THE USE OF THERMOGRAPHY IN CLINICAL THORACOLUMBAR DISEASE IN DACHSHUNDS

by

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Abstract

Objective – To evaluate the value of thermography in a clinical setting for dogs with thoracolumbar disease.

Animal Population – Thirteen client-owned short-haired Dachshunds presented to Kansas State University Veterinary Medical Teaching Hospital for paraparesis/paraplegia and diagnosed with thoracolumbar disease via myelogram/CT and confirmed during surgical decompression.

Procedures - Thermal images were obtained with a hand-held infrared camera with a focal plane array uncooled microbolometer. Images were obtained after physical exam and client consultation and prior to any pre-anesthetic medications, approximately 30+ minutes after entering the hospital. Additional images were obtained in the same manner at 24 hour intervals following surgery until discharge. Six regions of interest (ROI) were identified and recorded. The ROIs identified were right and left thoracic, lumbar and pelvic regions. From each of these regions average temperatures were taken.

Results - Temperatures in the pelvic region were significantly cooler ($p< 0.001$) over all days as compared to the thoracic and lumbar regions and to the overall mean temperature. The lumbar region temperature was significantly greater on day 0 as compared to thoracic and pelvic regions but was not significantly different on any of the following days. The thoracic temperatures were significantly greater than the lumbar and pelvic regions on day 2 but there was no significant difference on any of the preceding or following days. There was no significant difference between left and right on any of the days. There was a correlation of the pelvic region temperatures on day 3 in relation to the presenting neurological grade.

Conclusion - Although there were varied heat patterns detected in dachshunds with IVDD, these patterns did not correlate with neurological grade, lesion site or lateralization of the lesion. Although there was a correlation between neurological grades and the pelvic region temperatures on day 3, this time period is unlikely to provide clinical utility.

Clinical Relevance - The results of this study suggest that thermography is not a useful tool for the diagnosis or prognosis of thoracolumbar disease in dogs in a clinical setting.

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Dedication

I would like to dedicate this thesis to Mary Sargent, my loving wife and companion, who without her support everything I do would not be possible.

CHAPTER 1 - Thermography

History

Temperature in medicine

Temperature has been used in diagnosing illness since the time of Hippocrates, when, after placing wet mud on skin, it was noticed that it dried faster over tumors. It was not until the 16th century that thermometers were first developed. In 1597 Galileo developed the thermoscope, a crude version of a thermometer. (1) Fahrenheit, Huygens, Roemer and Celsius all proposed a need for a calibrated scale in the late 17th and early 18th centuries. Celsius proposed a scale based on the freezing and boiling points of water, with 100 being the freezing point and 0 being the boiling point. Linnaeus proposed a reversal of this scale as it is in use today. (1)

Dr. Carl Wunderlich developed the first clinical thermometer in 1868 that has been in use for the last 130 years. Today there has been a move away from glass thermometers to disposable thermocouple systems or aural radiation thermometers for clinical use.

John Herschel made the first thermal image in the early 1800's, which he called a thermogram, using carbon particles and alcohol in a process known as evaporography. The first electronic thermal sensors were developed in the 1940's. These scans were very slow, taking 2-5 minutes to complete. It was not until the 1970s and the advent of computers that color thermograms were possible.(2) With today's microprocessors, images are able to be captured and stored in small hand held units in real time.

Types of thermography

Liquid crystals

Liquid crystal temperature sensors became available in usable form in the 1960s. Originally the crystalline substances were painted on the skin, which had been previously coated with black paint. Three or four colors became visible if the paint was at the critical temperature range for the crystals. Micro-encapsulation of these cholesteric esters meant that these sensors could be packaged in a more convenient form as plastic sheet detectors.(2)

Microwave thermography

Microwave thermography systems consist of a radiation receiving antenna which can be placed in contact with the skin to minimize reflective loss at the tissue-air interface. The antenna can also be placed a short distance from the skin. The received signal is passed through multiple stages of amplification before sampling. The system is calibrated by comparison with a calibrated noise signal. Microwave thermography systems have shown the ability to detect temperature changes on the order of tenths of degrees Celcius.(3)

Both liquid crystal detectors and microwave thermography require contact with the skin, which itself may alter surface thermal conditions.(4)

Infrared thermography

Physics

Today's thermographic cameras detect radiation within the infrared spectrum of the electromagnetic spectrum. The electromagnetic spectrum covers EM wave energy having wavelengths from thousands of meters down to fractions of the size of an atom. Commonly recognized energies within the spectrum are radio waves, microwaves, infrared (heat), visible light, ultraviolet, x-rays and gamma radiation. Infrared radiation (IR) waves range from 0.9–14 µm. (5) Although infrared thermography is not without its own unique drawbacks, it does not require surface contact.

There are some complicating factors involved in measuring IR. The amount of energy emitted by a body is governed by the Stefan-Boltzmann radiation law for real bodies where σ is the Stefan-Boltzmann constant, T is the thermodynamic temperature and ε emissivity.

$$M(T,\varepsilon) = \varepsilon \cdot \sigma \cdot T^4$$

Radiant existence depends not only on temperature, but also on the emissivity value. Furthermore, an object with emissivity ε < 1 (all real objects) reflects (transmits) part of the radiation from the surroundings (Kirchhoff radiation law), and radiation passing through the atmosphere is attenuated. Measured radiant power φ can be then written:

$$\emptyset\left(T_{object}, T_{ambient}^{effctive}, T_{atmosphere}, \varepsilon, \tau\right) = \varepsilon \cdot \tau \cdot \emptyset(T)_{object} + (1-\varepsilon) \cdot \tau \cdot (T)_{ambient} + (1-\tau) \cdot \emptyset(T)_{atmosphere}$$

where ε is the object emissivity and τ is transmission through the atmosphere. Emissivity is a property determining energy transfer. It defines the fraction of radiation emitted by an object as compared with that emitted by a perfect radiator (blackbody). Emissivity value lies in ε ∈ (0, 1) and depends on object material, surface condition (surfacing method, geometry), object temperature, wavelength, and direction of radiation.(6) Theoretically the emissivity of a perfect black body equals 1, whereas the emissivity of a perfect white body equals 0.

Objects with lower emissivities are more reflective and therefore measuring the temperature of these objects is more complex. Humans and animals have emissivities of about 0.98 and are very close to a black body in nature.(2)

Types

Although there are many different type of materials used for the detectors in thermographic cameras they can be divided into two types, cooled and uncooled.

Cooled detectors are typically contained in a vacuum-sealed case and cryogenically cooled. This greatly increases their sensitivity since their own temperatures are much lower than that of the objects from which they are meant to detect radiation. Typical cooling temperatures range from 4 K to 110 K, 80 K being the most common. Without cooling, these sensors (which detect and convert infrared energy in much the same way as common digital cameras detect light, but are made of different materials) would be 'blinded' or flooded by their own radiation. The drawbacks of cooled infrared cameras are that they are expensive both to produce and to run. Cooling and evacuating of cooling gases are power- and time-consuming. The camera may need several minutes to cool down before it can begin working. Although the components that lower temperature and pressure are generally bulky and expensive, cooled infrared cameras provide superior image quality compared to uncooled ones. (7) The sensitivity of cooled IR cameras is generally in the range of 0.01°C.(8)

Uncooled thermal cameras use a sensor operating at ambient temperature, or a sensor stabilized at a temperature close to ambient using small temperature control elements. Modern uncooled detectors all use sensors that work by the change of resistance, voltage or current when heated by infrared radiation. These changes are then measured and compared to the values at the operating temperature of the sensor. Uncooled infrared sensors can be stabilized to an operating temperature to reduce image noise, but they are not cooled to low temperatures and do not require bulky, expensive cryogenic coolers. This makes infrared cameras smaller and less costly. However, their resolution and image quality tend to be lower than cooled detectors. This is due to differences in their fabricational processes, limited by currently available technology.(7) The sensitivity of uncooled IR cameras is generally in the range of 0.1°C. Detection within 0.3°C is considered sufficient for most medical thermograms.(8)

Uses

Uses for IR imaging are quite varied. They are used by the military, law enforcement, aviation, transportation, the building and manufacturing industries, research, and in the medical and veterinary professions.

