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Method for auxiliary use of thermography in diagnosing inflammation in the coxofemoral joint in dogs

Método para uso da termografia no diagnóstico auxiliar da inflamação na articulação coxofemoral em cães

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Abstract

Joint diseases are relatively common in domestic animals, such as dogs. The involved inflammation produces thermal emission, which can be imaged using specific sensors that allow capturing of infrared images. Given that there have been few reports on the use of thermography in the diagnosis of inflammation associated with diseases of the hip joint in dogs, we here propose a method for identification of inflammatory foci in dogs by using infrared thermometry. The present study aimed to find non-invasive and low-cost resources that could facilitate a clinical diagnosis in cases with inflammation in the coxofemoral joint of dogs. To this end, we developed a system in which the Flir Systems TG165 thermograph is coupled to a black PVC cannula with a 30-cm focus-to-animal distance. External effects of the environment on the temperature of the animals were compared with the body temperature as measured by a conventional thermometer. Thirty-one dogs with and without inflammation in the coxofemoral joint underwent clinical evaluation. We verified that the temperature registered by the thermograph in the animals with joint inflammation was significantly different from that in control animals without inflammation, in the lateral projection. The method showed a sensitivity of 80%, specificity of 87.5%, and accuracy of 83.87%. This standardized method of diagnosis of inflammatory foci in the coxofemoral articulation of dogs by way of thermography showed sensitivity, specificity, and satisfactory accuracy.

Key words: Infrared. Joint disease. Radiation.

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Resumo

Tentando buscar recursos não invasivos e de baixo custo, para auxiliar o diagnóstico clínico em casos de inflamação na articulação coxofemoral de cães, idealizou-se o presente trabalho, que teve como objetivo propor um método de diagnóstico, em casos de inflamação na articulação coxofemoral de cães, desenvolvido a partir do registro do aumento da temperatura no local da inflamação, mediante o emprego de um termógrafo do tipo TG165 da Flir Systems acoplado a uma cânula de PVC, negra, com 30 cm de distância foco-animal para diminuir os efeitos externos que o ambiente exerce sobre a temperatura dos animais, e comparando-a com a temperatura corpórea, aferida por um termômetro convencional. Foram submetidos à avaliação clínica, 31 cães com e sem inflamação na articulação coxofemoral, onde verificou-se que a temperatura, registrada pelo termógrafo, dos animais pertencente ao grupo com inflamação na articulação apresentou diferença significativa na projeção lateral, em relação a temperatura dos animais do grupo sem doença articular, também aferida através do aparelho termográfico. O método apresentou sensibilidade de 80%, especificidade de 87,5% e precisão de 83,87%. Conclui-se que a padronização do método de diagnóstico de focos inflamatórios na articulação coxofemoral de cães pela termografia apresentou sensibilidade, especificidade e precisão satisfatória.

Palavras-chave: Doenças articulares. Radiação. Infravermelho.

Introduction

Joint diseases are relatively common in domestic animals, particularly in dogs (FRIES; REMEDIOS, 1995; RETTENMAIER et al., 2002). Although the condition is more clinically relevant in medium and large breeds, such as Fila Brasileiro, Rottweiler, German Shepherd (WOOD et al., 2000; GINJA et al., 2009), there is no predilection for dog breeds. Lust et al. (1993) posited that the condition has a genetic component, although its occurrence has also been associated with aging in dogs.

Osteoarthritis, a multifactorial disease, may be associated with secondary causes, such as age, chronic lesions, local inflammation, obesity, hip dysplasia, and other factors (FRIES; REMEDIOS, 1995). The disease may have a symptomatic picture that does not correspond with radiological findings (WALLACE, 1987), and can range from a slight discomfort to severe pain when touched, claudication, and voluntary paresis of the hind limbs, which can progress to degenerative joint disease (FRIES; REMEDIOS, 1995; ALLAN, 2002; NOGUEIRA; TUDURY, 2002; NOGUEIRA et al., 2005; ROCHA et al., 2013).

Inflammatory processes result from the release of mediators and cell signaling initiated by molecules

deriving from the harmful process (SERHAN; CHIANG, 2004; OLIVA et al., 2004; RANG et al., 2008). These mediators trigger a cascade of events that include reprogramming of local metabolic activity and disruption of the balance of immune-neuroendocrine responses, involving changes in the patterns of blood flow and thermal energy distribution, which is accompanied by an increase in local temperature (CHANDRASEKHARAN et al., 2002; TAZIMA et al., 2008).

