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Dogs

Gingival Temperature Variations in Dogs: Assessing Healthy and Inflamed Gingiva Using Thermal Imaging Before and During Anaesthesia

Candemir Özcan[1] | Kürşad Yiğitarslan[2]

[1]Faculty of Veterinary Medicine, Department of Surgery, Kastamonu University, Kastamonu, Türkiye | [2]Faculty of Veterinary Medicine, Department of Surgery, Burdur Mehmet Akif Ersoy University, Burdur, Türkiye

Correspondence: Candemir Özcan (cozcan@kastamonu.edu.tr)

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ABSTRACT

Objectives: The aim of this study was to evaluate temperature differences in healthy (grade 0) and inflamed (grades 1 and 2) gingiva in dogs with varying gingival index (GI) scores, as well as the temperatures of different gingival regions (free gingiva [FG], attached gingiva [AG] and alveolar mucosa [AM]), using thermal imaging both before and during anaesthesia.

Animal Study: This study was carried out on 18 Golden Retrievers (males, $n = 8$; females, $n = 10$) aged 2–5 years (mean 3.25 ± 0.97 years) and weighing 15–29 kg (mean 22.35 ± 5.68 kg).

Procedures: Buccal surface temperatures of the FG, AG, and AM were recorded using a thermal camera in dogs before and during anaesthesia. The GI was utilised to assess the levels of gingivitis in the anaesthetised dogs.

Results: The difference in temperature between the maxillary and mandibular gingiva was quantified. Significant temperature variations were found between FG ($\Delta t = 0.79 \pm 0.23°C$, $p = 0.001$), AG ($\Delta t = 0.56 \pm 0.21°C$, $p = 0.008$), and AM ($\Delta t = 0.56 \pm 0.21°C$, $p = 0.009$). There was a statistically significant temperature difference (0.72 ± 0.24, $p = 0.008$) between grade 1 FG and AG. High correlation (correlation coefficient (r) = 0.931, $p < 0.01$) between the room temperature measured and body temperature measured ($r = 0.962$, $p < 0.01$) before and during anaesthesia. No significant correlation was observed between gingival temperature measurements of the same sites before and during anaesthesia. There was no correlation between gingival temperature and body temperature measured before and during anaesthesia.

Conclusion: This study shows local gingival temperature variations and the impact of environmental factors on body temperature during anaesthesia. The lack of correlation between gingival and body temperatures suggests that body temperature does not directly influence gingival temperature. These findings may help clinicians understand gingival health and temperature fluctuations. Further research is needed to determine the clinical significance and diagnostic value of gingival temperature changes.

Abbreviations: AG, attached gingiva; AM, alveolar mucosa; FG, free gingiva; GI, gingival index.

1 | Introduction

Gingivitis, the initial stage of periodontal disease, is often reversible through regular brushing (Enlund et al. 2023). This condition is characterised by recurring redness and inflammation of the gingival tissue, without any loss of connective tissue or bone attachment. If left untreated, gingivitis frequently progresses to periodontitis, which is a chronic inflammation of the tissues that support the teeth. This progression can result in the loss of connective tissue attachment and alveolar bone, leading to complications such as gingival recession, oronasal fistula, radicular abscesses, tooth mobility, and eventual tooth loss (Niemiec 2008).

Erythema of the gingiva is often recognised as the first clinical sign of gingivitis. This condition is typically accompanied by symptoms such as oedema, gingival bleeding during brushing or after chewing hard objects, and halitosis (Niemiec 2008). Notably, there is an absence of recession, furcation involvement, or tooth mobility during the presence of gingivitis (Wiggs and Lobprise 1997). Moreover, evidence indicates that gingivitis not only impacts the oral cavity but may also be associated with systemic diseases that affect organ functions, including those of the heart, liver, and kidneys (DeBowes et al. 1996; DeBowes 1998).

Subgingival plaque bacteria contribute significantly to the progression of periodontal disease by secreting bacterial toxins and metabolic products, which initiate the inflammatory response (Harvey 1998). This inflammatory activity triggers a complex sequence of events characterised by the release and action of various mediators at the site of inflammation. Mediators such as histamine, prostaglandins, and interleukin-1 are known to induce vasodilation of capillaries and enhance microvascular permeability (Teranishi 2023). Research has shown that gingivitis is associated with increased vascular permeability (Movila et al. 2018).

Interleukin-1 has been identified as a neutrophil pyrogen that affects the thermoregulatory centre in the brain (Dinarello 1984). It plays a crucial role in promoting the recruitment of cells to inflammatory sites, resulting in improved fluid flow and increased neutrophil counts (Lugler et al. 1983). These actions lead to elevated local temperatures and an enhanced presence of immune cells, such as neutrophils (Adams and Yokoyama 1987). Local temperatures within the normal range in the periodontal region are indicative of good periodontal health. Consequently, fluctuations in local temperature have been reported as a reliable indicator of inflammation associated with periodontal disease (Kung et al. 1990).