The military is one of the biggest users of IR systems. The use of IR allows the military to conduct missions in low visibility situations, resulting in both strategic and tactical advantages. Uses include target acquisition and sighting, reconnaissance, aviation and marine operations.

Law enforcement has used IR technology for surveillance and tracking in low light situations. Some of the current IR scopes are about the size of a flashlight. IR has been highly used by the border patrol, which uses both hand held systems and remote systems. IR has been quite useful for firefighters allowing them to see through smoke-filled rooms. Search and rescue team have also benefited from IR technology.

IR has seen use in the aviation, maritime, and transportation industries to aid in visibility in poor lighting conditions. It is even installed in some high-end passenger cars.

There are many uses in industry and the commercial segment for IR systems. Due to the high temperatures generated in many industrial processes, non-contact measurement of heat is essential in determining operating temperatures of the processes. Thermography is able to detect leaks of volatile gases which may pose a threat to human health. It can detect these leaks at a distance that is safe for the operator. Thermography is ideally suited to evaluating efficiency of heat sinks. Utility companies commonly use thermography to help detect impending failures, prevent electrical fires and monitor circuit loads. The construction industry uses IR imaging to evaluate heat loss from buildings, detect mold, water leaks and moisture.

Thermography has proven useful in studying biological systems. It has been used to monitor forests and crops for disease and climate and environmental impact. Thermography has been used in the study of honey bees and other insects. It was used to document behaviors of these bees that were previously unknown.(9)

Thermography in human and veterinary medicine is a developing field. It has advantages over other imaging techniques in that it non-invasive and with the current technology it is very rapid. It does not expose the patient to harmful x-rays like radiology. It can be performed without sedation or restraint and, in some instances from a distance.

Human Medicine

Infrared thermal imaging of the skin has been used for several decades to monitor the temperature distribution of human skin. Abnormalities such as malignancies, inflammation, and infection cause localized increases in temperature which show as hot spots or as asymmetrical patterns in an infrared thermogram. Even though it is nonspecific, infrared thermology is a powerful detector of problems that affect a patient’s physiology. While the use of infrared imaging is increasing in many industrial and security applications, it has declined in medicine probably because of the continued reliance on first generation cameras. There has been a resurgence of interest in medical applications of infrared thermography following new developments in software and camera technology.(10)

Blood Flow

Blood flow plays a major role in temperature regulation of the body. Local regions of hyperthermia can be associated with increased blood flow, while areas of hypothermia indicate diminished perfusion. An image generated by thermography can, therefore, be used to quantify blood flow into an organ or specific anatomical region.(4) Thermography has been used in human medicine to determine the circulatory status in ischemic limbs (11,12), renal transplant grafts(13), and skin grafts(14). Katz found that thermography was helpful in the early detection of acute compartment syndrome in trauma patients. He found that there was a temperature difference of 8.80°C between the proximal and distal legs in these patients.(15) In his work with skin flap grafts, de Weerd found that thermography registered successful arterial inflow as well as partial and total obstruction of arterial inflow.

Coronary Disease

An important use of thermography has been in the area of coronary disease. It has been applied in coronary artery bypass graft surgery to measure the cooling effect of cardioplegic solutions, or to evaluate coronary perfusion and graft patency.(16,17) Thermographic cameras have been used to detect atherosclerotic plaques within coronary vessels.(18,19)

Tumors

Thermography has been used to diagnose tumors and cancer. Kamardin and Kuzmichev reported on the use of thermography in the differential diagnosis of nodal goiter and thyroid cancer. The correct thermographic diagnosis was made in 59 of 66 patients with thyroid carcinoma.(20) Recently thermography was used to monitor angiogenesis in Kaposi's sarcoma patients. Kaposi's sarcoma (KS) is a highly vascular tumor that is a frequent cause of morbidity and mortality among people infected with acquired immunodeficiency syndrome (AIDS). The researchers concluded that thermography appeared to be very sensitive in assessing KS lesion progress during therapy.(21) The use of thermography has been used as an aid in the detection of breast cancer since the 1950s.(22) There has been some controversy over the technique, since contact thermography, as well as the removal of clothes, may change surface temperatures(23). This is further complicated by determining what represents a "normal" model(24), and the thermal changes associated with physiological changes, such as pregnancy(25), must be taken into account.(4) With the continued development of more sensitive infrared imagers(22) and dynamic infrared imaging(26), current state-of-the-art imagers are capable of detecting 3 cm tumors located deeper than 7 cm from the skin surface and tumors smaller than 0.5 cm can be detected if they are close to the surface of the skin.(22)(23)

Reproductive

Thermography has been used in reproductive research and diagnosis in both males and females. One study was able to link skin temperatures with ovulation.(27) IR thermography is used quite often to study the scrotum and testicles. In a recent study at the Tel Aviv University it was concluded that "Thermography is more sensitive and accurate for the detection of varicocele than Doppler ultrasound and physical examination, and it can be used for screening as a single modality in infertile men."(28) It has also been found useful in locating undescended testes which are nonpalpable and not detected by ultrasonography.(29) Thermography has also played a role in the study of human sexual function and dysfunction.(30,31)

Pain

Thermography has been used to study pain and anesthesia. Warm spots are often an indication of inflammation whereas cold spots may indicate sympathetic neuron activation. One study showed that there was a good relationship between changes in pain intensity and changes in symmetry of heat patterns for most of the disorders examined.(32) Another recent study showed that thermography can be used to reflect shoulder stiffness objectively in impingement syndrome, especially in those cases with a hypothermic thermal pattern.(33) Thermography has been used quite frequently in the study of complex regional pain syndrome type 1.(34,35) Other studies have looked at using thermography in evaluating local anesthesia protocols and effect. It was shown that thermography could provide an early and objective assessment of the success and failure of axillary regional blockades.(36)

Spinal Cord Injuries

As early as 1965 thermography has been examined for the use of patients with spinal cord injuries.(37) It has been documented that there are definite and sometimes very dramatic thermographic patterns in patients with spinal cord injuries.(38) In this study fourteen of fifteen subjects with complete spinal cord injuries had a thermal demarcation line across the trunk. This line represented a temperature gradient of 1 to 2.5 degrees Celsius. This transition line was very sharp and dramatic for ten of these individuals. These patterns have also been shown to correlate with phantom pain in these individuals.(39) One study showed that stimulating the spinal cord increased blood flow and helped relieve this phantom pain.(40) Recent research is investigating the use of thermography in the rehabilitation of spinal cord injury patients.(41)

