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HEAT TRANSFER IN SYNOVIAL JOINTS DURING THE PROCESS OF THE HEATING ARTICULAR: A PILOT STUDY

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Abstract: This study aims to measure superficial and deep tissue layers temperature variations in a dog´s knee to carry through a first analyze of the heating transfer process in synovial joint. The joint heating was done with two hidrocollator packs, applied during 30 minutes over skin surface of the knee joint involving it completely. Before and during all the heating process, the rectal temperature and the surface layers were monitored by a mercury thermometer and by thermocouples. The registry of the surface thermic field was done before and immediately after the use of the hidrocollator packs using a thermocamera. The inicial and terminal temperature values comparation were used to evaluate the effects of the hidrocollator packs over the temperature of each one of the tissue layer. The behavioral analysis of the temperature during the heating process was made based on temperature graphics in function of the time for each one of the regions in study. The mean variation temperature of the joint were of 5,7ºC ± 2,2ºC. The magnitude of the variation and the behavior of the temperature were, although, different for each one of the evaluated layers. Decreasing exponential equations of the first and second orders represented well the profiles of the temperature for the heating process and allowed the development of a relation between the temperature of the skin surface with the temperature intra-articular.

Keywords: Tissue heating, bioheating transfer, synovial articulation, temperature measurement

1. Introduction

The muscle and joint heating has been considered an effective method for the treatment of various human pathological conditions (Abramson *et al.*, 1964; Castor and Yaron, 1976; Borell *et al.*, 1980; Chen *et al.*, 1997; Lessard *et al.*, 1997; Sluka *et al.*, 1999; Starkey, 2001; Bel and Prentice, 2004). The benefits of this therapy depend, however, of the temperature that the biological tissues will reach during the heating process. In accordance with the literature, to occur therapeutic effects of the tissue heating it is needed that the temperature of the target treated structure varies within a certain average amplitude (Lehmann *et al.*, 1970; Harris and McCroskery, 1974; Weinberger and Lev, 1991). Alterations beyond this threshold will induce to placebo treatment, with no clinical effectiveness, and also the excess variations might damage the tissues (Lehmann *et al.*, 1966; Liu *et al.*, 1999; Greenhalgh *et al.*, 2004).

Currently, various method and techniques are available for the promotion of the heating of the corporal structures. Hidrocollator packs, ultra-sound devices, short-wave and micro-wave are among the most frequently used, mainly in physiotherapist applications (Fadilah *et al.*, 1997; Drapper *et al.*, 1999; Drapper *et al.*, 2002; Robertson *et al.*, 2005). These resources generate differentiated standards of tecidual heating which will influence as much in the magnitude as in the depth in witch the temperature modifications may occur (Lehmann *et al.*, 1966; Weinberger *et al.*, 1989; Liu *et al.*, 1999; Jiang *et al.*, 2002). Therefore, understand how the temperature of the different tissue alters in responds to the application of a certain thermal modalities is a important step to fundament the clinical effectiveness and safety of the thermotherapy treatments.

The studies about the temperature behavior of the biological systems during the heating process have been focused, in most of the cases, in the evaluation of the temperature behavior during the heating processes in a single tissue layer (Garret *et al.*, 2000; Deng and Liu, 2002). Rare are the literature works that evaluate the process of heating transfer considering the jointly as several tissue layers. Such fact has been contributing for the decision of the professionals about the use of the thermo therapy's modalities were made based more in the professional experience and less in the scientific evidences.

The present work comes, however, to add it to the existent research about the heating transfer in living tissue, using innovative approach a first analyze of the temperature behavior in the different tissue layer of the animal articulation. It aims, specifically, to measure superficial and deep tissue layers temperature variations in a dog´s knee to determine a mathematical model witch relate the temperature of the intra-articular with the temperature of the skin surface of the synovial joints *in vivo*.

2. Material and Method

For the realization of this study it was used an adult dog (*Canis familiaris*), with no defined race, with male genre, with corporal mass of 21,0 kg. The experimental protocol used was approved by the *Comitê de Ética em Experimentação Animal – CETEA* from University Federal of Minas Gerais and was conducted obeying to the ethical principles from the *Colégio Brasileiro de Experimentação Animal – COBEA* (Cobea, 2001).