The gingiva serves as an important microcirculation zone, particularly affected by the presence of gingivitis and periodontitis. The capillaries of the free gingiva (FG) are the first to respond when gingivitis occurs (Nuki and Hock 1974). The periodontal vascular system exhibits variations between individuals and species, with the dimensions of the periodontium differing along the mesial, distal, oral and buccal aspects of the alveoli (Mörmann et al. 1985). In humans, gingival temperature readings vary across gingival pockets, different regions around the same tooth, various tooth type, and between the maxillary and mandibular regions. These differences can be attributed to variations in blood circulation across distinct areas (Maeda et al. 1979; Mukherjee 1981).

The microvascular system in dogs exhibits distinctive changes in cases of acute inflammation, chronic inflammation and periodontitis (Hock et al. 1980). Studies have shown that when exposed to cold airflow, there is a noticeable difference in the gingival rewarming times between individuals with healthy gums and those with periodontitis. Patients with healthy gingiva tend to warm up more quickly compared to those with periodontitis. This delayed warming of tissues in individuals with periodontitis is attributed to a decline in the associated vascular system (Mörmann et al. 1985).

Variations in vascular circulation can lead to changes in tissue temperature, allowing for an assessment of the tissue's condition (Kunc and Knizkova 2012). Alterations in blood flow result in temperature fluctuations in adjacent tissues, making temperature a valuable and objective indicator for diagnosing periodontal disorders. Consequently, thermal cameras accurately capture these variations in tissue temperatures, helping to eliminate biases that may arise from personal perspectives (Barnett et al. 1989; Păunică et al. 2009).

Several indices have been developed to characterise various aspects of periodontal disease in humans. However, when these indices are used by researchers not involved in their development, it may result in inconsistent conclusions. Discrepancies in inspection outcomes often arise from the inherent inaccuracies in the evaluation process (Kingman et al. 1991). A precise definition of gingival health is crucial for any epidemiological research on periodontal health, as it enables comparisons between different population groups, facilitates the identification and management of risk factors, and assesses the effectiveness of treatments (Benamghar et al. 1982).

Thermographic images of the oral cavity indicate a pathogenic situation when the temperature differential exceeds 0.5°C (Schwartz et al. 2015). These images also assist in assessing the degree of inflammation in the gingival tissues of dogs (Yiğitarslan et al. 2023). In healthy individuals, the interdental papilla exhibits greater blood flow compared to the FG. Conversely, patients with chronic periodontitis show reduced gingival blood flow compared to healthy individuals (Nakamoto et al. 2012). This decline in vascularisation in chronic conditions is believed to contribute to these observations. Additionally, gingivitis and acute periodontitis have been associated with elevated gingival surface temperatures (Haffajee et al. 1992). The average temperature of the gingival pocket in healthy human gingiva is approximately 33.9 ± 0.4°C, with the mandibular gingiva typically exhibiting slightly higher temperatures than the maxillary gingiva. Furthermore, molar teeth have been found to be 1.5 ± 0.3°C warmer than incisor teeth (Ng et al. 1978). In dogs with clinically healthy gums, the FG temperature is reported to be lower than that of the attached gingiva (AG) and alveolar mucosa (AM) (Yiğitarslan et al. 2023).

The aim of this study was to evaluate temperature differences in healthy (grade 0) and inflamed (grades 1 and 2) gingiva in dogs with varying gingival index (GI) scores, as well as the

temperatures of different gingival regions (FG, AG and AM), using thermal imaging both before and during anaesthesia.

2 | Material and Methods

2.1 | Animals

This study was carried out on 18 Golden Retrievers (males, $n = 8$; females, $n = 10$) aged 2–5 years (mean 3.25 ± 0.97 years) and weighing 15–29 kg (mean 22.35 ± 5.68 kg), which were brought to the Kastamonu University Faculty of Veterinary Medicine Animal Hospital between 2024 and 2025.

2.2 | Inclusion Criteria

The study included client-owned dogs brought to the clinic for gingival examination and scaling procedures, which exhibited varying degrees of gingivitis but did not show any clinical signs of periodontal tissue destruction, tooth mobility and furcation defects. The study was specifically conducted on a single breed to eliminate the potential effects of interbreed variations in gingival vascularisation. Only systemically healthy animals were enrolled, as determined by physical examination and medical history. Dogs were required to be cooperative enough for oral examination and thermal imaging procedures without the need for sedation. Additionally, animals that had not received any antibiotic or anti-inflammatory treatment within the past four weeks were considered eligible for inclusion in the study.

2.3 | Tools Used in Gingival Examination

A periodontal probe was used to determine the gingival bleeding of the dogs and to measure the gingival pocket depths. A thermal camera (Trotec EC060V, France) was used to take gingival thermograms.

2.4 | Anaesthesia

An anaesthesia device (Kruuse, Jørgen Kruuse A/S, Denmark) was used for inhalation anaesthesia of dogs. 0.1 mg/kg diazepam (Diazem IM/IV, 10 mg/2 mL, Deva, Istanbul) was administered as a preanaesthetic, and 3 mg/kg propofol (Propofol 1%, Fresenius, Germany) was administered intravenously for induction. A disposable endotracheal tube (Rüsch, Willy-Rüsch, Germany) was used to ensure the patency of the respiratory tract. Isoflurane (Isoflurane, USP, United States) was used as an inhalation anaesthetic for the maintenance of anaesthesia. Anaesthesia was sustained by stabilising end-tidal concentrations of isoflurane at 1.7%. Core body temperature was recorded when an end-tidal isoflurane concentration of 1.7% was reached. The end-tidal CO_2 value was maintained within the range of 40–45 mmHg during anaesthesia.