Veterinary Medicine

Zoo Animals/Wildlife

There has been limited use of thermography for wildlife and zoo animals. There have been reports of diagnosing pregnancies in rhinoceroses(9) and giant pandas(42), and dead phalanges in elephants.(43)(9,43) Arenas evaluated the application of infrared thermal imaging to the tele-diagnosis of sarcoptic mange in the Spanish ibex.(44) In 2006, Dunbar found that thermograhpy could be useful to detect raccoons in the infectious stage and capable of exhibiting clinical signs of rabies.(45)

Herd Health

IR thermography has been used has been shown to be beneficial in herd heath programs for both swine and cattle. Röhlinger compared measurements made with infrared camera and a manual pyrometer on swine and found that results with the IR camera were comparable (46). Warriss found that ear temperatures in swine correlated with serum CK and cortisol levels, suggesting that higher temperatures were related to stress (47). Schaefer explored the early detection of disease in calves exposed to BVD. He found that IR temperatures, especially for facial scans, increased by 1.5°C to over 4°C ($P < 0.01$) several days to 1 wk before clinical scores or serum concentrations of acute phase protein indicated illness in the infected calves(48). In another study at the Plum Island Animal Disease Center, encouraging results were found by looking at foot temperatures as a screening method for foot-and-mouth disease (49). Using a combination of thermography and behavioral changes, Eicher found a greater change in temperatures and behavioral change in tail docked heifers than intact heifers during temperature manipulation. These changes were similar to those found in human amputees experiencing phantom pain of amputated limbs (50). In another study with dairy cattle Paulrud used a combination of ultrasound and thermography to study the effects on teats to over milking and considered them useful methods to indirectly and non invasively evaluate teat tissue integrity(51). Department of Animal Science, University of Manitoba, found that higher coronary band temperatures in cattle less than 200 days in milk was correlated with the incidence of sole hemorrhages and felt that thermography would be useful in monitoring hoof health in dairy cattle.(52)

Equine

Thermography has been used for the past 25 years in equine medicine. Specific applications include the foot, joint disease, long bone injuries, tendon injuries, ligament injuries, muscle injuries, and disease of the vertebral column.(8) Thermography can aid in the detection of numerous diseases of the foot including laminitis, navicular disease, abscesses and corns. It may help reveal disease in the early phase or when physical and radiographic findings are inconclusive.(53) A difference of more than 1°C between any of the four hooves is significant. In cases in which all the feet are involved, comparisons of the hoof temperature with the temperature of the area between the bulbs of the heel should be made. A difference of more than 1°C between any of the four feet is significant for foot lesions.(8) IR thermography can reveal inflammation associated with capsulitis and synovitis.(53) Thermal patterns of the joints have been shown to change 2 weeks before the onset of clinical signs of lameness. This permits alteration in training and close observation to prevent more serious disease.(8,53) Thermography of long bones is of less value except for evaluating dorsal metacarpal disease or stress fractures of the radius or tibia in areas where the bone is in close proximity to the skin. Thermography can help to distinguish between different grades of “bucked shin complex”. Changes in the thermographic pattern can precede clinical signs by up to 2 weeks.(8) Tendon and ligament lesions can also be seen up to 2 weeks prior to clinical signs. During assessment of healing the thermal changes do not correlate well with the structural reorganization of the tendon as assessed by ultrasonography. As the tendon undergoes neovascularization, the thermal pattern diffuses so that there is no longer a hot spot. (54) Thermography can help diagnose individual muscle injuries. IR offers two types of information important in the evaluation of muscle injury: it can locate an area of inflammation associated with a muscle or muscle group, and it illustrates atrophy well before it becomes apparent clinically.(8)Thermography seems to be particularly useful in diagnosing equine back pain. Localization of pain and radiology can be challenging in the equine patients due to their size. Many chronic locomotion faults, poor performance, and suspected spine related disease are difficult to diagnose and these problems are often inadequately localized and thus treated without success.(55) Contrary to most injuries, chronic back pain usually shows up as cold spots due to increased sympathetic nervous tone causing regionalized hypothermia from vasoconstriction.(55) Recently Fonseca combined thermography with ultrasound for equine back pain. He found that the two combined associated with a physical examination proved to be a rapid and efficient method for diagnosis of existing lesions in the thoracolumbar region.(56)

Small Animal

The use of thermography in small animals has been limited. Steiss found that thermography helped diagnose coccygeal muscle injury in English Pointers.(57) Recently Loughin evaluated thermographic imaging of the limbs of healthy dogs. He found that thermography produced consistent images with reproducible thermal patterns in ROIs examined in healthy dogs. Although the coat had a predictable influence to decrease the mean temperature, thermal patterns remained fairly consistent after the coat was clipped.(58) Thermographic patterns have been noted in dogs with spinal cord compression similar those seen in humans with spinal cord injury.(59) An experimental spinal cord lesion was created in 6 dogs with a balloon catheter and thermography was performed weekly for four weeks. Although a line of demarcation was not noticed, there was a significant decrease in temperature in the pelvic regions of these dogs as compared to the thoracic and lumbar areas. These temperature differences gradually returned to almost normal after four weeks.

Conclusion

Thermography is a developing technology in human and veterinary medicine. It has proven itself to be valuable in different settings and purposes. With developing technology thermography is becoming easier to perform as well as more accurate. It does not expose the patient to harmful radiation and can be performed without anesthesia or sedation. It has proven useful in helping to detect tumors, lameness, inflammation, blood flow during surgery and well as postsurgical, orthopedic and neurological injuries. With further studies and the advancement of the technology, thermography in a clinical setting will become a standard tool for both physicians and veterinarians.

References

(1) IMSS - Multimedia Catalogue - Instrument - IV.7 Thermoscope. Available at: http://brunelleschi.imss.fi.it/museum/esim.asp?c=404007. Accessed 7/22/2008, 2008.

(2) Ring EFJ. The historical development of thermometry and thermal imaging in medicine. Journal of medical engineering technology 2006;30(4):192.

(3) Medcyclopaedia - Microwave thermography. Available at: http://www.medcyclopaedia.com/library/topics/volume_i/m/microwave_thermography.aspx. Accessed 7/28/2008, 2008.

(4) YANG P P T,. LITERATURE SURVEY ON BIOMEDICAL APPLICATIONS OF THERMOGRAPHY. Bio-medical materials and engineering 1992;2(1):7.

(5) Wikipedia contributors. Electromagnetic spectrum. Available at: http://en.wikipedia.org/wiki/electromagnetic_spectrum?oldid=227278023. Accessed 7/24/2008, 2008.

(6)

Thermography Applications in Technology Research.

InfraMation 2004 Proceedings; 2004.

(7) Wikipedia contributors. Thermographic camera. Available at: http://en.wikipedia.org/wiki/infrared_camera?oldid=224340401. Accessed 7/27/2008, 2008.

(8) Turner . Diagnostic thermography. The Veterinary clinics of North America. Equine practice 2001;17(1):95.

(9) Kastberger G. Infrared imaging technology and biological applications. Behavior research methods, instruments, computers 2003;35(3):429.

(10) Jones BF. A reappraisal of the use of infrared thermal image analysis in medicine. IEEE transactions on medical imaging 1998;17(6):1019.

(11) Spence VA. The relationship between temperature isotherms and skin blood flow in the ischemic limb. The Journal of surgical research 1984;36(3):278.

(12) Chikura B. Sparing of the thumb in Raynaud's phenomenon. Rheumatology 2008;47(2):219.

(13) Kopsa H. Use of thermography in kidney transplantation: two year follow up study in 75 cases. Proceedings of the European Dialysis and Transplant Association 1979;16:383.