The experiment was carried through in the surgical block in the Veterinarian Hospital of the University Federal of Minas Gerais, to the temperature of 22,9^{o}C and air relative humidity of 41%. All the procedures were carried through in the right knee, with the animal positioned in left lateral decubitus, over a surgical table adequately lined. Before the beginning of the procedures, the animal was pre-medicated with xilazina 2% (1,0 mg/kg, intravenous) and right after submitted the general anesthesia. This was inducted with pentobarbital 3% (12,5 mg/kg, intravenous) and kept with additional doses of the same fármaco, in such way that the animal continued during the whole experimental period in the third plane of the third anesthetic level.

After tricotomia and anti-sepsia of the skin surface of the knee D with PVPI® and iodate alcohol, were positioned, in an aseptic way, thermocouples type K special class (0,25 mm of tickness and error limit of ±1,1^{o}C or ±0,4%) in the areas which it was desired to monitor the joint temperature: externally, in the skin surface, one medially and another laterally to the joint and, internally, in the subcutaneous, pericapsular and intra-articular regions. These last ones were implemented and positioned in their respective places with the help from cannulas which served as guide to the passage of the thermocouples. Before being positioned in their respective places, all the thermocouples were previously sterilized. The perception of the tissue sensation during the insertion of the thermocouples helped in the localization of the subcutaneous and periscapsular. The confirmation of the thermocouples in the intra-articular region was made by the previous aspiration of the synovial liquid through the cannula. All the thermocouples (external and internal) were fixed in their respective places by simple sutures.

To help the analysis and to check if the methodology used for the application of the thermal resources were effective in promoting uniform skin heating, and consequently of the layer close to them, the thermal field of the skin surface was also monitored immediately before and after the heating application using a thermo camera *Thermovision AGEMA*-P20 (*FLIR SYSTEM*™). For the realization of these measurements the considered emissivities for the skin was 0,95 and the equipment were positioned with 0,60 m of distance from the target, focused over the anterior aspect of the knee. The images captured by the thermocamera were transferred for a computer and processed using the ThermaCAM™ Researcher 2001 (*FLIR SYSTEM*™) program.

The rectal temperature was also monitored during the whole experimental period using, initially, a glass mercury thermometer *BD* Thermoflat®, with 0,1ºC resolution, in which later add it a thermocouples type K, with the same already described characteristics. The thermometer reading was made each ten minutes, until the positioning time of the thermocouple in the rectal mucosa and, later, each half hour for the clinical evaluation of the animal. The initial readings of the mercury thermometer were used to calculate the mean values of the rectal anesthesia pré-sedation/induction and the ones of the thermocouples to evaluate the behavior of the corporal temperature during the application of the thermotherapy resource.

The system for data acquisition DATAPAC©1990-2005, *Klin Tracker for Windows v3.04*, was used for acquisition and storage of the data. This acquisition started after the thermocouples were positioned and fixed in their respective places and extended continuously until the ending of the experiment, with the data register each two seconds. At the end of the experimental period, the data were transferred to a micro-computer (Pentium® M45-S355, TOSHIBA) to be processed and analyzed.

As source of heating it was used two hidrocollator packs (*MERCUR Body Care*®), weighting 1,0 kg, previously warm in water at the mean temperature of 80,2^{o}C ± 0,1^{o}C during half an hour. The hidrocollator packs were applied at an mean temperature of 76,7^{o}C ± 0,1^{o}C, for a period of 30 minutes, one medially and the other laterally to the knee, in such a way that the joint became completely involved. Before being applied, the hidrocollator packs were wrapped in a towel, in such way that existed two layers of towel between the skin and the compresses. Crepom bands were used for the fixation of the packs and to keep an adequate contact between the thermo therapy resource and the joint surface. The thermal isolation of the system was made with the help of three other towels positioned over the hidrocollator packs, in order to involve the group completely. The application of the thermal resource followed the recommendations of the *Australian Physiotherapy Association* (*APA*) (Robertson *et al.,* 2001). During the process, the leg of the target joint remained elevated (approximately 30º abduction), in order to avoid interference in the thermal exchanges due to the contact between the physical agent and the surgical table.

The hidrocollator packs were also monitored during the while period of joint heating by thermocouples type K, identical to the ones used for the temperature measurement of the joint, positioned inside each ones of the hidrocollator packs. The acquisition and storage of these data were carried through the DATAPAC©1990-2005 system.

