter estimate	Difference (Y) compared to RT		
	RT–AT	**RT–OT**	**RT–CBT**
Mean difference (95% CI)	0.13 (0.04 to 0.22)	1.30 (1.10 to 1.50)	15.30 (13.12 to 17.48)
Limit of agreement	−0.44 to 0.70	0.06 to 2.53	1.93 to 28.66
Lower limit (95% CI)	−0.44 (−0.61 to −0.28)	0.06 (−0.29 to 0.41)	1.93 (−1.83 to 5.69)
Upper limit (95% CI)	0.70 (0.54 to 0.87)	2.53 (2.19 to 2.88)	28.66 (24.91 to 32.42)
Regression equation	$Y = -9.18 + 0.24\,X$	$Y = -19.77 + 0.54\,X$	$Y = -235.11 + 6.45\,X$
Slope coefficient (95% CI)	0.24 (0.06 to 0.42)	0.54 (0.15 to 0.93)	6.45 (2.31 to 10.59)
***P*-value**	0.012	0.008	0.003

The Bland–Altman analysis for RT and AT demonstrated a mean difference of 0.13°C (95% CI: 0.036 to 0.224, P=0.0077). The LoA ranged from – 0.44°C to 0.70°C. Regression analysis produced a slope of 0.24 (P=0.0117). A total of 55.6% of data points were within ±0.5°C of the mean difference (– 0.37°C to 0.63°C) (Figure 3, Table 1).

The comparison between RT and CBT revealed a mean difference of 15.30°C (95% CI: 13.12 to 17.48, P<0.0001). The LoA ranged from 1.93°C to 28.66°C. Regression analysis produced a slope of 6.45 (P=0.0031). A total of 11.1% of data points were within ± 0.5°C of the mean difference (14.80°C to 15.80°C) (Figure 3, Table 1).

DISCUSSION AND CONCLUSION

The main objectives of the study were to correlate RT with some non-invasive measurements that can be widely used by farmers at a practical level and to compare AT, OT and CBT with RT in clinically healthy sheep. We found that AT recorded the highest level of agreement with RT for assessing CT in these anatomical regions. When RT measurement is not possible, AT and OT can be considered as alternatives for monitoring CT in clinically healthy sheep.

The RT is considered the reference for clinical evaluation of CBT_{emp} in animals (5). Rectal thermometers are generally reliable and reasonably accurate, including the clinical digital thermometer (14). However, rectal thermometry has been linked to possible drawbacks such stress, disease transfer, and animal rectal injuries (7-9). For these reasons, at the daily herd management level, non-contact methods may be more interesting because they are simpler and less expensive (26). Furthermore, RT measurement requires at least 15 seconds per measurement (27). The rectal thermometer must be cleaned after measuring each animal to reduce the possibility of cross-contamination, which adds even more time to this period (8). Because rectal thermometry has several disadvantages (7-9), the current study explored an alternative location for temperature measurement in sheep using a DT. This method of measurement is less invasive and easily implemented.

In agreement with previous studies (14,28), in general, AT was lower than RT. The lower AT compared to RT may be attributed to the fact that the axillary region is more peripheral and thus cooler than the body core (28). In peripheral regions, heat loss is greater, and temperatures measured at the skin surface tend to be lower than core temperature due to the insulating effect of subcutaneous tissues and the relatively lower blood flow in this area (29). Given that a clinically acceptable difference has been defined as ±0.5 °C (1), the axillary region may be considered a viable alternative to RT measurement in sheeps.

In the present study, compared with OT measurements in 33 sheep deviated from RT by more than ±0.5 °C below RT (Figure 3). OT measurements were consistently lower than RT in this study, consistent with previous reports in the literature (17,30). This difference is likely due to the ocular region's proximity to the body surface and its greater exposure to environmental influences such as wind, ambient temperature, and humidity (17,31). In contrast, RT serves as the gold standard for assessing CBT, offering greater stability and reduced susceptibility to external variation (1,5,6). Additionally, thermal imaging of the ocular area measures surface temperature, whereas rectal thermometry records internal temperature. This methodological distinction likely explains the lower ocular temperature values observed (17,32). In comparison with RT, the temperature recorded at a specific anatomical site reflects not only whether its mean value is higher or lower than that of the rectum, but also the variability of the differences (and consequently the width of the 95% CI for the mean difference), the magnitude of the bias, and, as discussed above, the consistency of that bias. In the present dataset, AT demonstrated the smallest bias and the highest proportion of measurements falling within the limits of agreement with RT.

Consistent with previous studies (33,34), CBT tended to be lower than RT. This decrease can be explained by the fact that although the coronary band is a superficial and peripheral region of the body, rectal temperature reflects core temperature, and surface temperatures always tend to be lower than core temperature because temperature decreases from the center of the body to the periphery (33,34). As a result, considering Table 1 and comparing all measurements, AT showed the smallest deviation when all measurements were considered and therefore can be used as an alternative method to assess BCT.

Our study has some limitations. First of all, a relatively high proportion of young sheep were included, which might restrict how far the results can be applied to elder populations. Furthermore, the absence of hypothermic/hyperthermic sheep restricts our ability to evaluate the accuracy of detecting hypothermia/hyperthermia. Therefore, future research should examine the accuracy of AT, OT, and CBT measurements in hypothermic sheep. Potential variations in thermometer placement for AT and RT measurements may have influenced the results of the present study. In addition,

factors such as blood flow, stress, activity level, blinking, local inflammation, ambient temperature, wind, humidity, sunlight, and floor temperature can substantially affect IRT measurements.

In conclusion, AT, OT, and CBT measurements provide temperature measurements within seconds. While OT and CBT measurements are valuable for rapid and non-invasive assessment of body temperature, they may not replace RT measurements due to differences in environmental factors and measurement methods. AT measurement may be more clinically applicable because it measures temperature with a DT readily available to clinicians and does not require additional time to interpret images and analysis results. However, temperature measured at these other sites cannot be interchanged with RT. In clinically healthy sheep where RT measurement is not possible or is likely to be inaccurate, RT measurement may be the preferred method. In the future, standardizing measurements made with thermal cameras and minimizing environmental influences will increase the reliability of measurements.

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CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Study planning and conceptualization were performed by FT. Methodology and formal analyses were carried out by FT, LEY, SO, MGS and AG. Validation and visualization were performed by FT, LEY, UE, MGS, AG, YK, ÖT and TA. Investigation was mainly conducted by YK, ÖT and TA. Writing of the original draft was conducted by FT and LEY, while review and editing were performed by SO. The final evaluation of the manuscript was completed with the contributions of all authors.

ETHICAL STATEMENT

The protocol implemented for managing sheep received approval from the Atatürk University Local Ethics Committee of Animal Experiments approved the study (Decision no: 2025/274).

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