(14) de Weerd L. Intraoperative dynamic infrared thermography and free-flap surgery. Annals of plastic surgery 2006;57(3):279.

(15) Katz LM. Infrared imaging of trauma patients for detection of acute compartment syndrome of the leg. Critical care medicine 2008;36(6):1756.

(16) Suma H. Intraoperative coronary artery imaging with infrared camera in off-pump CABG. The Annals of thoracic surgery 2000;70(5):1741.

(17) Iwahashi H. New method of thermal coronary angiography for intraoperative patency control in off-pump and on-pump coronary artery bypass grafting. The Annals of thoracic surgery 2007;84(5):1504.

(18) Diamantopoulos L. Thermal heterogeneity within human atherosclerotic coronary arteries detected in vivo: A new method of detection by application of a special thermography catheter. Circulation 1999;99(15):1965.

(19) García-García HM. Diagnosis and treatment of coronary vulnerable plaques. Expert Review of Cardiovascular Therapy 2008;6(2):209.

(20) Kamardin LN. [Thermography in the differential diagnosis of nodular goiter and thyroid cancer]. Vestnik khirurgii im. I.I. Grekova 1983;130(5):70.

(21) Vogel A. Using quantitative imaging techniques to assess vascularity in AIDS-related Kaposi's sarcoma. IEEE Engineering in medicine and biology society conference proceedings 2006;1:232.

(22) González FJ. Infrared imager requirements for breast cancer detection. IEEE Engineering in medicine and biology society conference proceedings 2007;2007:3312.

(23) Borten M. Equilibration between breast surface and ambient temperature by liquid crystal thermography. Journal of reproductive medicine 1984;29(9):665.

(24) Osman MM. Thermal modeling of the normal woman's breast. Journal of biomechanical engineering 1984;106(2):123.

(25) Burd LI. The relationship of mammary temperature to parturition in human subjects. American journal of obstetrics and gynecology 1977;128(3):272.

(26) Agostini V. Evaluation of different marker sets for motion artifact reduction in breast dynamic infrared imaging. IEEE Engineering in medicine and biology society conference proceedings 2007;2007:3377.

(27) Shah A. Determination of fertility interval with ovulation time estimation using differential skin surface temperature (DST) measurement. Fertility and sterility 1984;41(5):771.

(28) Gat Y. Physical examination may miss the diagnosis of bilateral varicocele: a comparative study of 4 diagnostic modalities. The Journal of urology 2004;172(4 Pt 1):1414.

(29) Lai HS. Role of thermography in the diagnosis of undescended testes. European urology 1998;33(2):209.

(30) Kukkonen TM. Thermography as a physiological measure of sexual arousal in both men and women. The journal of sexual medicine 2007;4(1):93.

(31) Woodard TL. Contribution of imaging to our understanding of sexual function and dysfunction. Advances in psychosomatic medicine 2008;29:150.

(32) Sherman RA. Thermographic correlates of chronic pain: analysis of 125 patients incorporating evaluations by a blind panel. Archives of physical medicine and rehabilitation 1987;68(5 Pt 1):273.

(33) Park J. The effectiveness of digital infrared thermographic imaging in patients with shoulder impingement syndrome. Journal of shoulder and elbow surgery 2007;16(5):548.

(34) Niehof SP. Thermography imaging during static and controlled thermoregulation in complex regional pain syndrome type 1: diagnostic value and involvement of the central sympathetic system. Biomedical engineering online 2006;5:30.

(35) Niehof SP. Reliability of observer assessment of thermographic images in complex regional pain syndrome type 1. Acta orthopaedica belgica 2007;73(1):31.

(36) Galvin EM. Thermographic temperature measurement compared with pinprick and cold sensation in predicting the effectiveness of regional blocks. Anesthesia analgesia 2006;102(2):598.

(37) WRIGHT HM. NEURAL AND SPINAL COMPONENTS OF DISEASE: PROGRESS IN THE APPLICATION OF "THERMOGRAPHY". The Journal of the American Osteopathic Association 1965;64:918.

(38) Sherman RA. Differences between trunk heat patterns shown by complete and incomplete spinal cord injured veterans. Paraplegia 1987;25(6):466.

(39) Sherman RA. Relationships between near surface blood flow and altered sensations among spinal cord injured veterans. American journal of physical medicine 1986;65(6):281.

(40) Broseta J. Influence of spinal cord stimulation on peripheral blood flow. Applied neurophysiology 1985;48(1-6):367.

(41) Zivcak J. Methodics of IR Imaging in SCI Individuals Rehabilitation. IEEE Engineering in medicine and biology society conference proceedings 2005;7:6863.

(42) Durrant BS. New technologies for the study of carnivore reproduction. Theriogenology 2006;66(6-7):1729.

(43) Boldstar.
Boldstar Infrared Services Helps Zoo Staff with Ailing Elephant. 04/04/03; Available at: http://www.boldstarinfrared.com/elephant_boldstar.pdf. Accessed 7/29, 2008.

(44) Arenas AJ. An evaluation of the application of infrared thermal imaging to the tele-diagnosis of sarcoptic mange in the Spanish ibex (Capra pyrenaica). Veterinary parasitology 2002;109(1-2):111.

(45) Dunbar MR. Use of infrared thermography to detect signs of rabies infection in raccoons (Procyon lotor). Journal of Zoo and Wildlife Medicine 2006;37(4):518.

(46) Röhlinger P. [Results of no-contact measurement of surface temperature in swine]. Archiv für experimentelle Veterinärmedizin 1980;34(5):759.

(47) Warriss PD. Estimating the body temperature of groups of pigs by thermal imaging. The Veterinary record 2006;158(10):331.

(48) Schaefer AL. The use of infrared thermography as an early indicator of bovine respiratory disease complex in calves. Research in veterinary science 2007;83(3):376.

(49) Rainwater-Lovett . Detection of foot-and-mouth disease virus infected cattle using infrared thermography. The veterinary journal 2008.

(50) Eicher SD. Short communication: behavioral and physiological indicators of sensitivity or chronic pain following tail docking. Journal of dairy science 2006;89(8):3047.

(51) Paulrud CO. Infrared thermography and ultrasonography to indirectly monitor the influence of liner type and overmilking on teat tissue recovery. Acta Veterinaria Scandinavica 2005;46(3):137.

(52) Nikkhah A. Short Communication: Infrared Thermography and Visual Examination of Hooves of Dairy Cows in Two Stages of Lactation. Journal of dairy science 2005;88(8):2749.

(53) Eddy AL. The role of thermography in the management of equine lameness. The veterinary journal 2001;162(3):172.

(54) Correlation between contact thermography and ultrasonography in the evaluation of experimentally-induced superficial flexor tendonitis. Proceedings American Association of Equine Practitioners; 1987.

(55) Graf von Schweinitz D. Thermographic diagnostics in equine back pain. The Veterinary clinics of North America. Equine practice 1999;15(1):161.

(56) Fonseca B. Thermography and ultrasonography in back pain diagnosis of equine athletes. Journal of equine veterinary science 2006;26(11):507.

(57) Steiss J. Coccygeal muscle injury in English Pointers (limber tail). Journal of veterinary internal medicine 1999;13(6):540.

(58) Loughin CA. Evaluation of thermographic imaging of the limbs of healthy dogs. American journal of veterinary research 2007;68(10):1064.