By the end of the experimental period, the animal was submitted to euthanasia and the dissection of the knee joint was carried through for confirmation of the thermocouples positioning in each one of the tissue layers of interests.

2.1 Methods for the analyze of the temperature data

The physical model to simulate the knee of the animal was to consider an unique cylinder (Fig. 1), compound by for annealing concentric layers, each one representing a different kind of tissue: the skin, the subcutaneous, the periscapular and intra-articular regions. The mean of the initial (T_i) and terminal (T_f) temperatures, the maximum (T_{max}) and minimum (T_{min}) temperature and the differences between the maximum and minimum temperatures ($\Delta T_{max-min}$) and between the terminal and initial temperatures (ΔT_{f-i}) for each one of the regions were used to evaluate the effect in the thermal resource over the temperature of each one of the tissue layers.

The behavior analysis of the temperature during the heating process of the joint were made based on the temperature graphics T (°C) in function of the time t (s) obtained for each one of the regions in study. Basing of the aspect of the obtained curves, exponential decreasing equations [Eq. (1)] were selected to do the mathematical adjust of data. These were carried through using the programs ORIGIN v 6.0 e MATLAB v 6.5.1.

$$T = T_0 + \Delta T \cdot e^{-t/\tau} \tag{1}$$

Where: T is the temperature (°C) in the time t
t is the time (s)
T_0 is the temperature (°C) in the time $t = \infty$
ΔT is the difference between the initial and terminal temperature Ti (°C) e T_0
τ is the time constant of the system(s)

The time constants τ obtained were compared between them and, based in this comparison, it was looked determine the existence of relations between the temperature behavior of the evaluated areas, with emphasis in the relation of the skin as the intra-articular region. The time (t_e) from which the temperature variation in the advance of time was smaller than ± 0,5% of the terminal value of the temperature was also determined for each one of the evaluated layers and using as criteria for the definition of the system stability.

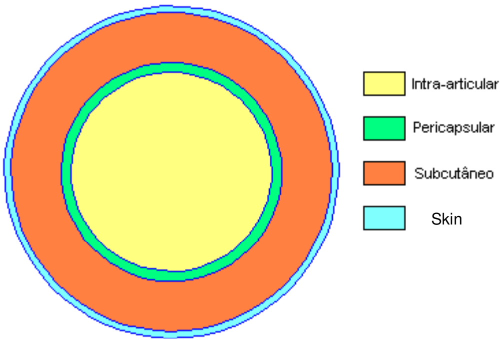

Figure 1. Physical model designed to represent the joint knee of a dog.

3. Results and Discussion

The mean of the rectal temperature before the animal be sedated and anesthetized was of 37,8°C ± 0,1°C and changed to 35,9°C ± 0,2°C at the end of the experiment. According to literature (Giacobini, 1990), the corporal temperature for a healthy dog it varies in normal situations, between 37,5°C a 39,9°C. The lower values of the corporal temperature found at the end of the experimental period may be consequence of the depressive effect of the drugs used to sedate and anesthesia the dog. According to Muir and Hubbel (1995), Prado *et al.* (1997) e Maria *et al.* (2004), the xilazina and the pentobarbital, due the reduction of the conduction of the stimulation of the brain cortex, may cause undesired pharmacological effects, such as cardio-respiratory depression, decrease in the corporal temperature, salivation and vomit.

The acquired data in the preceding time of the application of the thermal resource shown that the temperature of the evaluated layer are different among themselves and are lower than the rectal temperature (Tab. 1). This founds are in agree with Pardasani and Adlakha (1995) that say that the temperature is not equal a will not either be equally sustained in the different parts of the body. In the most central part, it tends to be a in a higher level and precisely controlled, in contrast to the most superficial layers, which are commonly lower and varies more, according with the external conditions.