2.5 | Taking Thermograms

Measurement procedures after intubation were performed as previously described by Yiğitarslan et al. (2023). Anaesthetised dogs were placed in the lateral position. Thermograms were taken using a thermal camera to assess the temperature of the buccal gingival surface. The lips protecting the tooth surface were retracted to expose the teeth and gums. The temperature was allowed to stabilise for 30 s. Following the first picture, thermographic images of the buccal gingiva on the right side of the upper and lower jaw were captured at a 20 cm distance for 120 s, with intervals of 30 s. The same process was carried out on the left side of the maxilla and mandible.

TABLE 1 | Criteria for the GI systems (Löe and Silness 1963).

Indeks grade	Clinical finding
0	Healthy gums, no inflammation.
1	Mild inflammation: A slight change in colour and slight oedema; no bleeding on probing.
2	Moderate inflammation: There is oedema, redness, shine, and bleeding on probing.
3	Severe inflammation: There is oedema, redness, and ulceration present; there is spontaneous bleeding.

2.6 | Recording of Clinical Examination Findings

Clinical symptoms, such as redness, oedema and gingival bleeding, were assessed and documented using GI (Löe and Silness 1963) in Table 1. The severity of the illness was assessed based on the index system.

2.7 | Evaluation of Thermograms

Thermal images obtained with a thermal camera were analysed with the IC IR Report Software program. The FG, AG and AM temperature values at each tooth level were determined linearly and recorded (Figure 1).

2.8 | Statistic

The IBM SPSS 20 program was used in the analysis of the data. In the evaluation of normal distribution, skewness and kurtosis values were considered. As a result of the analysis, the data with skewness and kurtosis values between −1.5 and +1.5 were normally distributed. An ANOVA Tukey test was conducted to assess the significance of the temperature difference between the index grades of the gingival regions. The *t*-test was used to evaluate the importance of the temperature difference between (r) maxillary and mandibular gingiva in FG, AG and AM. $P < 0.05$ was considered statistically significant. A paired *t*-test was applied for normally distributed data to evaluate the impact of core temperature and ambient temperature on gingival temperature, whereas the Wilcoxon signed rank test was employed for non-normally distributed data (grade 0 FG, AG and AM).