(59) Kim W, Kim M, Kim SY, Sea K, Nam T. Use of digital infrared thermography on experimental spinal cord compression in dogs. Journal of Veterinary Clinics 2005;22(4):302.

(60) Bray . The canine intervertebral disk. Part One: structure and function. The Journal of the American Animal Hospital Association 1998;34(1):55.

(61) Seim H. Thoracolumbar disk disease: diagnosis, treatment, and prognosis. Canine practice 1995;20(1):8.

(62) Jerram R. Acute thoracolumbar disk extrusion in dogs. I. The Compendium on continuing education for the practicing veterinarian 1999;21(10):922.

(63) Cudia S. Thoracolumbar intervertebral disk disease in large, nonchondrodystrophic dogs: a retrospective study. The Journal of the American Animal Hospital Association 1997;33(5):456.

(64) Bray . The canine intervertebral disk. Part Two: degenerative changes - non-chondrodystrophoid versus chondrodystrophoid disks. The Journal of the American Animal Hospital Association 1998;34(2):135.

(65) Besalti O. The role of extruded disk material in thoracolumbar intervertebral disk disease: A retrospective study in 40 dogs. The Canadian veterinary journal 2005;46(9):814.

(66) Jerram R. Acute thoracolumbar disk extrusion in dogs. II. The Compendium on continuing education for the practicing veterinarian 1999;21(11):1037.

(67) Toombs JP, Waters DJ. Textbook of Small Animal Surgery. In: Slatter D, editor. . Third ed. Philadelphia: WB Saunders Co.; 2003. p. 1193-1209.

(68) Schulz KS. Correlation of clinical, radiographic, and surgical localization of intervertebral disc extrusion in small-breed dogs: a prospective study of 50 cases. Veterinary surgery 1998;27(2):105.

(69) Squires A. Use of the ventrodorsal myelographic view to predict lateralization of extruded disk material in small-breed dogs with thoracolumbar intervertebral disk extrusion: 104 cases (2004-2005). Journal of the American Veterinary Medical Association 2007;230(12):1860.

(70) Olby NJ. The computed tomographic appearance of acute thoracolumbar intervertebral disc herniations in dogs. Veterinary radiology ultrasound 2000;41(5):396.

(71) Ito D. Prognostic value of magnetic resonance imaging in dogs with paraplegia caused by thoracolumbar intervertebral disk extrusion: 77 cases (2000-2003). Journal of the American Veterinary Medical Association 2005;227(9):1454.

(72) Levine JM. Evaluation of the success of medical management for presumptive thoracolumbar intervertebral disk herniation in dogs. Veterinary surgery 2007;36(5):482.

(73) Levine S. Recurrence of neurological deficits in dogs treated for thoracolumbar disk disease. The Journal of the American Animal Hospital Association 1984;20(6):889.

(74) Mann F. Recurrence rate of presumed thoracolumbar intervertebral disc disease in ambulatory dogs with spinal hyperpathia treated with anti-inflammatory drugs: 78 cases (1997-2000). Journal of veterinary emergency and critical care 2007;17(1):53.

(75) Moissonnier P. Thoracolumbar lateral corpectomy for treatment of chronic disk herniation: Technique description and use in 15 dogs. Veterinary surgery 2004;33(6):620.

(76) Brisson B. Recurrence of thoracolumbar intervertebral disk extrusion in chondrodystrophic dogs after surgical decompression with or without prophylactic fenestration: 265 cases (1995-1999). Journal of the American Veterinary Medical Association 2004;224(11):1808.

(77) Bartels KE. Outcome of and complications associated with prophylactic percutaneous laser disk ablation in dogs with thoracolumbar disk disease: 277 Cases (1992-2001). Journal of the American Veterinary Medical Association 2003;222(12):1733.

(78) Kazakos G. Duration and severity of clinical signs as prognostic indicators in 30 dogs with thoracolumbar disk disease after surgical decompression. Journal of veterinary medicine. Series A 2005;52(3):147.

(79) Ferreira A. Thoracolumbar disc disease in 71 paraplegic dogs: influence of rate of onset and duration of clinical signs on treatment results. The Journal of small animal practice 2002;43(4):158.

(80) Davis GJ. Prognostic indicators for time to ambulation after surgical decompression in nonambulatory dogs with acute thoracolumbar disk extrusions: 112 Cases. Veterinary surgery 2002;31(6):513.

(81) Scott H. Laminectomy for 34 dogs with thoracolumbar intervertebral disc disease and loss of deep pain perception. The Journal of small animal practice 1999;40(9):417.

CHAPTER 2 - Thoracolumbar Disk Disease

Anatomy

Intervertebral disks (IVD) are located in every intervertebral space along the spinal column, except in the atlantoaxial joint (C1-C2) and between the coccygeal vertebrae.(1) Each disk is composed of the nucleus pulposus, annulus fibrosis and two cartilaginous endplates.(1) The IVD is bounded dorsally and ventrally by the dorsal and ventral longitudinal ligaments.(1) The IVD is also bordered dorsally by the intercapital ligament from T1-T2 to T10-T11extending from each rib head over the dorsal annulus, acting as a natural dorsal buttress.(2) The nucleus pulposus is an amorphous gelatinous mass which is surrounded by the annulus fibrosis consisting of lamellae of fibrocartilaginous tissue. (1)The endplates resemble hyaline cartilage and form the cranial and caudal borders of the IVD.(1)

Pathophysiology

It is generally considered that there are two types of disk extrusion, classified by Hansen as types I and II. (1) These types are generally seen in chondrodystrophoid and nonchondrodystrophoid dogs respectively.

Hansen type I

Hansen type I disk degeneration is the most common form of disk extrusion seen in dogs and is common in chondrodystrophoid breeds but can happen in any breed.(3,4) Dachshunds are far more prone to intervertebral disk disease (IVDD) than any other breed, accounting for 45% - 70% of all cases.(5) Other commonly affected breeds include Pekingese, Beagles, Welsh Corgis, Lhasa Apsos, Shih Tzu, Miniature Poodles, and Cocker Spaniels. (2,6) Many of these dogs are between the ages of 3 to 6 years old.(3)Extrusions can be quite explosive and associated with significant hemorrhage.(5) Clinical signs are usually acute and neurological deficits can be dramatic.(3) Degeneration of the intervertebral disk is associated with a loss of water from the nucleus pulposus, due in part to a lowering of the proteoglycan concentration.(5)(1) In the chondrodystrophoid do these changes occur rapidly and by one year of age the mucoid nucleus has been replaced almost entirely by cartilaginous material. The calcification of the disk is the next appearant change and calcified disks can be seen radiographicly as early as five months of age.(5) As the disk degenerates it loses its compressive abilities, placing strain on the annulus fibrosis. This strain causes disruption of the lamellae and eventually nuclear material to erupt dorsally through the annulus fibrosis and impacts the spinal cord.(3,5)

Hansen type II

Hanson type II degeneration is generally seen in nonchondrodystrophoid breeds at a much older age than Hansen type I. (5)Typically these dogs are between 8 to 10 years old at time of presentation. (2) As the dog ages the nucleus pulposus slowly begins to dehydrate but rarely calcify. Over time the disk bulges into the vertebral canal compressing the spinal cord.(5) Generally these dogs will have a very slow progression of pain, neurological signs or may even be asymptomatic.(7)

