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Can thermal imaging technique be an effective method to assess pulp health in dogs?: a pilot study

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Abstarct: This study aimed to determine the effectiveness of thermograms obtained from canine teeth of dogs with healthy gingiva and no tooth discoloration in assessing pulp vitality and quickly determining tooth vitality. The study included 64 canine teeth of 16 non-brachiocephalic, crossbred, male dogs with healthy periodontal tissue and no radiolucent areas in the periapical region. Thermograms of the canine teeth were taken and it was evaluated whether the coronal pulp tissue caused a temperature difference on the tooth surface. In the statistical analysis, it was determined that the coronal pulp caused a temperature increase of 0.34°C on the tooth surface (P> 0.05). As a result, it was concluded that the thermal camera can give an idea to the physician in the evaluation of blood flow in the pulp and help in deciding tooth vitality.
Keywords: Dog, pulp vitality, thermography.

Termal görüntüleme tekniği köpeklerde pulpa sağlığını değerlendirmede etkili bir yöntem olabilir mi?: ön çalışma

Özet: Bu çalışma, sağlıklı diş etlerine sahip ve dişinde herhangi bir renk değişikliği gözlenmeyen köpeklerin kanin dişlerinden alınan termogramların pulpa canlılığını değerlendirmedeki etkinliğini belirleyebilmek ve diş canlılığına hızlı bir şekilde karar verebilmek amacıyla yapıldı. Çalışmada sağlıklı periodontal dokuya sahip ve radyografide periapikal bölgede radyolusent alanlara rastlanmayan 16 adet non-brakiosefalik, melez, erkek köpeğe ait 64 adet kanin diş dahil edildi. Kanin dişlere ait termogramlar alınarak koronal pulpa dokusunun diş yüzeyinde bir sıcaklık farkı oluşturup oluşturmadığı değerlendirildi. Yapılan istatistik analizde koronal pulpanın diş yüzeyinde 0,34°C bir sıcaklık artışına sebep olduğu tespit edildi (P> 0,05). Sonuç olarak termal kameranın pulpada kan akımının değerlendirilmesinde hekime bir fikir verebileceği ve diş canlılığına karar vermede yardımcı olabileceği kanısına varıldı.
Anahtar kelimeler: Köpek, pulpa canlılığı, termografi.

Introduction

The dental pulp is a vital tissue inside the tooth. The dental pulp consists of blood vessels, nerves, connective tissue, and specialized cells. It serves several functions, including providing nourishment to the tooth, conveying sensory information, and participating in the formation of dentin. The dental pulp is protected by the hard tissues of the tooth, enamel, and dentin (Kazmi et al., 2022). The volume of the pulp cavity decreases with age, but various

factors can influence its size. These factors encompass tooth type, tooth position, gender, breed, nutritional status, and environmental factors (Maeda, 2020). Dental pulp has three parts: coronal pulp, radicular pulp, and apical foramen. Coronal pulp fills the pulp cavity in the crown part of the tooth (Kazmi et al., 2022).

In veterinary dentistry, determining the state of pulpal health is crucial for identifying and treating a range of dental pathologies. However, accurately assessing the condition of the pulp can be challenging due to the protective layer of enamel and dentin that surrounds it, and the fact that animals cannot communicate their pain to their caregivers (Proulx et al., 2022). Given the difficulty in accurately assessing pulpal health in veterinary dentistry, it is crucial to exercise caution when interpreting the results of pulp tests to avoid misdiagnosis and inappropriate treatment. Therefore, the results of such tests must be scrutinized closely and evaluated with care (Chen & Abbott, 2009).

Various methods are used by veterinarians to evaluate dental vitality in dogs, and some of the most used methods include:

Visual Inspection of the Crown of the Tooth: The visible part of a tooth, known as the crown, is made up of three main components: enamel, dentin, and pulp. Any modifications to these structures can result in changes to the tooth's appearance due to the way it transmits and reflects light. Discoloration of teeth can be categorized based on where the staining occurs, either on the outer surface (extrinsic) or within the tooth itself (intrinsic) (Feigin et al., 2022).