Can be observed that as much as there is a thermal gradient between the corporal temperature and the temperature of the skin, there exist also between the mean temperature of the skin (31,9°C ± 1,9°C) and the temperature intra-articular (33,1°C ± 0,4°C). According to Low and Reed (2001), this difference may be kept thanks to the low thermal conductivity of the interpostos tissues between the skin and the most central region (Bowman *et al.*, 1975) and to the organization of the vascular net and distribution of the blood flow in these tissues (Chen and Holmes, 1980; Pardasani and Adlakha, 1995). This organization could also explain the differences found between the temperature of the skin regions, a time that the main vases responsible for the irrigation of the lower members are concentrated in the internal side of the legs (Pennes, 1948; Chato, 1980; Weinbaum and Jiji, 1985; Qinghong *et al.,* 2003).

Table 1. Rectal and articular temperature before the application of the thermical resources (mean ± standard deviation).

Situation	Temperature (°C)					
	Rect	**Skin (medium region)**	**Skin (lateral region)**	**Subcutaneo**	**Pericapsular**	**Intra-articular**
Pré-thermotherapy	36,3 ± 0,2	33,7 ± 0,1	29,8 ± 0,3	30,5 ± 0,1	29,5 ± 0,1	33,4 ± 0,1

3.1 Joint heating

The hidrocollator packs, at the mean temperature of 76,7°C ± 0,1°C, applied by 30 minutes over the skin surface of the knee, were effective in raising the temperature of all the studied regions (Tab. 2). This found is in agreement with the majority of the thermo therapy works, which mention the increase of the tissue temperature in reply to the superficial heating (Abramson *et al.,* 1964; Mainardi *et al.,* 1979; Weinberger *et al.,* 1989; Draper *et al.,* 2004). In mean. The temperature of the join had suffered an elevation of 5,7°C ± 2,2°C, with peak in the temperature occurring after 30 minutes of heating.

Table 2. Temperature of the skin and the subcutaneous, pericapsular and intra-articular regions for the process of heating articular (mean ± standard deviation).

Temperature (°C)	Regions				
	Skin (medium region)	**Skin (lateral region)**	**Subcutaneo**	**Pericapsular**	**Intra-articular**
Ti	33,9 ± 0,3	30,4 ± 0,6	30,6 ± 0,1	29,4 ± 0,1	33,5 ± 0,1
Tf	39,2 ± 0,1	36,2 ± 0,1	37,3 ± 0,0	38,6 ± 0,1	36,8 ± 0,0
Tf – Ti	5,3 ± 0,2	5,8 ± 0,6	6,6 ± 0,1	9,1 ± 0,2	3,3 ± 0,1
Tmax	39,4 ± 0,2	36,3 ± 0,1	37,4 ± 0,2	39,2 ± 0,2	36,9 ± 0,1
Tmax – Ti	5,5 ± 0,2	5,0 ± 0,1	6,6° ± 0,1	9,8 ± 0,2	3,4 ± 0,2

The behavior of the temperature in the hidrocollator packs, of the skin and of the intra-articular region during the heating process can be visualized in the Fig. 2. It is possible to observe that the temperature elevation of the tissue does no follow the temperature reduction of the hidrocollator packs. This keeps falling until the end of the heating process ($t_{e(pack)}$ = 1718 seconds) to the step that the intra-articular region and specially from the skin tend to stabilize quicker ($t_{e(intra\text{-}artic)}$ = 1408 seconds e $t_{e(skin\ surface)}$ = 1128 seconds, respectively). According to Low and Reed (2001), this happened because the heating added in one single part of the body is dispersed by conduction and by convection until become lost in other surfaces and, consequently, the temperature increase in a specific place will be the equilibrium between the gain and dispersion of the heating. Keller and Seiler (1971) e Vanhoutte *et al.* (2002) tell that the body hability in alter the blood flow which circulate through the vascular plexus and by the tissue anastomoses arterio-venosas is one of the main elements of the control of the temperature of the tissue.

At the and of the heating process, the hidrocollator packs presented the mean temperature of 63,3°C ± 1,10°C, the skin of 37,2°C ± 1,5°C and the intra-articular region of 36,8°C ± 1,1°C. The analise of the images refering to the thermical field of the skin surface in the pos-heating (Fig. 3B) had shown that the used technique for the application of the hidrocollator packs was adequate to promote homogenous heating of the skin, once that this presented itself relatively uniform. Such fact is important in the interpretation of the results once that the temperature of each one of the tissue layers was measured in only one point and an non-uniform distribution of the heating could result in mistaken interpretation of the data.