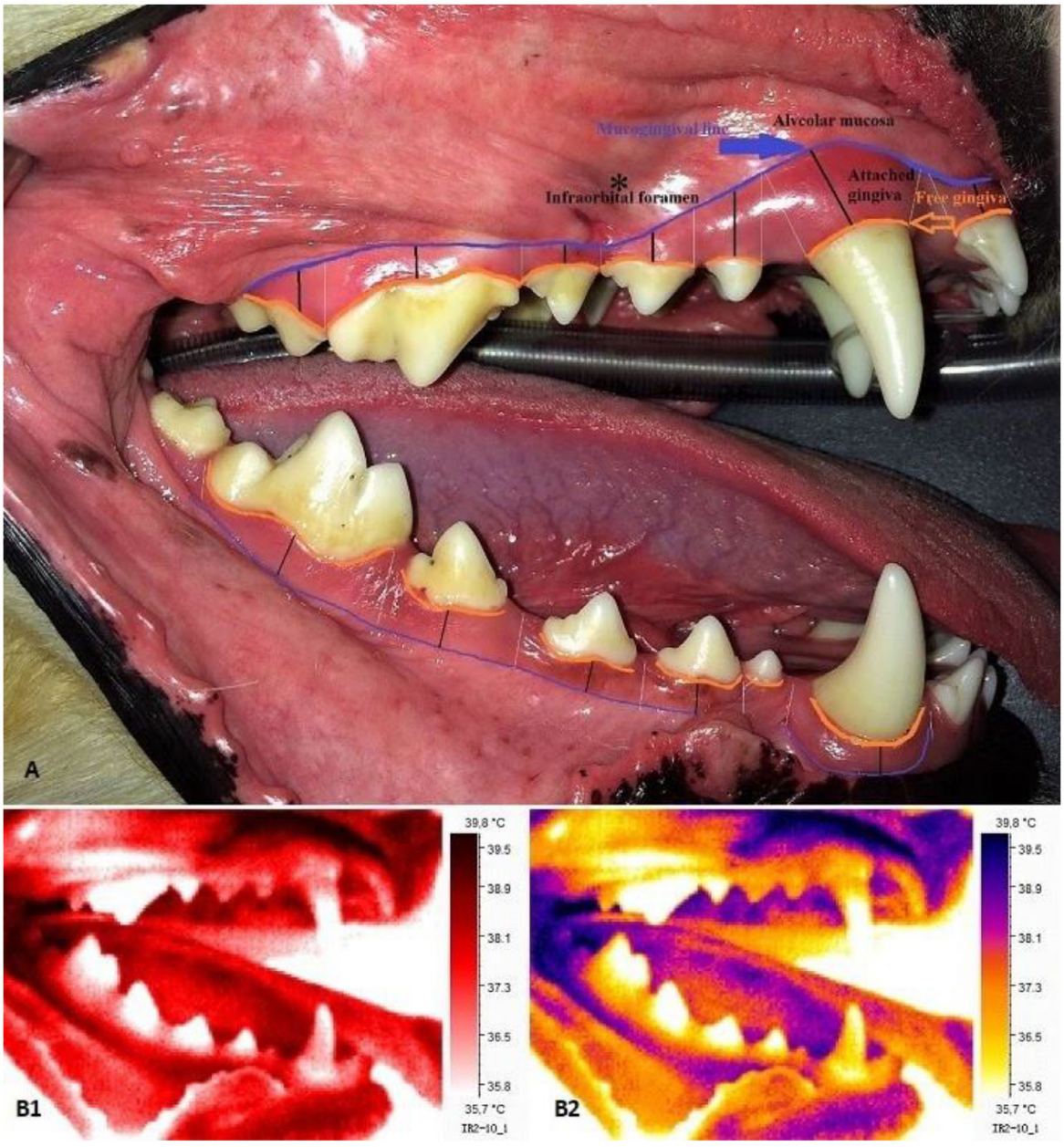

FIGURE 1 | This illustration demonstrates the segmentation of the gingiva and identifies the specific areas from which thermal measurements are taken, encompassing the gingiva surrounding each tooth. (A) The FG temperature was detected in the orange region. The white line delineates the periphery of the gingiva that encloses each tooth. The black line shows the area of the AG. Linear average temperature measurements were taken at anywhere in this area. The blue line shows the mucogingival junction. This line forms the upper boundary of the AG. A few millimetres above the blue line, the temperature of the AM at each tooth level was measured. (B1,B2) Thermal images in different colour palettes.

3 | Results

This study included 18 Golden Retriever dogs (males, $n = 8$; females, $n = 10$) aged between 2 and 5 years (mean 3.25 ± 0.97). Their body weight was between 15 and 29 kg (mean 22.35 ± 5.68 kg).

Figure 2 illustrates the temperatures of the buccal maxillary and mandibular gingiva at various GI levels as measured with a thermal camera. A total of 202 teeth and their corresponding gingival tissues in the maxilla were analysed. Among these, 56 were classified as grade 0 GI, exhibiting no signs of bleeding, hyperaemia, or swelling; 55 were assessed as grade 1, characterised by hyperaemia and swelling without bleeding; and 91 were categorised as grade 2, presenting with bleeding. Notably, there were no instances of spontaneous bleeding, resulting in the absence of grade 3 GI. Table 2 provides the average temperature values for the different gingival areas examined. The thermal images of gingiva with varying degrees of inflammation according to the GI are shown with distinct patterns in Figure 3.

An ANOVA Tukey test was conducted to evaluate the temperatures of various anatomical regions of the gingiva based on different GI grades (Table 3). The findings revealed that the initial

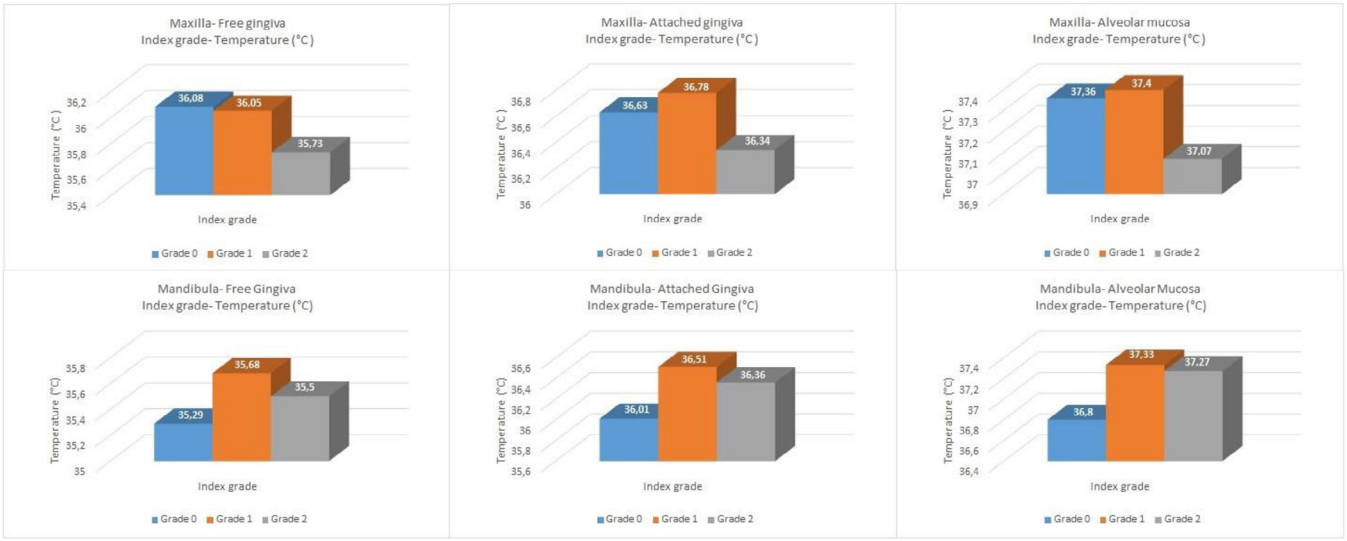

FIGURE 2 | Demonstration of maxillary and mandibular FG, AG and AM temperatures according to GI levels.