Veterinary professionals recognize the importance of tooth discoloration as a potential indicator of tooth nonvitality and can diagnose and recommend appropriate treatment options with a high degree of accuracy (Hale, 2001).

Discoloration of teeth can appear in a range of shades from yellow to dark brown, as well as pink and purple. Among these colors, pink, yellow, and gray are the most observed, and they can be indicative of changes in the pulp of traumatized teeth. Pink discoloration, for instance, may occur due to factors such as intrapulpal hemorrhage or internal resorption (Feigin et al., 2022). Pulpal ischemia and pulpal death without bacterial contamination may produce subtle tooth discoloration (Holan & Fuks, 1996)

The issue of tooth discoloration poses two significant obstacles for dentists. Firstly, it requires an understanding of the underlying causes and their impact on the overall health of the affected teeth (Hattab et al., 1999). Secondly, determining the most suitable treatment plan can be a challenge (Feigin et al., 2022).

Electric Pulp Test (EPT): This method is used to determine the vitality of a tooth pulp by applying an electric current to the tooth and measuring the response of the pulp. During this

test, an electric signal is applied to a tooth and a live pulp typically responds with a sensation such as pain. The device used during the test controls the strength and duration of the electric signals applied to the tooth, indicating the status of the tooth pulp (Chen & Abbott, 2009). The ionic flow of dentinal fluid within the dentinal tubules leads to the generation of action potentials from intact A delta fibers, resulting in a positive outcome (Narhi et al., 1979).

The electric pulp test provides information about nerve conduction and the presence of nerve fibers, but it cannot determine the integrity and health status of the pulp. It has been reported that there is no relationship between the positive response obtained from the electric pulp test and the histological condition of the pulp (Mumford, 1967).

Teeth that have suffered trauma, although alive, temporarily lose their sensory functions and do not respond to electric pulp testing, while teeth with partial necrosis, despite the absence of blood flow in the pulp, give a positive response (Peterson et al., 1999).

Cold Test: The cold test is the most used pulp sensitivity test. Its application causes the dentinal fluid within the dentinal tubules to contract and move outward (Brännström, 1963; Brännström, 1986). This sudden movement of dentinal fluid exerts hydrodynamic forces on the A-delta nerve fibers within the pulp-dentin complex, resulting in sharp localized pain (Proulx et al., 2022). The cold test is performed using ice sticks (0°C), solid carbon dioxide gas (CO_2) sticks (-78°C), ethyl chloride (-5°C), and dichlorodifluoromethane (DDM) (-50°C). The main difference between the tests is the temperature differential applied (Fleury & Regan, 2006). The cold test can be used to differentiate between reversible and irreversible reasons. After the stimulus is removed, it should be assessed whether the pain continues or disappears immediately. If there is pain that persists even after the stimulus has been removed, it may indicate irreversible pulpitis (Gopikrishna et al., 2009).

Laser Doppler Flowmetry (LDF): LDF is a method that allows direct measurement of blood flow in small blood vessels of the microvascular system. It was first used by Gazelius et al. (1986) in dentistry. LDF is used to measure blood flow in the pulp for vitality assessment of traumatized teeth. In periodontics, it is used to measure gingival blood flow after crest augmentation, and in reason, it is used to measure gingival blood flow in flaps after Le Fort I osteotomy (Dodson et al., 1994; Zanetta-Barbosa et al., 1993). In this technique, the laser beam is directed onto the tissue where blood flow is to be measured. When the beam enters the tissue, it is scattered and absorbed by moving red blood cells and stationary tissue elements. According to the Doppler principle, photons scatter and change their frequency when they encounter moving red blood cells. Photons encountering stationary elements are scattered but do not change their position in Doppler. Part of the beam is reflected to the photon detector, creating

a signal. Red blood cells constitute the most moving objects in the dental pulp. Therefore, the reflected and collected photons provide a measure of blood flow in the pulp (Gazelius et al., 1986; Wilder-Smith, 1988).