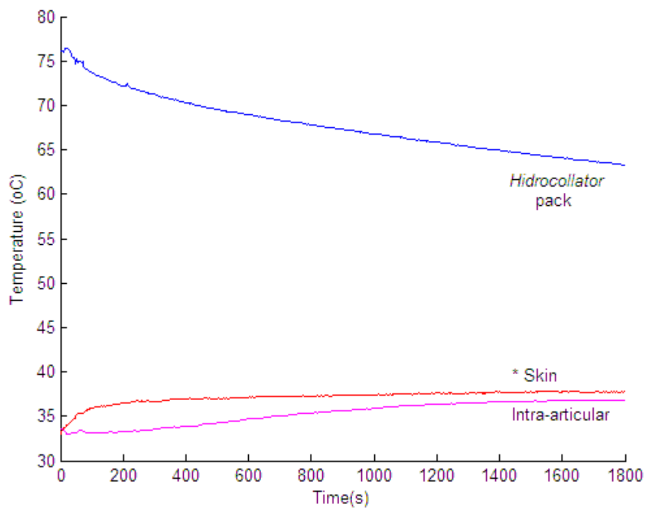

Figure 2. Behavior of the temperature in the hidrocollator packs, of the skin surface and of the intra-articular region during the heating period.
*Skin represents the mean temperature between the medium and lateral region of the skin of the knee.

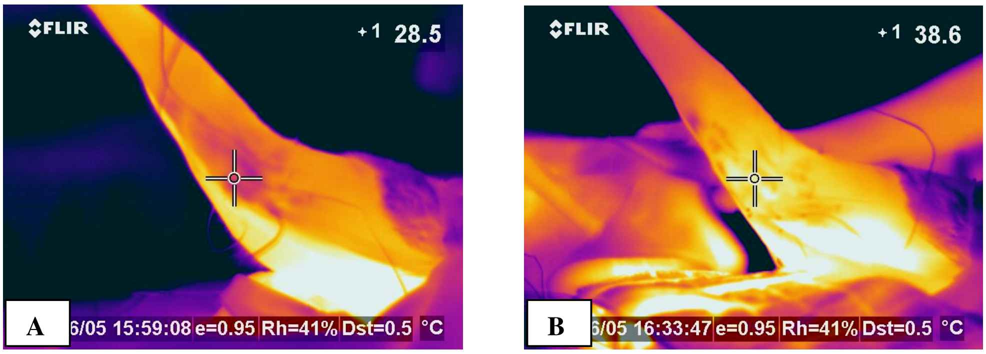

Figure 3. Thermal field of the skin surface in the joint knee of the dog. A: pre-thermotherapy image; B: image after themotherapy.

The temperature profile during the time for the heating process of the joint can be viewed in the Fig. 4. It can be observed that in all the tissue layers, the temperature layers presents the exponential behavior in the time and, with the exception of the periscapular region, all of them tend to steady state at the end of the experiment.

As general rule, the time in which the tissue will respond to a determine gradient of temperature will depend on its thermal capacity C (J/^{o}C), in other words, of it mass (ρV) and of is specific heat (c_p). Any increase in C will make the thermal system responds more slowly to the variations in their thermal environment and will increase the needed time for the thermal equilibrium be reached. This time can be interpretaded as the thermal time constant τ (s) of the system (Incropera and Dewitt, 2003). The time constants for each one of the layers of the model and of the joint of the knee of the dog are represented in Tab. 3. It can be observed that, with exception of the medium skin and of the intra-articular regions the time constants of the layers are relatively close.

Lehmann *et al.* (1966) tell that the distribution and the temperature behavior of the tissue layer can be marcadely modified by the cooling effect produced by the increase in the blood flow in the skin region. This one intends to avoid that the tissue temperature exceeds the limits of the thermal safety, transferring the excess of energy for out of the system (Draper *et al.,* 2004).