TABLE 2 | The temperatures of different regions of the gingiva in anaesthetised dogs with varying grades of gingival disease.

Index grade	*n*	Free gingiva temperature (°C)	Attached gingiva temperature (°C)	Alveolar mucosa temperature (°C)
0	56	36.08 ± 1.42	36.63 ± 1.30	37.36 ± 1.39
1	55	36.05 ± 1.23	36.78 ± 1.22	37.40 ± 1.32
2	91	35.73 ± 1.14	36.34 ± 1.06	37.07 ± 1.13
3	0	–	–	–

Note: n, number of cases.

temperature change, indicating gingival inflammation, occurred in grade 1 AG. In healthy gingiva (grade 0), the temperature difference between FG and AG was not statistically significant ($\Delta t = 0.55 \pm 0.25$, $p = 0.88$). However, in inflamed gingiva (grade 1), a significant temperature difference was observed between FG and AG ($\Delta t = 0.72 \pm 0.24$, $p = 0.008$) (Figure 4). Additionally, the temperature variation across different anatomical regions of the gingiva was found to be statistically significant in dogs with grade 2 GI ($p < 0.001$).

A total of 201 teeth and gums were evaluated in the mandible. Among these, 69 were classified as grade 0, 63 as grade 1, and 69 as grade 2. Notably, there were no instances of spontaneous bleeding in any of the gums, indicating the absence of grade 3 levels of inflammation. Table 4 presents the mean temperature values across different gingival areas. The gingival temperature at grade 0 GI level (36.80 ± 0.98°C) was statistically different from those at grade 1 (37.33 ± 1.06°C) and grade 2 (37.27 ± 1.10°C) ($p < 0.05$). However, no significant temperature differences were observed between grade 1 and grade 2 ($p > 0.05$). A direct relationship was identified between the temperature of the mandibular AM and the GI levels, with a significant increase in AM temperatures corresponding to elevated GI levels ($p < 0.05$). An ANOVA Tukey test was employed to compare temperature readings across various GI levels of the mandibular gingiva, revealing a significant temperature difference of approximately 0.5°C between healthy (grade 0) and inflamed (grades 1 and 2) gingiva in the AM. The study findings are detailed in Table 5.

A t-test was conducted to evaluate the significance of the temperature differences between the maxillary and mandibular gingiva across the FG, AG and AM. The study demonstrated a statistically significant temperature difference between the maxillary and mandibular FG ($\Delta t = 0.79 \pm 0.23$°C, $p = 0.001$), AG ($\Delta t = 0.56 \pm 0.21$°C, $p = 0.008$), and AM ($\Delta t = 0.56 \pm 0.21$°C, $p = 0.009$) at grade 0.

The relationships between examination room temperature, body temperature and GI were assessed before and during anaesthesia. The median room temperature before anaesthesia was 19.60°C (95% CI: 19.30°C–21.20°C) and during anaesthesia was 20.38°C (95% CI: 19.30°C–21.50°C). The analyses revealed a strong correlation between the room temperature measured before and during anaesthesia (correlation coefficient (r) = 0.931, $p < 0.01$). This finding underscores that the ambient temperature remains relatively consistent before and during the anaesthesia process.

The analysis results indicated a strong positive correlation between the temperatures of grade 0 FG and AG measured before anaesthesia ($r = 0.708$, $p < 0.01$). A significant correlation was also observed between these two variables during anaesthesia ($r = 0.652$, $p < 0.05$). Furthermore, the temperature of grade 0 AM measured before anaesthesia demonstrated a weaker correlation with the other regions, showing a significant correlation only with AG ($r = 0.617$, $p < 0.05$). No significant correlation was found between gingival temperature measurements of the same sites before and during anaesthesia.

TABLE 3 | Mean temperature difference between different gingival regions according to GI levels in the maxilla.

Dependent variable (GI level)	(I) Anatomic region of gingiva	(J) Anatomic region of gingiva	Mean temperature difference (I − J)	Std. error	*p*
Grade 0	FG	AG	−0.55	0.25	0.088
		AM	−1.28*	0.25	0.000
	AG	FG	0.55	0.25	0.088
		AM	−0.72*	0.25	0.016
	AM	FG	1.28*	0.25	0.000
		AG	0.72*	0.25	0.016
Grade 1	FG	AG	−0.72*	0.24	0.008
		AM	−1.34*	0.24	0.000
	AG	FG	0.72*	0.24	0.008
		AM	−0.61*	0.24	0.031
	AM	FG	1.34*	0.24	0.000
		AG	0.61*	0.24	0.031
Grade 2	FG	AG	−0.60*	0.16	0.001
		AM	−1.33*	0.16	0.000
	AG	FG	0.60*	0.16	0.001
		AM	−0.72*	0.16	0.000
	AM	FG	1.33*	0.16	0.000
		AG	0.72*	0.16	0.000

*The mean difference is significant at the 0.05 level.