Pulse Oximeter: Pulse oximeter, is a SaO_2 imaging device commonly used in medicine to reason oxygen saturation levels in the blood of patients undergoing intravenous anesthesia. It is a completely objective test that does not rely on subjective reactions from the patient. The pulse oximeter sensor has two light-emitting ends: one that emits red light (640 nm) and the other that emits infrared (940 nm) light. On the other side of the tissue where the ends are applied is a photodetector. Oxygenated hemoglobin and non-oxygenated hemoglobin absorb red and infrared light in different amounts, which is detected by the photodetector. The relationship between the pulsatile changes in red light absorption and those in infrared light absorption is evaluated by the pulse oximeter, and arterial blood saturation is determined (Gopikrishna et al., 2009).

Dental Transillumination: This method involves applying a light source from the back of the tooth and observing the tooth's interior for any cavities or fractures. It is a useful test for identifying any issues within the tooth. It has many applications in restorative dentistry. One of them is using near-infrared light transillumination (NILT) for early detection and minimally invasive treatment of carious lesions (Vinothkumar, 2021). The principle of this method is to light on the teeth and see the carious areas as darker than the healthy ones (Marouane & Chtioui, 2020). This method can be an alternative or a supplement to radiography. It has been shown to be reliable, repeatable, and effective (Lara-Capi et al., 2017; Marouane & Chtioui, 2020).

Dental transillumination also uses light to illuminate the tooth and measure the blood flow in the pulp chamber. This method uses laser speckle imaging (LSI) technology to provide light from the back of the tooth and capture images from the front of the tooth. Near-infrared light (NILT) can be used as a light source (Stoianovici et al., 2011). This method can help to assess dental vitality without radiation exposure and with minimal invasiveness (Stoianovici et al., 2011; Zhang & Yelick, 2010). However, it is stated that the electric pulp testing method is less reliable than the cold test in detecting non-vital teeth (Proulx et al., 2022).

Radiography: X-ray imaging is used to visualize the structures inside the canine tooth. This method is very useful for detecting problems in the roots of the tooth. Dental radiographs provide essential information for the diagnosis of endodontic disease. Radiographs do not provide direct information on pulpal health, but many of the effects of pulpal pathology are radiographically visible (Dupont & DeBowes, 2009). The points to pay attention to in radiographs are the width and number of pulp horns, the width and shape of the pulp chamber,

the width and shape of the pulp canal, the thickness and density of dentin, the width and position of the apical foramen, the presence and size of periradicular lesions (Edwards et al., 2021; Rowe & Ford, 1990).

There are objective methods that measure dental vitality directly or determine the blood flow or oxygen saturation of the pulp. These include laser Doppler flowmetry, spectrophotometry, pulse oximetry, thermography, and optical coherence tomography (Gopikrishna et al., 2009; Aubeux et al., 2021; Grabliauskienė et al., 2021). The advantages of these methods are that they can evaluate dental vitality without radiation exposure, painlessly and non-invasively. The disadvantages are that they are expensive, lack standardized protocols, and can be affected by various factors (Gopikrishna et al., 2009; Aubeux et al., 2021).

There are also subjective methods that indirectly measure dental vitality or determine the pulp's sensitivity status. These include thermal tests, electrical tests, test cavities, and anesthesia use. The advantages of these methods are that they are easy to apply and low-cost. The disadvantages are that they expose to radiation, cause pain and invasiveness, and give subjective results. One of the reasons for preferring objective methods in animals is that they do not give subjective results and do not require cooperation with the patient for the responses to be obtained (Gopikrishna et al., 2009; Aubeux et al., 2021).

A thermal camera is used to determine the health status of the gums in dogs (Yiğitarslan et al., 2023). It is also stated that a thermal camera can be an effective method in distinguishing different clinical findings in the gums of dogs (Yiğitarslan & Özcan, 2023). It is emphasized that the temperatures in the examined regions should be correlated with the temperature in different regions of the body and that the degree of acceptability of these temperature changes should be determined (Kaya et al., 2023).