The thermal energy generated in this way in a living organism could, initially, be eliminated by convective processes, conduction, and radiation emission in the infrared spectral range, with wavelengths ranging from 2 to 20 μm (WINSOR; WINSOR, 1985; ANBAR et al., 1998). Furthermore, the relationship between high temperatures and is well known (RING, 2004).

Specific sensors that allow capturing of infrared images were developed based on the Stefan-Boltzmann law (JONES, 1998), and with advances in thermography techniques, thermal sensitivity of up to 0.02°C has been achieved. The non-invasiveness of thermography allows mapping of the body and detection of foci of thermal emission that maybe associated with inflammatory processes

(RING; COLLINS, 1970; EDDY et al., 2001; ROBERTO; SOUZA, 2014). Since the development of the technique, several studies in veterinary and human medicine (BRIOSCHI et al., 2007; NUNES et al., 2007; BANDEIRA et al., 2012; SEGUNDO; AZEVEDO, 2015) have been performed.

Given the paucity of literature on the use of thermography in the diagnosis of inflammation associated with diseases of the hip joint in dogs, we proposed a method for the diagnosis of these inflammatory foci using infrared thermometry.

Material and Methods

The protocols described below complied with biosafety and ethical standards and were approved by the Ethics Committee for Animal Experimentation of University XXX under protocol number 063/2016.

Adult dogs ($n = 31$), of different breeds and both sexes, were obtained from the clinic of the Veterinary Hospital of the XXX University.

Upon admission of the animals, the personal data of the guardian and data of the animal, such as its name, age, sex, weight, and rectal temperature (measured using a clinical thermometer), were recorded in a registration form. An informed consent form was also filled out, in which the guardian was informed about the research conditions, and they agreed to the inclusion of the animal in the planned study. Each animal was then subjected to a detailed anamnesis and clinical orthopedic examination, as suggested by Nogueira and Tudury (2002). Animals with clinical signs compatible with hip inflammation underwent radiographic examinations, and those who exhibited clinical complaints of claudication were included in the study. The control group was comprised of dogs that did not have hip articulation problems.

After registration, all animals were transferred to an air-conditioned room at 25°C and relative air humidity above 70%, for 20 minutes, to minimize

the effects of the environment on the temperature of the animal. After this period, the temperature at the axis of the hip joint in the anteroposterior and lateral projection was recorded using a digital thermograph (model TG165, Flir Systems, Wilsonville, OR, USA), with a resolution of 60×80 pixels, to capture electromagnetic waves in the infrared spectrum, which makes it possible to record temperature within 3 seconds of exposure. In this study, a 30-cm long PVC cannula, coated with matte black film, was coupled to the end of the device to minimize external interferences that could hinder the readings. The temperature of the animals was recorded simultaneously, minimizing the effects of circadian rhythms on temperature variation.

After positioning the animal appropriately for recording the temperature, the cannula and the equipment were juxtaposed over the desired region. The same focal length was maintained throughout, and emission proportional to an area of 1.23 cm² was obtained. The emissivity of the equipment was adjusted to $\epsilon = 0.95$ in all measurements. The data obtained were tabulated and used in calculation.

For animals without joint disease, the interval between the temperature recorded by the equipment (T_t) and body temperature (T_b) was obtained by the equation $DT_{wnjd} = T_{t_{free\ jd}} - T_{b_{free\ jd}}$. This difference was normalized by the relation $DT_{free\ jd} / T_{b_{free\ jd}}$ to allow comparison of readings could be compared. The mean and standard deviation of these control animals were obtained by the equation $DT_{free\ jd}^M / T_{b_{free\ jd}}$.

For animals clinically diagnosed with joint problems, the same procedure was applied, and the difference obtained as $DT_{wjd} = T_{t_{wjd}} - T_{b_{wjd}}$.

The inflammation difference (ID), which may be associated with inflammation of the hip joint was obtained as the difference between the value $DT_{wjd} / T_{b_{wjd}}$ measured for each animal with joint problems and the mean value of the parameter $DT_{sda}^M / T_{b_{free\ jd}}$ obtained for the control group animals ($DT_{free\ jd}^M / T_{b_{free\ jd}}$); i.e., $ID = DT_{wjd} / T_{b_{wjd}} - DT_{free\ jd}^M / T_{b_{free\ jd}}$.