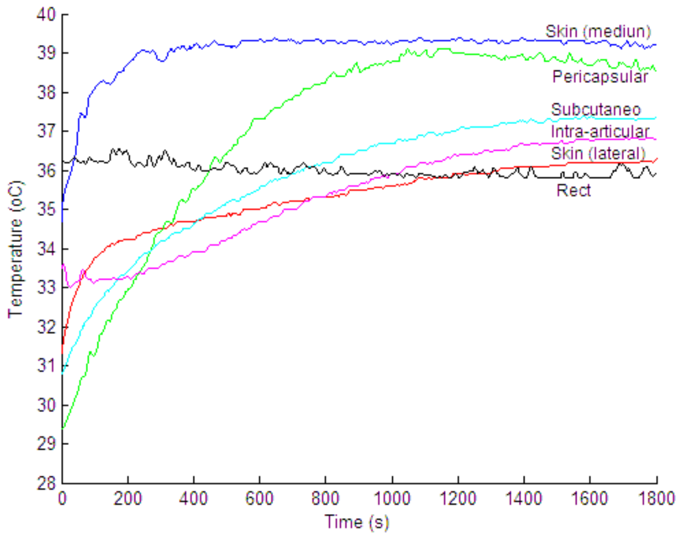

Figure 4. Behavior of the rectal temperature, of the skin (medium and lateral side) and of the subcutaneous, periscapsular and intra-articular regions during the heating process of the knee of the dog.

Table 3. Time constants of the regions that constitutes the joint model for the heating process.

Joint layers	Time constant (s)*
Skin (lateral region)	562,6
Skin (medium region)	91,4
Subcutaneo	509,2
Pericapsular	361,0
Intra-articular	1510,0

*Note: time constants considering the tissue behavior as being represented by a decreasing exponential function of the first order.

Among the evaluated tissue layers, can be observed that the temperature of the intra-articular region presents a different behavior compared to the other in the initial time of the heating, keeping practically stable until the time t = 200 s ("dead time"). Only after this interval is that this one began to rise. Horvath and Hollander (1949) described, in their study, a bahevaior similar to this. According to the author, the skin temperature increased marcadly in reply to application of hot compresses in the skin surface, while the temperature of the deeper tissues reduces slightly ou reamined stable. This phenomenom was called "reflex cooling" and rarely has been described in the literature. According to Horvath and Hollander (1949), the increase of the temperature of the surface causes the blood to be directed to the most superficial tissue layers, inductind to a momentaneous fall in the temperature of the deep tissues or avoinding for some times that the same varies in reply to the applied heating source. Weinberger and Levi (1991) tell also that when the tissue heating be carried through conduction, the fact that the thermal conductivity differ from a tissue to other limits, in certain way, the time needed for variations of the temperature in the most deep tissue layers.

3.2 Analise of the behavior of the temperature during the process of joint heating

The analise of the regression curves of the temperature for the layers from the articular model shown that the thermic behavior of the tissues can be well represented by exponential decreasing equations of the first and second order ($Chi^2 = 0{,}02$; $R^2 = 0{,}99$). The inclusion of another term, as provided by the exponential function of the third order, does not provided improved in the aproximation. This sugests that the heating transfer in the living tissues during the heating process, although a complex phenomenon , occurs by two main mechanisms, the conduction and convection, depending of the physiological characteristics of the tissues, sometimes one predominating the other and, in other moments, complement themselves.

As a general rule, the results of the regression for the temperature of the medium region of the skin, for the subcutaneous tissue and for the periscapular region does not differed in a significant way while using the exponential equations of the first, second of third order, show that in these tissues, the behavior of the temperature can be represented by a exponential function of the first order (Fig. 5 a Fig 7). Such fact sugests that the heating transfer in this regions has string dependencies with one of the mechanisms of heating transfer. The physiological characteristics in this regions (tissue of greater perfusion relating to the lateral skin and the intra-articular regions) indicate that this mechanism is probably conection.

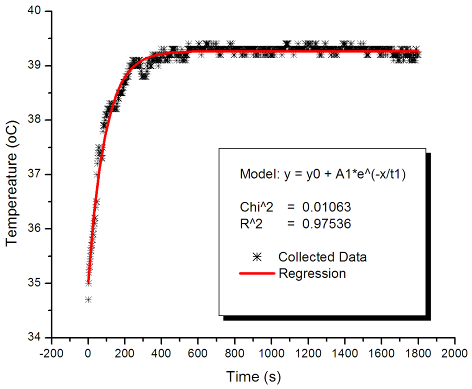

Figure 5. Result of the data regression for the temperature for the medium region of the skin (T_{pm}) using the exponential function of the first order, where: $T_{pm} = 39{,}3 - 4{,}2 \cdot e^{-t/91{,}4}$