While the mean body temperature before anaesthesia was 39.09 ± 0.35°C, it was 38.96 ± 0.38°C during anaesthesia and this result shows that anaesthesia affects body temperature (Δt: 0.12 ± 0.1°C, $p < 0.05$). A strong correlation was observed between body temperatures measured before and during anaesthesia ($r = 0.962$, $p < 0.01$). However, no significant correlation was found between body temperatures and gingival temperatures. This high correlation suggests that the measurement of gingival temperature before and during anaesthesia is independent of body temperature.

Gingival temperature measurements taken from different sites (FG, AG, and AM) before anaesthesia exhibited a strong correlation with one another. Similarly, the gingival temperature measurements at these sites during anaesthesia also demonstrated a robust correlation. However, the results of the measurements obtained before and during anaesthesia varied significantly, and no significant correlation was observed between these two time points.

4 | Discussion

Gingivitis is characterised by distinct symptoms such as swelling, increased blood flow and bleeding along the gum margins (Wiggs and Lobprise 1997). This study utilised thermal imaging to evaluate the severity of gingival inflammation in the maxilla. Our findings demonstrate a correlation between temperature changes and the severity of inflammation, as indicated by grades 0, 1 and 2. Specifically, inflammation was associated with significant increases in thermal temperatures at index grades 1 and 2, underscoring the potential of thermal imaging as a tool for detecting and assessing the progression of gingival inflammation.

The gingival vascular system, recognised as a microcirculatory zone, plays a critical role in the early defence against periodontitis. Increased vascular density is thought to contribute to these initial immune responses. Nuki and Hock (1974) highlighted the rapid response of capillaries in the FG during the onset of gingivitis, emphasising their pivotal role in the inflammatory process. However, our findings diverged from traditional human studies, revealing a notable difference in the pattern of temperature changes across the gingival regions. Unexpectedly, the AG showed the first significant temperature change, contrary to what is typically observed in the FG. Moreover, no significant temperature difference was found between the FG and AG in healthy gingiva, whereas a marked difference emerged in inflamed gingiva (grade 1). This suggests that thermal variations may serve as an early indicator of inflammation. So, a noticeable difference in temperature of 0.72 ± 0.24°C between FG and AG could be used to show that there is inflammation, giving us new information about how the gingival temperature is controlled in dogs.

The periodontal vascular system is highly complex, displaying a network of blood vessels that varies across different anatomical regions. Mörmann et al. (1985) noted differences in the length of the periodontium across various aspects of the alveoli, including

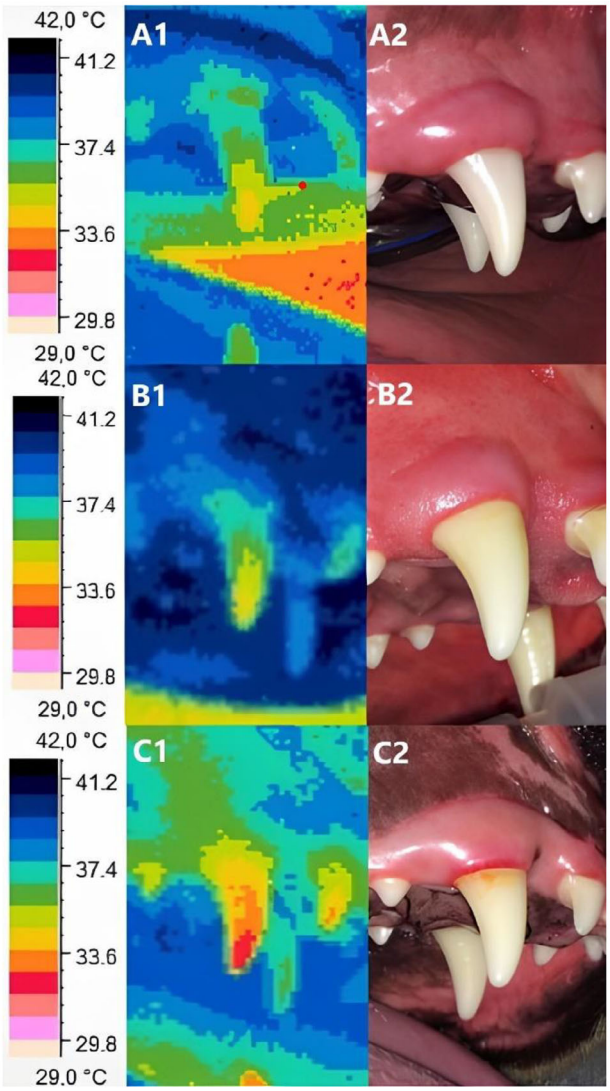

FIGURE 3 | Thermal and intraoral images of grade 0 (A1,A2), grade 1 (B1,B2) and grade 2 (C1,C2) gingiva according to GI. (A1,B1,C1) Thermal images. (A2,B2,C2) Intraoral images. Different patterns are observed in healthy (grade 0) and inflamed (grade 1 and grade 2) gingiva of the maxillary canine teeth. The thermal images show an increase in temperature in grade 1 gingiva, followed by a decrease in temperature in grade 2 gingiva.

the mesial, distal, oral and buccal regions, underscoring the intricate nature of periodontal morphology. In our study, we observed significant temperature differences between the FG, AG and AM. These findings suggest that variations in blood flow patterns across different anatomical locations may play a role in the observed temperature disparities. By employing precise thermal imaging techniques, we identified these variations, highlighting the potential of thermal imaging as a valuable tool for evaluating anatomy and physiology in periodontal research.