When the ID is positive, the animal could be considered to be suffering inflammation. If the value was negative, the animal was considered “free of inflammation” by thermographic evaluation.

Calculations were performed separately for temperature recorded for the anteroposterior and lateral projections.

Using Student's *t*-test in Microsoft Excel 2010 software, the statistical significance of differences in mean values was evaluated with a significance level set at $p < 0.05$. The sensitivity and specificity of the diagnosis determined in this way were calculated, following the recommendations of Reis (2003) and Hastie (2009), to assess the viability of the method as a diagnostic aid.

Results and Discussion

The mean age of the dogs was 9.5 ± 2.5 years. Of the 31 dogs, 22 were males and nine were females, and their mean weight was 16.76 ± 6.73 kg.

We sought to develop a diagnostic method based on temperature values measured by a thermograph, as no effective method for assigning a parameter indicating association between temperature variation in the hip joint and the presence of local inflammation has been reported in the literature.

The use of thermography and associated techniques has been used in $T_{j_{AAD}}$ diseases in veterinary medicine previously, for instance, the study by Purohit and McCoy (1980), which diagnosed inflammation in the superficial digital flexor tendons in race horses. Other important studies were that of Ring and Ammer (2008), which investigated the occurrence of diseases involving the neuromuscular and skeletal systems using thermal imaging, and that of Turner (2010), which investigated the detection of low back pain in horses with spinal problems,

and found thermographic evaluations to have a sensitivity of 98.5%. Rantanen (2010) proposed algorithms for evaluating thermographic images related to the presence of foci of inflammation in superficial and deep areas in horses.

To develop the method, it was necessary to consider the natural decrease in the animal's body temperature, as estimated from the rectal temperature taken at the level of the joint, and to define to what extent this temperature would drop in animals not suffering from joint disease, as expressed by $DT_{free\ jd} = T_{t_{free\ jd}} - T_{b_{free\ jd}}$. We normalized this difference, i.e., $DT_{free\ jd}$ was divided by $T_{b_{free\ jd}}$ (body temperature), so that these values could be compared across animals. Thus, the mean value for the normalized difference $DT_{free\ jd}^M / T_{b_{free\ jd}}$ was obtained so that this measure could be used when measuring the normalized temperature difference obtained in animals with joint disease, by the equation $ID = [(T_{b_{wjd}} - T_{t_{wjd}}) / T_{b_{wjd}}] - D_{free\ jd}^M / T_{b_{free\ jd}}$.

This equation above should be written as $[DI + D_{free\ jd}^M / T_{b_{free\ jd}}] / TA_1 = [(T_{b_{wjd}} - T_{t_{wjd}}) / T_{b_{wjd}}] / TA_2$, where TA_1 and TA_2 correspond to the contributions of room temperature at the time of thermographic evaluations. Since the tests were carried out in an air-conditioned environment at 25°C , where all animals were allowed to rest for at least 20 minutes to reduce their stress and provide thermal accommodation, TA_1 was considered to be equal to TA_2 and the equation was simplified as follows: $ID = [(T_{b_{wjd}} - T_{t_{wjd}}) / T_{b_{wjd}}] - D_{free\ jd}^M / T_{b_{free\ jd}}$.

The values of ID obtained, respectively, for animals without and with joint disease, relevant to the hip joint at the anteroposterior projection, shown in Tables 1 and 2. No significant differences were found between the normalized temperature difference values between these two groups ($p = 0.0827$).

Table 1. Standardized temperature differences at the anteroposterior projection in the hip joint of animals without joint disease.

Animal	Weight (Kg)	Sex	Tc _{sda} (W)	Tt _{sda} (W)	(Tc _{sda} -Tt _{sda})/Tc _{sda} (C/1C)
1	12.0	M	38.6	31.1	0,194
2	16.4	M	38.7	29.2	0.246
3	20.0	M	38.0	31.1	0,182
4	13.0	M	38.4	36.6	0.047
5	14.0	F	38.3	32.3	0.157
6	13.4	F	38.0	30.0	0.211
7	15.0	F	38.1	36.5	0.042
8	12.0	M	38.6	31.1	0,194
9	15.0	F	38.1	30.3	0.205
10	16.2	M	38.7	29.2	0.246
11	18.0	M	38.0	33.2	0.126
12	14.8	M	38.6	33.8	0.124
13	12.0	M	38.6	28.7	0.257
14	12.9	F	38.6	33.0	0.145
15	19.0	M	38.4	30.3	0.211
16	16.9	M	38.5	36.6	0.049
				Mean ± MSE	0.164 ± 0.018

Male (M), Female (F); Tc_{sda} - Body temperature of animals without joint disease;

Tt_{sda} - Temperature at the joint of animals without joint disease; C - Degrees Celsius; C/1C -Degrees Celsiusper degree Celsius of body temperature.