Different methods have been reported in the literature to evaluate pulp vitality. Sensory analyses performed to evaluate pulp vitality in dogs may result in false negative or false positive outcomes. We think that thermal imaging may be an effective method for an objective evaluation of pulp vitality. This study was conducted to demonstrate that the coronal pulp in dogs with healthy teeth causes a temperature increase on the tooth surface and to report that this temperature increase may be used as an auxiliary diagnostic method for objectively evaluating pulp vitality.

Materials and Methods

Animals: In this study, 16 non-brachycephalic male dogs with healthy gums, which were brought to the Surgery Clinic of Burdur Mehmet Akif Ersoy University Faculty of

Veterinary Medicine for castration, were used as animal subjects. The examination was performed on canine teeth with numbers 104 ($Canine_{104}$), 204 ($Canine_{204}$), 304 ($Canine_{304}$), and 404 ($Canine_{404}$) according to the Triadan numbering system.

Inclusion criteria: A periodontal probe was used to determine the periodontal health of the dogs. X-ray was taken in an oblique position for examination of the periapical region. Dogs with no clinical bleeding in the gums and no radiolucent areas in the periapical region on radiograph were included in the study.

Anesthesia: An anesthesia device (Draeger, Primus®, Germany) that had two vaporizers and an automatic ventilator was used to perform general anesthesia on dogs. A preanesthetic dose of 0.1 mg/ kg of diazepam (Diazem amp® IM/IV, 10 mg/2 ml, Deva, Istanbul) was given intravenously and anesthesia was induced with 3 mg/kg of propofol (Propofol® 1% Fresenius, Germany). A disposable endotracheal tube (Rüsch, Willy-Rüsch Ltd., Germany) with a suitable size was inserted to keep the airway open. Sevoflurane (Sevoflurane, USP®, United States), a volatile anesthetic, was used to maintain anesthesia.

Examination and taking thermograms: The dogs were placed in a lateral position on the examination table while they were under anesthesia. Thermograms of canine teeth from both sides of the upper and lower jaws were taken from 20 cm away with a thermal camera (Trotec® EC060V, 160x120 pixels, France) (Figure 1).