Diagnosis

Most animals will present with severe neurological signs, although hyperesthesia will be the only sign in some animals.(3) History, signalment and physical exam should give the clinician a presumptive diagnosis of thoracolumbar disk disease. Differential diagnosis should include fracture or luxation, tumor, diskospondylitis, fibrocartilage embolism, meningitis or myelitis and degenerative myelopathy.(3) A thorough neurological exam will help localize the lesion.(7) A grading system can be used to classify the extent of the neurological deficit. (3)

Table 2.1 Neurological grading system

Grading system based on Neurological Signs	
Grade 1	Spinal hyperesthesia (pain) only
Grade 2	Mild ataxia with enough motor function for weight-bearing
Grade 3	Severe ataxia without weight-bearing ability
Grade 4	No motor function, but deep pain sensation is present
Grade 5	No deep pain sensation is present

Radiology

Survey radiographs are not diagnostic for IVDD but can help to rule out differential diagnoses such as fracture or luxation, diskospondylitis or, in some cases, tumor.(3) Findings which may support IVDD are narrowing, wedging, or collapse of the intervertebral disk space; collapse of the articular facets; narrowing or fogging of the intervertebral foramen; and calcified material within the vertebral canal.(8) Plain film radiography is not very accurate in determining the site of disk extrusion.(3,9) It is recommended that myelography or advanced imaging be performed prior to surgery.(3,8,9)

Myelography

Myelography has been show to be 85% to 98% accurate in locating the site of disk extrusion.(3,9,10) In a recent study by Squires on 104 cases of disk extrusion they were able to correctly identify the side of disk extrusion in 89% of the cases verified surgically.(10) This study also identified patterns of contrast deviation and described a phenomenon they described as Paradoxical Contrast Obstruction (PCO) where the side with the longest contrast disturbance is opposite of the lesion.

Advanced imaging

Computed tomography (CT) and Magnetic resonance imaging (MRI) are becoming more widely available. CT is very reliable in determining the location and lateralization of disk extrusion.(11) MRI has been shown not only to be able to locate lesions but findings can have some prognostic value.(12)

Treatment

The clinician's choice of treatment should be determined on a case by case basis. Treatment options include medical management and surgery. Non ambulatory patients warrant myelography and surgery.(7)

Medical Management

Medical management of thoracolumbar disk disease is generally accepted in cases where the animal is still ambulatory. (2,7,13)One study found a 54.7% success rate for dogs that were treated with medical management.(14) Strict cage confinement is the hallmark for conservative therapies. Pharmacological therapy has been controversial and two recent studies found glucocorticoid administration negatively impacted success rates and increased recurrence rates.(13,15) Animals treated with NSAIDs or methylprednisolone sodium succinate (MPSS) were less likely to experience recurrence.(15)(14)

Surgical

Dogs which are non-ambulatory on presentation or do not respond to medical treatment are candidates for surgery. The primary goal during surgery is decompression of the spinal cord by removal of extruded disk material. Several surgical techniques have been described; fenestration, dorsal laminectomy, hemilaminectomy, pediculectomy, foraminotomy and lateral corpectomy.(2,7,8,16) Fenestration is controversial for both treatment and prophylaxis of IVDD.(7,8) A recent study suggested that there was some benefit to prophylactic fenestration.(17) Percutaneous laser disk ablation has been recently developed and appears to reduce the incidence of recurrence in animals with a predisposition to IVDD.(18)

Prognosis

The prognosis of dogs with thoracolumbar disk disease depends on the amount of spinal cord damage. Recurrence rates for dogs treated medically are between 31% and 50%(13-15). Between 86% and 96% of dogs that have intact deep pain sensation benefit from surgery(19-21). The loss of deep pain sensation is a negative prognostic factor. The success rate for these dogs ranges from about 50% to 62%.(19,22) Duration of clinical signs does not appear to have an impact on success rates but does lengthen the time to recovery.(19,20) MRI has been shown to have significant prognostic value in one study.(12) It was found that 100% of animals without areas of hyperintensity on T2 weighted images recovered regardless of deep pain sensation whereas only 55% of the animals with areas of hyperintensity made successful recoveries.

Conclusion

Thoracolumbar disk disease is a common ailment seen in veterinary clinical practice. Most common is Hansen Type I disk disease seen primarily in Dachshunds as well as other chondrodystrophoid breeds. Diagnosis of thoracolumbar disk disease is made primarily on signalment, physical and neurological exam finding and confirmed with radiography and myelogram or advanced imaging techniques. Dogs have a fair chance of recovery with conservative treatment and a good to excellent chance of recovery with surgery as long as they have deep pain sensation.

References

(1) Bray . The canine intervertebral disk. Part One: structure and function. The Journal of the American Animal Hospital Association 1998;34(1):55.

(2) Seim H. Thoracolumbar disk disease: diagnosis, treatment, and prognosis. Canine practice 1995;20(1):8.

(3) Jerram R. Acute thoracolumbar disk extrusion in dogs. I. The Compendium on continuing education for the practicing veterinarian 1999;21(10):922.

(4) Cudia S. Thoracolumbar intervertebral disk disease in large, nonchondrodystrophic dogs: a retrospective study. The Journal of the American Animal Hospital Association 1997;33(5):456.

(5) Bray . The canine intervertebral disk. Part Two: degenerative changes - non-chondrodystrophoid versus chondrodystrophoid disks. The Journal of the American Animal Hospital Association 1998;34(2):135.

(6) Besalti O. The role of extruded disk material in thoracolumbar intervertebral disk disease: A retrospective study in 40 dogs. The Canadian veterinary journal 2005;46(9):814.

(7) Jerram R. Acute thoracolumbar disk extrusion in dogs. II. The Compendium on continuing education for the practicing veterinarian 1999;21(11):1037.

(8) Toombs JP, Waters DJ. Textbook of Small Animal Surgery. In: Slatter D, editor. . Third ed. Philadelphia: WB Saunders Co.; 2003. p. 1193-1209.

(9) Schulz KS. Correlation of clinical, radiographic, and surgical localization of intervertebral disc extrusion in small-breed dogs: a prospective study of 50 cases. Veterinary surgery 1998;27(2):105.

(10) Squires A. Use of the ventrodorsal myelographic view to predict lateralization of extruded disk material in small-breed dogs with thoracolumbar intervertebral disk extrusion: 104 cases (2004-2005). Journal of the American Veterinary Medical Association 2007;230(12):1860.

(11) Olby NJ. The computed tomographic appearance of acute thoracolumbar intervertebral disc herniations in dogs. Veterinary radiology ultrasound 2000;41(5):396.

(12) Ito D. Prognostic value of magnetic resonance imaging in dogs with paraplegia caused by thoracolumbar intervertebral disk extrusion: 77 cases (2000-2003). Journal of the American Veterinary Medical Association 2005;227(9):1454.

(13) Levine JM. Evaluation of the success of medical management for presumptive thoracolumbar intervertebral disk herniation in dogs. Veterinary surgery 2007;36(5):482.

(14) Levine S. Recurrence of neurological deficits in dogs treated for thoracolumbar disk disease. The Journal of the American Animal Hospital Association 1984;20(6):889.

(15) Mann F. Recurrence rate of presumed thoracolumbar intervertebral disc disease in ambulatory dogs with spinal hyperpathia treated with anti-inflammatory drugs: 78 cases (1997-2000). Journal of veterinary emergency and critical care 2007;17(1):53.

(16) Moissonnier P. Thoracolumbar lateral corpectomy for treatment of chronic disk herniation: Technique description and use in 15 dogs. Veterinary surgery 2004;33(6):620.