Table 2. Standardized temperature difference atanteroposterior projection in the hip joint of animals with joint disease and the difference in inflammation.

Animal	Weight (Kg)	Sex	Tc _{cda} (W)	Tt _{cda} (W)	(Tc _{cda} -Tt _{cda})/Tc _{cda} (C/1C)
1	15.9	F	38.5	32.4	0.158
2	14.3	M	38.0	33.2	0.126
3	14.0	M	38.3	36.9	0.037
4	38.4	F	38.1	27.9	0.268
5	22.0	M	39.3	29.6	0.247
6	10.9	F	38.9	28.8	0.260
7	14.0	M	38.2	36.9	0.034
8	27.3	M	38.7	29.5	0.238
9	35.2	M	38.4	30.8	0,198
10	18.5	M	39.2	27.5	0.299
11	10.0	M	39.1	27,1	0.307
12	25.2	F	37.9	28.0	0.261

continue

continuation

13	11.2	M	39.2	29.1	0.258
14	10.1	M	39.0	29.3	0.249
15	17.0	M	38.5	26.6	0.309

Male (M), Female (F); T_{cda} - Body temperature of animals with joint disease; T_{tda} - Temperature at the joint of animals with joint disease; Inflammation difference $ID = [(T_{cda} - T_{tda}) / T_{cda}] - D_{sda}^M / T_{cda}$, where D_{sda}^M / T_{cda} represents the mean of the normalized values obtained for the control group; C - Degrees Celsius; C/1C - Degrees Celsius per degree Celsius of body temperature.

For the lateral projection, there was a significant difference in the normalized joint temperature differences between animals with and those without joint disease ($p = 0.0407$) as shown in Tables 3 and 4, demonstrating that, in the thermographic evaluation using the proposed methodology, the angle of capture of the temperature at the joint has

an effect, as, anatomically, the regional circulatory contributions and the superposition of the tissues associated with the joint affect the homogeneity of the temperature distribution by influencing the propagation of thermal energy by conduction, convection, and even by emission of infrared radiation in local tissues.

Table 3. Standardized temperature difference of the hip joint at the lateral projection of animals without joint disease.

Animal	Weight (Kg)	Sex	T_{cda} (W)	T_{tda} (W)	$(T_{cda} - T_{tda}) / T_{cda}$ (C/1C)
1	12.0	M	38.6	28.7	0.257
2	16.4	M	38.7	30.3	0.217
3	20.0	M	38.0	33.0	0.132
4	13.0	M	38.4	34.8	0.094
5	14.0	F	38.3	28.6	0.253
6	13.4	F	38.0	28.6	0.247
7	15.0	F	38.1	32.0	0.160
8	12.0	M	38.6	36.2	0.062
9	15.0	F	38.1	28.9	0.241
10	16.2	M	38.7	28.3	0.269
11	18.0	M	38.0	30.9	0.187
12	14.8	M	38.6	27.6	0.285
13	12.0	M	38.6	34.5	0.106
14	12.9	F	38.6	31.1	0.194
15	19.0	M	38.4	29.2	0.240
16	16.9	M	38.5	34.8	0.096
				Mean \pm MSE	0.119 \pm 0.017

Male (M), Female (F); T_{cda} - Body temperature of animals without joint disease; T_{tda} - Temperature at the joint of animals without joint disease; C - Degrees Celsius; C/1C - degrees Celsius per degree Celsius of body temperature; MSE - mean standard error.

Table 4. Standardized temperature difference of the hip joint at the lateral projection of animals with joint disease and the thermal difference in inflammation.