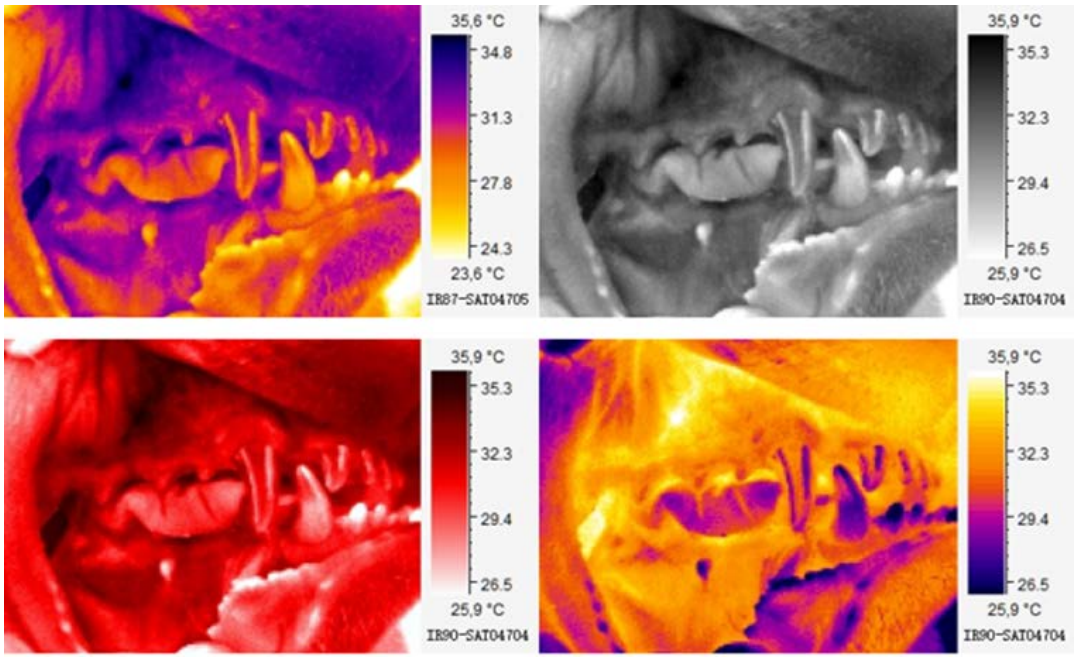

Figure 1. The appearance of the thermal image of the pulp tissue on the tooth surface of a dog with a vital tooth in different color palettes.

Evaluation of thermograms: IC IR Report Software® program was used to analyze thermograms and the temperature difference between the pulp tissue projection on the tooth surface and the rest of the tooth area was recorded (Figure 2). The region of interest (ROI) was determined based on the average temperature of the area. The temperature difference between the areas was calculated.

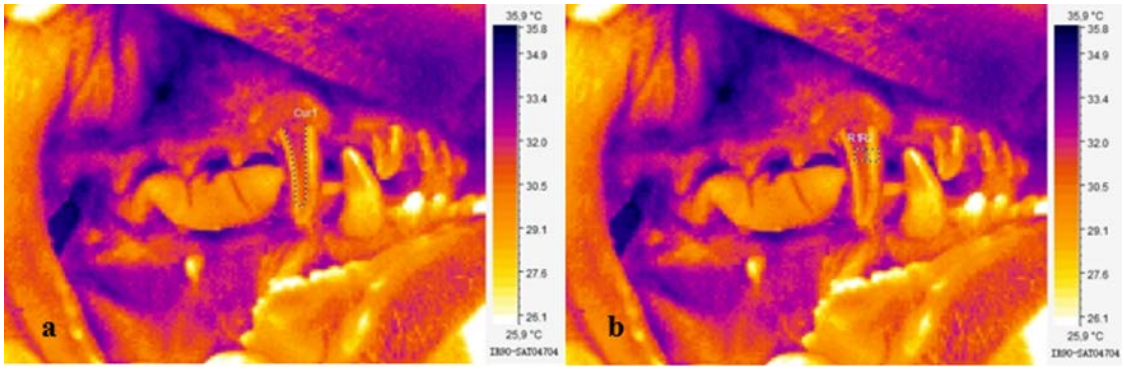

Figure 2. a: Thermal image of the pulp tissue on the tooth surface. b: Obtaining temperature data from R1 (pulp temperature on the tooth surface) and R2 regions.

Statistical analysis: PASW Statistics 18 software was used for data analysis. Independent Samples T Test analysis was performed to determine the statistical significance level between the R1 and R2 area temperatures of the teeth numbered according to the triadan numbering system. Mann Whitney U analysis method was used to determine the statistical significance level of the temperature difference (ΔT°C) between maxillary (104 and 204 number) and mandibular (304 and 404 number) canine teeth. $P< 0.05$ was considered statistically significant. The values in the article are given as mean ± standard error.

Results

Dental and gingival examinations of 16 male dogs aged 2-5 years, brought to the Surgery Clinic of Burdur Mehmet Akif Ersoy University, Faculty of Veterinary Medicine, Animal Hospital with castration request, were performed. Clinical and thermographic examination of 64 canine teeth was performed. The temperatures measured in the ROI area are shown in Table 1.

The average R1 area temperature of canine teeth numbered 104 was measured as 32.71±0.33°C and R2 area temperature as 32.28±0.31°C. The R1 area temperature representing the temperature caused by the pulp on the enamel surface of all teeth was higher than the R2 area temperature. The temperature difference between the areas was measured as 0.43°C. However, this temperature difference was not statistically significant ($P> 0.05$).

Table 1. The temperature of the coronal pulp on the tooth surface (R1) and the enamel temperature (R2) in canine teeth.