(17) Brisson B. Recurrence of thoracolumbar intervertebral disk extrusion in chondrodystrophic dogs after surgical decompression with or without prophylactic fenestration: 265 cases (1995-1999). Journal of the American Veterinary Medical Association 2004;224(11):1808.

(18) Bartels KE. Outcome of and complications associated with prophylactic percutaneous laser disk ablation in dogs with thoracolumbar disk disease: 277 Cases (1992-2001). Journal of the American Veterinary Medical Association 2003;222(12):1733.

(19) Kazakos G. Duration and severity of clinical signs as prognostic indicators in 30 dogs with thoracolumbar disk disease after surgical decompression. Journal of veterinary medicine. Series A 2005;52(3):147.

(20) Ferreira A. Thoracolumbar disc disease in 71 paraplegic dogs: influence of rate of onset and duration of clinical signs on treatment results. The Journal of small animal practice 2002;43(4):158.

(21) Davis GJ. Prognostic indicators for time to ambulation after surgical decompression in nonambulatory dogs with acute thoracolumbar disk extrusions: 112 Cases. Veterinary surgery 2002;31(6):513.

(22) Scott H. Laminectomy for 34 dogs with thoracolumbar intervertebral disc disease and loss of deep pain perception. The Journal of small animal practice 1999;40(9):417.

CHAPTER 3 - THE USE OF THERMOGRAPHY IN CLINICAL THORACOLUMBAR DISEASE IN DACHSHUNDS

Introduction

Thermography is a developing field in both human and veterinary medicine. It has been used in humans to help in the diagnosis of tumors and cancer(1-4), reproductive disorders(5-9), neurological pain disorders(10-15) and blood flow disorders(16-19). It has been used in human surgery for coronary bypass procedures(20-23), renal transplants(24) and free skin grafts to assess blood flow(25).

Veterinary medicine has also investigated use of thermography. It has been studied for use in zoo animals and wildlife for the diagnosis of rabies (26), sarcoptic mange(27) and pregnancy(28,29). There has also been research in the use of thermography in food animal medicine for monitoring stress levels in swine(30,31), detection of BVD in exposed calves(32), and screening for foot-and-mouth disease in cattle(33). There have been studies in dairy cattle for determining temperature and behavioral changes in dairy heifers after tail docking (34), the effects of over milking on teat ends(35) and sole hemorrhages in lactating cattle(36). Equine medicine has probably seen the most use of thermography. It has been used for diagnosing foot abscesses (37,38), laminitis(37), lameness(38,39) and back problems in the equine patient(40). The use of thermography has been limited in small animal medicine. There have been studies on limber tail in English Pointers (41) and the normal limbs of healthy dogs(42).

Thermography has been used both in human and veterinary medicine for spinal cord injuries and other back related problems. A distinct temperature transition zone has been shown in humans with complete spinal cord injuries, where the temperatures distal to the spinal cord lesion were 1 to 2.5 degrees Celsius cooler.(43) Patterns seen in patients with spinal cord injuries corresponded with phantom pain felt by these individuals.(11) It has been shown that stimulation of the spinal cord increased blood flow and helped relieve this phantom pain.(44) An experimental model in dogs has shown that there is a similar decrease in temperature in experimentally induced lesions caudal to an induced spinal cord injury.(45) To the authors knowledge there has not been a study on the prognostic value of these findings, nor a study examining the difference in temperature in naturally occurring spinal cord injury in dogs.

Materials and Methods

Animals – Thirteen consecutive client-owned short haired dachshunds were presented to Kansas State University Veterinary Medical Teaching Hospital (KSU VMTH) for paraparesis/paraplegia. Standard protocol for treatment of neurological patients was followed in all cases. Dogs were given a full physical exam and neurological exam by a board certified surgeon or surgical resident. Neurological grades were identified and recorded. All animals had myelogram and/or CT to identify and localize the lesion. A standard hemilaminectomy was performed and animals were recovered in the ICU. Post-op analgesia was provided in all cases according to normal clinical protocols. Animals were discharged as the recovery of each animal dictated. At no time did the study alter or change the animal's treatment.

Thermal imaging - Thermal images were obtained with a hand held infrared camera with a focal plane array uncooled microbolometer[a]. Images were obtained after physical exam and client consultation and prior to any pre-anesthetic medications, approximately 30+ minutes after entering the hospital. This allowed animals to acclimate to controlled atmospheric conditions within the hospital in accordance with recognized thermographic guidelines. All images were obtained with the animal on the floor and minimal restraint of the head to position the body as straight as possible. The camera was approximately 36 inches from the patient for all images obtained. Additional images were obtained in the same manner at 24 hour intervals following surgery until time of discharge. Animals were kept in ICU or ward cages within the VMTH. Images were analyzed using image analysis software[b]. Six regions of interest (ROI) were identified and recorded. The ROIs identified were right and left; thoracic (approx. T5-T11), lumbar (approx. T12-L4) and pelvic regions (approx. L5-S3)(Figure 3.1). From each of these regions average temperatures were taken.(Appendix A) Repeated measures analysis of variance was used to compare changes over time and between ROIs with a commercial statistics software package[c].

Results

Thirteen short-haired dachshunds were included in the study. All animals were presented to KSU VMTH for presumptive IVDD. These dogs ranged in age from 2 years to 11 years with a mean age of 6.3 years. There were 6 females (46%) and 7 males (54%). Neurological grades at time of presentation were: five Grade 2 (38.5%), six Grade 3 (46.2%), one Grade 4 (7.7%) and one Grade 5 (7.7%)(Table 3.1). The lesions were localized between T10 – L5: one T10-T11, four T11-T12, one T11-T13, one T12-T13, two T13-L1, two L1-L2, one L2-L4 and one L3-L5. The neurological status of all animals improved so that they were able to be discharged to their owners.

Table 3.1 – Neurological grades

Grading system based on Neurological Signs	
Grade 1	Spinal hyperesthesia (pain) only
Grade 2	Mild ataxia with enough motor function for weight-bearing
Grade 3	Severe ataxia without weight-bearing ability
Grade 4	No motor function, but deep pain sensation is present
Grade 5	No deep pain sensation is present

Comparison between days

Mean temperatures for the entire back ranged between 31.61°C and 33.26°C for all days.(Table 3.2) The temperatures for day 0 (presentation) were significantly less ($p=0.01$) than any of the following days. There was no significant difference between days 1 through 5 for the means of the entire back. (Appendix B)

Table 3.2 - Mean temperature for entire back.

DAY	Mean Temperature	S.D.
0	31.61	1.36
1	32.43	0.97
2	33.03	1.63
3	32.56	0.93
4	33.21	1.87
5	33.26	1.48

With the exception of the pelvic ROIs, temperature changes of the ROIs across days was similar to that of the entire back, with the thoracic and lumbar areas and left and right being significantly cooler on day 0 than all of the following days. There was no significant difference between the temperatures for the pelvic ROIs between days.

Comparison between ROIs

Temperatures in the pelvic region were significantly cooler ($p< 0.001$) over all days as compared to the thoracic and lumbar regions as well as the overall mean temperature.(Table 3.2) The lumbar region temperature was significantly greater on day 0 as compared to thoracic and pelvic regions but was not significantly different on any of the following days. The thoracic temperatures were significantly greater than the lumbar and pelvic regions on day 2 but there was no significant difference on any of the preceding or following days. There was no significant difference between left and right on any of the days.