According to Schwartz et al. (2015), a temperature difference greater than 0.5°C is indicative of a pathogenic condition when interpreting thermographic images of the oral cavity. This study identified significant temperature disparities across gingival regions and between different index grades. Specifically, the temperature in the mandibular AM showed a statistically significant difference between grade 0 and grades 1 and 2 ($p < 0.05$). These temperature differences underscore the potential of thermal imaging as a highly sensitive diagnostic tool for the early detection of gingivitis. Furthermore, these findings enhance our understanding of the complex relationship between various gingival areas and the progression of periodontal diseases, offering valuable insights into the underlying mechanisms of these conditions.

According to a study by Ng et al. (1978), the average temperature of the gingival pocket in individuals with healthy gums is reported to be 33.9 ± 0.4°C. Additionally, it was observed that the temperature of the mandibular gingiva was 0.7 ± 0.2°C higher than that of the maxillary gingiva. However, our findings in dogs with periodontal health show a different trend. Specifically, the temperature of the FG on the buccal surface of the maxilla was 36.08 ± 1.42°C, while the AG exhibited a slightly higher temperature of 36.63 ± 1.30°C. The highest temperature recorded was in the AM at 37.36 ± 1.39°C. Conversely, in the mandible, the temperature of the FG averaged 35.29 ± 1.17°C, with the AG showing a notable increase to 36.80 ± 0.98°C and the AM recording a temperature of 37.01 ± 1.22°C. Interestingly, our results differ from human studies, as we found that in dogs with healthy gums, the maxillary gingiva tends to be warmer than the mandibular gingiva. The temperature differences between the FG, AG and AM were statistically significant. Specifically, the difference in FG was 0.79 ± 0.23°C ($p = 0.001$), in AG it was 0.56 ± 0.21°C ($p = 0.008$), and in AM it was 0.56 ± 0.21°C ($p = 0.009$). These findings suggest that anatomical differences may be an effective factor in gingival temperature. It also supports previous studies (Ng et al. 1978; Mukherjee 1978; Mukherjee 1981) which showed that the number of blood vessels varies in different parts of the body.

Hock and Nuki (1971) observed a network of blood vessels in the gingival tissues of puppies that had likely not experienced prolonged inflammation. These arteries appeared thin and straight in structure. Table 2 illustrates why the grade 2 index reflects lower temperatures compared to grades 0 and 1 in various regions of the maxillary gingiva. Grade 2 primarily reflects the chronic nature of the condition rather than the immediate severity of inflammation. Thermography, as demonstrated in this study, remains the only technique capable of accurately distinguishing between healthy gingiva and persistently inflamed tissue.

There was no significant correlation between gingival temperature measurements at the same sites before and during anaesthesia. As mentioned in the study's limitations, the lack of significant correlation between gingival temperature measurements at the same sites before and during anaesthesia is likely due to the influence of respiratory air, which may have affected the results. The strong correlation observed between body temperatures measured before and during anaesthesia could be attributed to the duration of anaesthesia, as suggested in the literature (Sessler et al. 2008).

It is stated that tissue perfusion may decrease after anaesthesia (Safak et al. 2024). In this study, the measurements were taken immediately after the dogs were intubated. A difference of 0.12 ± 0.1°C is statistically significant but clinically insignificant, as this small variation does not have a substantial impact on the overall physiological condition of the dogs. However, no

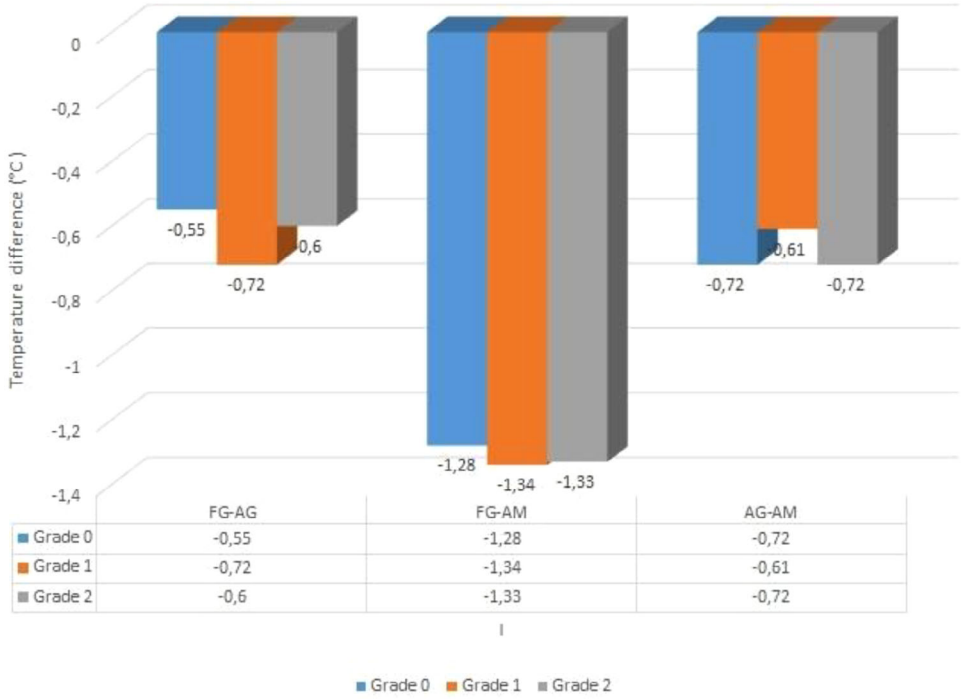

FIGURE 4 | Temperature difference between different anatomical regions of the gingiva in the maxilla according to GI levels.