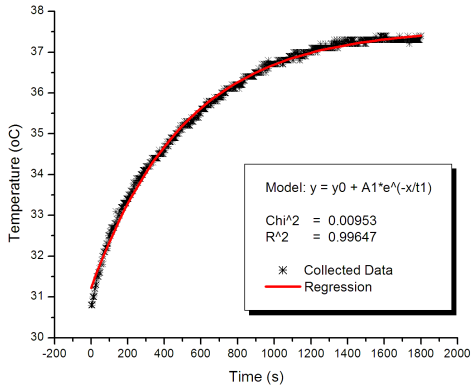

Figure 6. Result of the data regression for the temperature subcutaneo tissue (T_{sc}), using the exponential function of the first order, where: $T_{sc} = 37{,}6 - 6{,}4 \cdot e^{-t/509{,}2}$

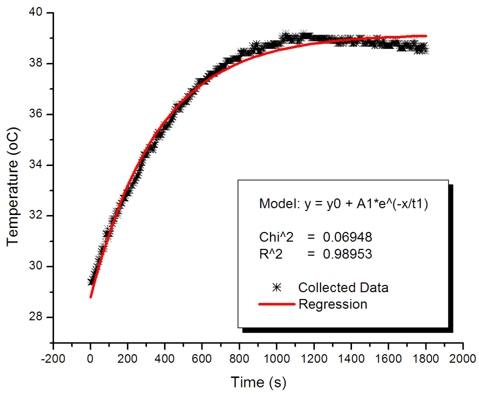

Figure 7. Result of the data regression for the temperature of the periscapular region (T_{pc}), using the exponential function of the first order where: $T_{pc} = 39{,}2 - 10{,}4 \cdot e^{-t/361{,}0}$

On the other way, the temperature behavior of the lateral region of the skin and the intra-articular region are well represented by exponential functions of the first order (Fig. 8 e Fig. 9), indicating that in this regions the heating transfer by thermal difusion and by convection are both responsable by the heating transfer that occur in this tissues.

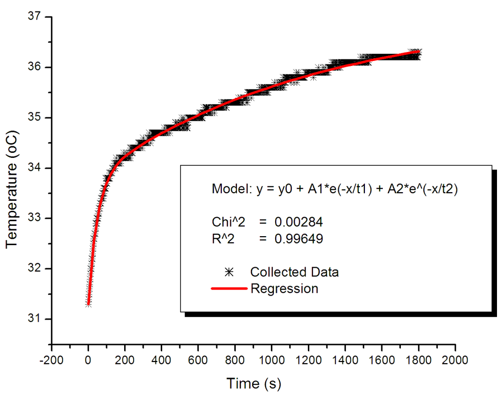

Figure 8. Results of the data regression for the temperature of the lateral region of the skin (T_{pl}), using exponential function of the second order, where: $T_{pl} = 37{,}1 - 2{,}5 \cdot e^{-t/48{,}3} - 3{,}3 \cdot e^{-t/1223{,}2}$

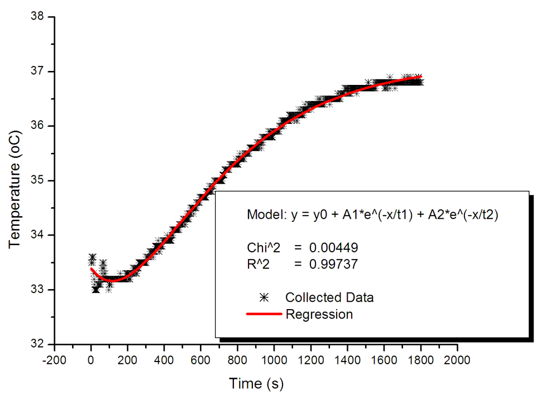

Figure 9. Result of the data regression for temperature of the intra-joint medium (T_{ia}) using the exponential function of the second order, where: $T_{ia} = 37{,}2 - 21{,}5 \cdot e^{-t/422{,}7} + 17{,}8 \cdot e^{-t/320{,}0}$