Case No	$Canine_{104}$		$Canine_{204}$		$Canine_{304}$		$Canine_{404}$	
	R1	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
1	33.8	32.7	36.2	35.8	34.7	34.4	33.5	33.0
2	31.5	31.1	31.7	31.4	31.5	31.4	32.2	31.9
3	31.6	31.3	31.5	31.1	31.5	31.4	32.5	32.4
4	31.9	31.5	31.9	31.5	32.0	31.8	31.4	31.3
5	32.3	32.0	33.0	32.3	32.5	31.8	31.9	31.7
6	34.3	33.8	32.9	32.8	31.8	31.6	31.3	30.4
7	33.3	32.8	31.5	31.3	30.2	30.0	31.8	31.6
8	31.8	31.6	30.6	30.2	30.7	30.6	30.2	30.1
9	30.6	30.3	31.3	31.0	31.6	31.2	30.7	30.3
10	33.3	32.8	33.1	32.8	32.9	32.6	33.0	32.8
11	34.7	34.1	33.7	33.3	34.1	33.8	33.2	33.0
12	33.2	32.5	34.0	33.6	30.9	30.6	31.5	31.2
13	30.4	30.2	33.7	33.2	33.3	33.1	33.1	32.7
14	34.1	33.7	34.6	34.3	32.4	32.1	33.9	33.4
15	34.4	34.1	33.6	33.1	32.7	32.5	32.2	32.0
16	32.3	32.1	33.7	33.4	33.6	33.3	32.8	32.5

The average R1 area temperature of canine teeth numbered 204 was measured as 32.93±0.36°C and R2 area temperature as 32.56±0.35°C. The R1 area temperature of all teeth was higher than the R2 area temperature. The temperature difference between the areas was measured as 0.36°C. The temperature difference was not statistically significant (P> 0.05).

The average R1 area temperature of canine teeth numbered 304 was measured as 32.27±0.31°C and R2 area temperature as 32.01±0.30°C. The R1 area temperature of all teeth was higher than the R2 area temperature. The temperature difference between the areas was measured as 0.26°C. The temperature difference was not statistically significant (P> 0.05).

The average R1 area temperature of canine teeth numbered 404 was measured as 32.20±0.25°C and R2 area temperature as 31.89±0.25°C. The R1 area temperature of all teeth was higher than the R2 area temperature. The temperature difference between the areas was measured as 0.30°C. The temperature difference was not statistically significant (P> 0.05).

The average R1 area temperature of canine teeth numbered 404 was measured as 32.20±0.25°C and R2 area temperature as 31.89±0.25°C. The R1 area temperature of all teeth was higher than the R2 area temperature. The temperature difference between the areas was measured as 0.30°C. The temperature difference was not statistically significant (P= 0.66).

A temperature difference of 0.34°C was detected between the coronal pulp temperature and enamel surface temperature values of 64 canine teeth. However, this temperature difference was not statistically significant (P> 0.05).

The ΔT value of maxillary and mandibular canine teeth (numbered 104 and 204) was 0.59°C higher than the ΔT value of mandibular canine teeth (numbered 304 and 404). However, this difference was not statistically significant ($P< 0.05$). The ΔT values are shown in Table 2.

Table 2. The temperature difference (ΔT°C) between the R1 and R2 areas in canine teeth.

Case No	$Canine_{104}$ ΔT°C (R1-R2)	$Canine_{204}$ ΔT°C (R1-R2)	$Canine_{304}$ ΔT°C (R1-R2)	$Canine_{404}$ ΔT°C (R1-R2)
1	1.1	0.4	0.3	0.5
2	0.4	0.3	0.1	0.3
3	0.3	0.4	0.1	0.1
4	0.4	0.4	0.2	0.1
5	0.3	0.7	0.7	0.2
6	0.5	0.1	0.2	0.9
7	0.5	0.2	0.2	0.2
8	0.2	0.4	0.1	0.1
9	0.3	0.3	0.4	0.4
10	0.5	0.3	0.3	0.2
11	0.6	0.4	0.3	0.2
12	0.7	0.4	0.3	0.3
13	0.2	0.5	0.2	0.4
14	0.4	0.3	0.3	0.5
15	0.3	0.5	0.2	0.2
16	0.2	0.3	0.3	0.3