TABLE 4 | Average temperature values of different gingival regions in the mandible.

GI levels	*n*	FG temperature (°C)	AG temperature (°C)	AM temperature (°C)
0	69	35.29 ± 1.17[a]	36.06 ± 1.04[a]	36.80 ± 0.98[a]
1	63	35.68 ± 1.26[a]	36.51 ± 1.15[a]	37.33 ± 1.06[b]
2	69	35.50 ± 1.32[a]	36.36 ± 1.26[a]	37.27 ± 1.10[b]
3	0	–	–	–

Note: n- Number of cases.

[a,b]There is a statistical difference between different uppercase superscripts in the same column ($p < 0.05$).

significant correlation was found between body temperatures and gingival temperatures. This could be due to the low subcutaneous fat tissue in areas like the gingiva (Tander et al. 2005). Tissues that are poor in subcutaneous fat, such as the gingiva, may experience higher heat loss, which could explain the lack of correlation between the gingival and body temperatures. The gingival temperature measurements taken from different sites before anaesthesia exhibited a strong correlation, and similar correlations were found during anaesthesia. However, the significant variation between measurements taken before and during anaesthesia, without any significant correlation between these time points, may not be solely attributed to anaesthesia. This variation could also be due to the influence of respiratory air on measurement results, as discussed in the study limitations, especially since measurements were taken immediately after the dogs were intubated.

This study has certain limitations that must be acknowledged. The primary limitation is the small sample size, which stems from the study being conducted on clinical cases admitted to our clinic. This, combined with the focus on Golden Retrievers, may limit the generalisability of the findings and impact the statistical power. Another limitation is that gingival thermograms taken before anaesthesia could have been affected by the animals' breathing, leading to temperature measurements that may be either warmer or colder than normal. As a result, the study's findings may not fully represent the broader population. Additionally, the lack of long-term follow-up data limits the understanding of potential changes over time. Future research with larger, more diverse groups and extended follow-up is necessary to validate and expand upon these findings.

The results and discussion underscore thermal imaging as a highly sensitive method for assessing canine gum health. This research not only highlighted temperature variations across different gingival regions but also demonstrated how thermal changes can serve as early indicators of inflammation. The distinct temperature differences between healthy and inflamed gum tissues emphasise the precision of thermal imaging in detecting pathological conditions with notable sensitivity. Furthermore, the analysis revealed intriguing variations in temperature distribution, likely influenced by unique blood vessel patterns in

TABLE 5 | The temperature difference between GI levels in the mandible.

Dependent variable (anatomic regions of gingiva)	(I) GI levels	(J) GI levels	Mean difference (I − J)	Std. error	*p*
FG	Grade 0	Grade 1	−0.39	0.21	0.176
		Grade 2	−0.20	0.21	0.606
	Grade 1	Grade 0	0.39	0.21	0.176
		Grade 2	0.18	0.21	0.669
	Grade 2	Grade 0	0.20	0.21	0.606
		Grade 1	−0.18	0.21	0.669
AG	Grade 0	Grade 1	−0.44	0.20	0.076
		Grade 2	−0.29	0.19	0.293
	Grade 1	Grade 0	0.44	0.20	0.076
		Grade 2	0.14	0.20	0.750
	Grade 2	Grade 0	0.29	0.19	0.293
		Grade 1	−0.14	0.20	0.750
AM	Grade 0	Grade 1	−0.53*	0.18	0.012
		Grade 2	−0.47*	0.17	0.025
	Grade 1	Grade 0	0.53*	0.18	0.012
		Grade 2	0.05	0.18	0.943
	Grade 2	Grade 0	0.47*	0.17	0.025
		Grade 1	−0.05	0.18	0.943

*The mean difference is significant at the 0.05 level.

different anatomical areas. These findings deepen our understanding of canine periodontal physiology and hold significant implications for clinical diagnosis and treatment monitoring. Thermal imaging offers veterinarians and researchers a valuable tool for identifying and managing gingival disorders in dogs, ultimately improving oral health outcomes. Additionally, this study opens new avenues for the exploration of thermal imaging in veterinary dentistry, potentially leading to innovative approaches for the prevention and treatment of periodontal disease.

Author Contributions

Candemir Ozcan: investigation, data collection resources, writing manuscript draft, review and editing. **Kürşad Yiğitarslan**: data collection, final checks, editing. All authors read and approved the final manuscript.

Ethics Statement

All measurements and exams conducted on canines complied with ethical guidelines. The Local Animal Ethics Committee of Kastamonu University approved the experimental protocols for this study. Approval date/number: 26.04.2024/11.

This study conducted following approval by the Kastamonu University Local Ethics Committee of Animal Experimentation (date: 26.04.2024, approval number: 2024/ 11).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/vms3.70475.

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