The analises carried through, together with the results of the regression, show that the lateral region of the skin and the intra-articular region has some similar physiological characteristics and that with the exception of the dead time period, the thermal behavior of this two regions tends to follow a similar profile (both dont hit the equilibrium state). Bases in that information, we executaded a new data regression of the temperature of the intra-articular region in which the "dead time" (200 seconds) was rejected. The new obtained time constant for the intra-articular region was compared with the time constant of the lateral region of the skin in order to determine if the temperature in this two regions could be related by some equation. The resulting equation of the new data regression of the temperature data for the intra-articular region, obtained using an exponential equaton of the first order was:

$$T_{ia} = 37{,}1 - 6{,}0 \cdot e^{-t/639{,}2} \quad \textbf{(2)}$$

In this equation can be verified that the time found constant (τ = 639,2 seconds) is close to the time constant of the regression of the skine curve (lateral region), when this one was obtained also by a decreasing exponential function of the first order (τ = 560 segundos).

Calculating then the difference (*Dif*) among the equation of the lateral region of the skin (Fig.8) and of the intra-articular region (Fig. 9), obtained after the "dead time" being rejected, and considering that both posses the same time constant τ, it can be concluded that:

$$Dif = T_{ia} - T_{pl} = (37{,}17 - 6{,}0 \cdot e^{-t/\tau}) - (36{,}6 + 3{,}4 \cdot e^{-t/\tau}) \quad \textbf{(3)}$$

In order to express *Dif* in function of the temperature of the lateral region of the skin T_{pl} and in that way relate the temperature of the intra-articular region T_{ia}, it added and subtracted the number 27,7 in the Eq. (3), obtaining:

$$Dif = 0{,}76 \cdot T_{pl} - 26{,}8 \quad \textbf{(4)}$$

Therefore:

$$T_{ia} = 1{,}76 \cdot T_{pl} - 26{,}8 \qquad (t > 200 \text{ s}) \quad \textbf{(5)}$$

The curve correpondent to the Eq. 5, can be vistualized in the Fig.10. The same represents a good aproximation for the colected data, since it disdain the initial time of the heating process (t < 200 seconds). The erros relative to the different times in which the intra-articular temperature begins to be stimated are represented in the Tab. 4.

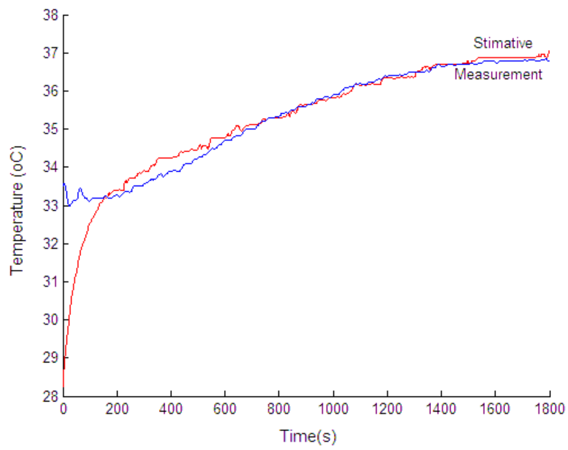

Figure 10. Profile of the temperature for the intra-articular region during the heating process. Blue curve (measurement): represent the values of the temperature for the intra-articular region of the knee of the dog, colected during the experimental period; Red curve (stimative): represents the values of the temperature stimated based in the equation $T_{ia} = 1{,}76 \cdot T_{pl} - 26{,}8$

Table 4- Maximum error for the equation related to the time in which the temprature is estimated.

Inicial time (s)	**Maximum error (%)**
200	1,42%
400	1,42%
800	0,70%
1200	0,70%
1500	0,70%

7. Conclusions

The pilot carried through evidentiated that the joint knee of a dog is a good model for the study of the tissue temperature during the processes of heating and cooling, once the the changes of the temperature inducted in the skin, in the subcutaneous tissue, in the periscapular region and in the intra-articular region by the application of the themotherapy resource could be evaluated.

The analyze of the colecter data and the obtained curves with this pilot had shown that the process of heating transfer in the synovial joint is a complex phenomenon due to involve physical and physiological aspects that, beyond being particular to each tissue, interact between themselves, during even more complex the study of the heating transfer in the biological systems.

Even though, a mathematical model realting the temperature of the ost internal tissue layers and of the skin surface could have been stabilished based in the regression, indicating that the temperature heating of the intra-articular region can be estimated based on the temperature of the lateral region during the heating process.

8. References

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