Animal	Weight (Kg)	Sex	T _{cda} (W)	T _{t_{cda}} (W)	(T _{cda} - T _{t_{cda}})/T _{cda} (C/1C)	ID (C/1C)
1	15.9	F	38.5	34.7	0.099	-0.091
2	14.3	M	38.0	30.6	0.195	0.005
3	14.0	M	38.3	33.0	0.138	-0.052
4	38.4	F	38.1	27.2	0.286	0.096
5	22.0	M	39.3	26.8	0.318	0.128
6	10.9	F	38.9	28.4	0.270	0.080
7	14.0	M	38.2	33.0	0.136	-0.054
8	27.3	M	38.7	28.1	0.274	0.084
9	35.2	M	38.4	30.4	0.208	0.018
10	18.5	M	39.2	28.0	0.286	0.096
11	10.0	M	39.1	27.9	0.286	0.096
12	25.2	F	37.9	27.1	0.285	0.095
13	11.2	M	39.2	26.8	0.316	0.126
14	10.1	M	39.0	28.8	0.261	0.072
15	17.0	M	38.5	25.8	0.330	0.140

Male (M), Female (F). T_{cda} - body temperature of animals with joint disease. T_{j_{AAD}} - Temperature at the joint of animals with joint disease. Thermal difference in inflammation ID = [(T_{cda} - T_{t_{cda}})/T_{cda}] - D_{sda}^M/T_{cda}^M, where D_{sda}^M/T_{cda}^M represents the mean of the values normalized for the control group. C - Degrees Celsius; C/1C - degrees Celsius for each degree Celsius of body temperature.

Table 4 shows a comparison of the ID values, whose unit (C/1C) corresponds to the local temperature variation per degree of body temperature change in the evaluated animal, in animal with and those without joint disease. Among the animals with a positive ID, some demonstrated greater variations than others, which may be associated with the intensity of the inflammatory process in the tissues related to the hip joint. It is important to note that some animals were clinically symptomatic of joint inflammation (3 of 15 animals, 20%), but had a negative ID value, i.e., an ID that was below the critical limit of thermal variation in the joints of animals without joint disease.

Given that two of the animals without joint disease showed normalized temperature difference values above the critical limit, we determined the sensitivity and specificity as 80.0%, and 87.5%, and the accuracy of the method was 83.87%. Since sensitivity measures the proportion of animals

clinically diagnosed with joint inflammation that showed a positive ID value, and specificity measures the proportion of animals without joint disease that had a negative ID value, the results obtained in this study could be considered satisfactory, and similar to those obtained by Head et al. (1999), who reported a sensitivity of 86.0% and a specificity of 89% when using thermography to identify and monitor breast cancer. These results also emphasized the importance of this methodology as a tool that could aid in the diagnosis of inflammatory processes, in agreement with the report by Ring and Ammer (2008), who investigated diagnosis of diseases of the neuromuscular and skeletal systems by thermography.

There were no significant differences in the temperature values obtained for males and for females ($p = 0.382$ for evaluations in the anteroposterior direction and $p = 0.648$ for evaluations in the lateral direction).

Thermography has been shown to be useful for the evaluation of abnormal alterations in the patterns of superficial temperature variation caused by tissue injuries in local musculature and tissues, although some authors, such as Valberg (2006), have pointed out that this procedure may have limited applicability to the identification of deeper lesions.

The emission of thermal energy in the form of infrared radiation does not occur uniformly but varies according to the characteristics of local and circulatory metabolism and its regulation by the immune and neuroendocrine systems, as pointed out by Anbar (1994). According to Cetinkaya and Demirutku (2012), thermography is particularly useful for identification of deep inflammatory foci the thermographic images show fields of contrast between areas with different thermal density, which was associated with the local temperatures measured in the regions containing inflammatory foci.

This thermographic imaging protocol allows monitoring of the evolution of inflammatory processes in the lateral projection of the hip joint, even during therapy, as demonstrated by Basile et al. (2010a,b), who evaluated the evolution of the inflammatory picture of the thoracic limbs of horses over a period of 150 hours, and demonstrated the oscillation of temperature in the inflamed areas during therapy, up to the final phase of the treatment.

Conclusions

The results of the present study indicate that this infrared thermography method can be used for diagnosis of inflammatory foci at the hip joint in dogs, with good sensitivity, specificity, and satisfactory accuracy when the images are captured at the lateral projection of the joint. The simplicity of the method, the stability of the results, and the rapidity of the diagnosis make this a useful clinical approach that can improve animal welfare.

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