Discussion

The dental pulp is a vital tissue inside the tooth. The dental pulp consists of blood vessels, nerves, connective tissue, and specialized cells. It serves several functions, including providing nourishment to the tooth, conveying sensory information, and participating in the formation of dentin. The dental pulp is protected by the hard tissues of the tooth, enamel, and dentin (Kazmi et al., 2022). Hence, it is necessary to test that the pulp is alive, and its vitality continues for the tooth to remain vital. Since the pulp is living tissue, a temperature change on the tooth surface would be caused by the blood flow here.

The volume of the pulp cavity decreases with age. Other factors affect pulp size. These include tooth type, tooth position, gender, race, nutritional status, and environmental factors (Maeda, 2020). However, the pulp does not always cause a temperature change on the tooth surface as seen in Figure 1. It was thought that this was due to the shrinkage of the pulp volume caused by age and other factors mentioned in the literature.

Dental pulp has three parts: coronal pulp, radicular pulp, and apical foramen. Coronal pulp fills the pulp cavity in the crown part of the tooth (Kazmi et al., 2022). In this study, only the coronal pulp temperature was evaluated. The coronal pulp provides a temperature increase in an area equal to its volume on the tooth surface. Although there is no statistically significant

temperature increase, the temperature increase on the tooth surface can be distinguished in different color palettes on thermograms (Figure 1).

In veterinary dentistry, determining the state of pulpal health is crucial for identifying and treating a range of dental pathologies. However, accurately assessing the condition of the pulp can be challenging due to the protective layer of enamel and dentin that surrounds it, and the fact that animals cannot communicate their pain to their caregivers (Proulx et al., 2022). In methods determined by the sensory response, situations may be evaluated as a false positive or false negative. The dog's failure to respond in situations where there is pain can cause erroneous evaluations. The method used in this study provides the possibility of objective evaluation based on temperature increase. The thermal camera's sensitive detectors detect even the smallest temperature changes. Thus, it was thought that the thermal camera could give an idea to the clinician about pulp health.

EPT is used to determine the vitality of a tooth pulp by applying an electric current to the tooth and measuring the response of the pulp. During this test, an electric signal is applied to a tooth and a live pulp typically responds with a sensation such as pain. The device used during the test controls the strength and duration of the electric signals applied to the tooth, indicating the status of the tooth pulp (Chen & Abbott, 2009). Evaluations made with a thermal camera do not require a sensory response. Therefore, a thermal camera provides an advantage to the clinician in evaluating pulp health status.

There are objective methods that measure dental vitality directly or determine the blood flow or oxygen saturation of the pulp. These include laser Doppler flowmetry, spectrophotometry, pulse oximetry, thermography, and optical coherence tomography (Aubeux et al., 2021; Gopikrishna et al., 2009; Grabliauskienė et al., 2021). The advantages of these methods are that they can evaluate dental vitality without radiation exposure, painlessly and non-invasively. The disadvantages are that they are expensive, lack standardized protocols, and can be affected by numerous factors (Aubeux et al., 2021; Gopikrishna et al., 2009). In this study, difficulties were encountered in standardizing the diagnostic protocol. There are not enough studies where pulp vitality is evaluated with the thermal camera.

Conclusion

This study is the first study that used thermographic methods to evaluate pulp health in dogs. It was observed that the pulp cavity in the healthy canine tooth caused a 0.34°C increase on the tooth surface in dogs. To see the adequacy of the thermal camera and the reliability of

the findings obtained in this regard, studies comparing different examination methods are needed.

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This research received no grant from any funding agency/sector.

Ethical Statement

This research was carried out based on the permission of Burdur Mehmet Akif Ersoy University Local Animal Ethics Committee dated 13.03.2019 and numbered 504.

Conflict of Interest

The authors declared that there is no conflict of interest.

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