Figure 3.1 – Thermogram demonstrating temperature gradient and ROIs

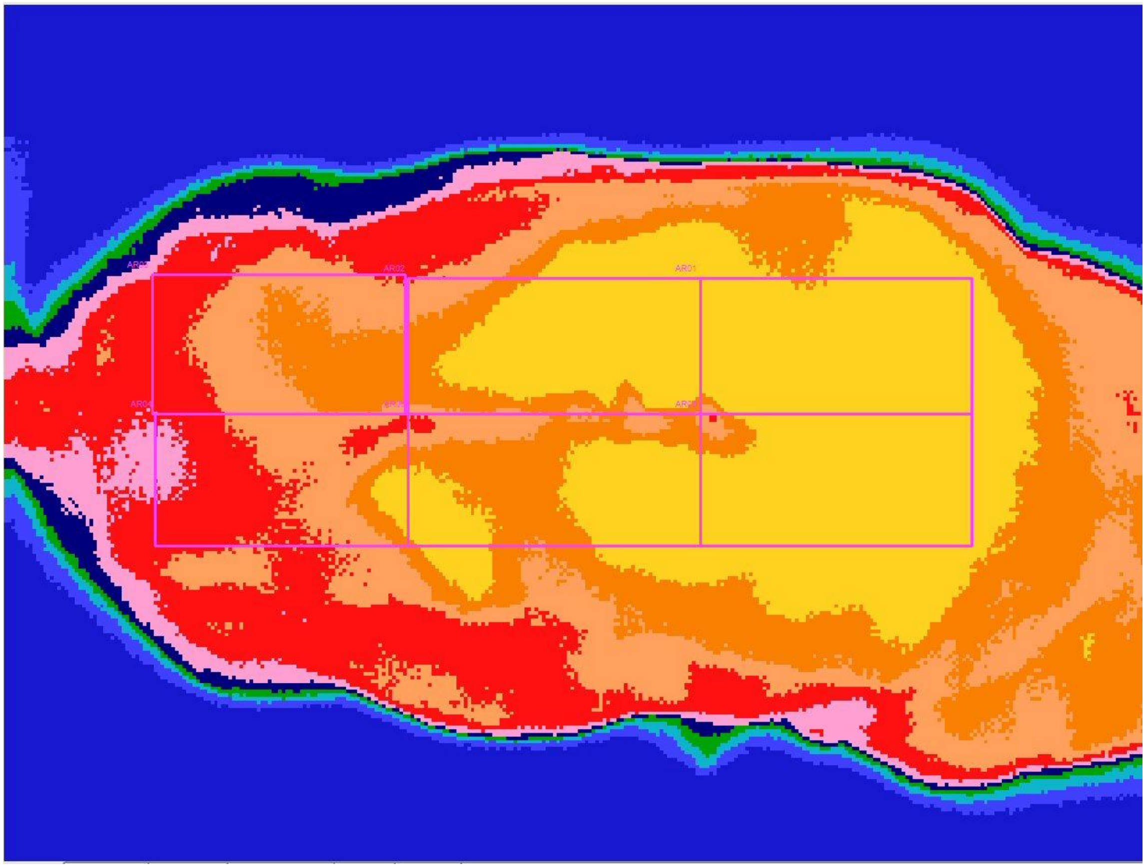


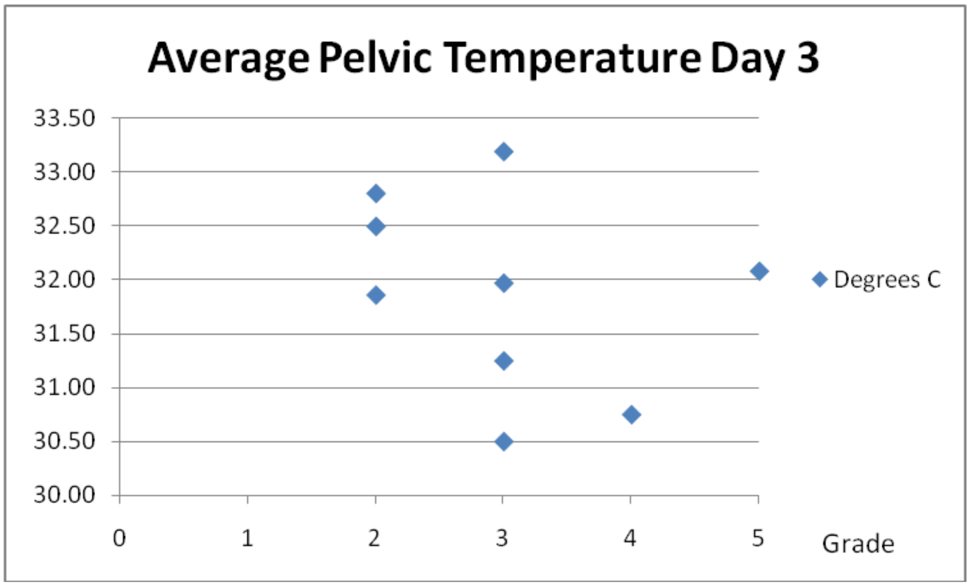
Table 3.3 - Mean temperatures for ROIs. * indicates significant difference

ROI	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
Entire back	31.61	32.43	33.03	32.56	33.21	33.26
Thoracic	31.61	32.65	33.43*	32.95	33.74	33.90
Lumbar	31.94*	32.52	33.13	32.83	33.49	33.99
Pelvic	31.28*	32.12*	32.53*	31.88*	32.40*	31.89*
Left	31.56	32.43	33.07	32.62	33.22	33.13
Right	31.66	32.42	32.99	32.49	33.19	33.39

Temperature and neurological signs

There was a strong correlation (Pearson's r = -.8221, p = 0.007) with the pelvic temperature on day 3 and presenting neurological signs (Figure 3.2)(Appendix C). Presenting neurological signs or recovery did not correlate to temperature at any other time.

Figure 3.2 – Average pelvic temperature by neurological grade



Discussion

The goal of this study was to determine if thermography would be a benefit in the diagnosis and prognosis of IVDD in dogs. The neurological grade has been shown to be prognostic for chances for return to function for dogs undergoing decompressive surgery for IVDD. (46-48) Dogs with grade 4 neurological deficits or better have been shown to have between 86% and 96% chance of successful return to function.(46-48) Grade 5 dogs have between 50% to 62% chance of return to function.(46,49) MRI has also been shown to be more accurate for assessing prognosis.(50) Only 55% of the animals studied that had areas of hyperintensity on MRI returned to function, whereas 100% of those without areas of hyperintensity returned to function, regardless of neurological grade. The disadvantage of MRI is that it is more costly, time consuming and requires general anesthesia. Obvious advantages are that MRI allows localization of the lesion as well as provide a prognosis.

Thermography is a quick, easy and non-invasive procedure that can be performed in the exam room without sedation. It has been used in horses for diagnosis of back pain in horses which can cause subtle gait abnormalities.(37,38,40,51) Temperature changes in these patients correspond to changes in the sympathetic autonomic nervous system (vasomotor tone).(38) Alterations in vasomotor tone show as a decrease in temperature (cold spots). Previous studies in both humans and dogs have shown that there is a decrease in the temperature gradient distal to spinal cord lesions.(43,45) The question left open from these studies was the possible benefit for small animals in a clinical situation.

The results of this study confirm previous studies with experimentally induced spinal cord lesions, that there is indeed a significant decrease in temperature caudal to naturally occurring spinal cord lesions. This decrease in temperature is evident from the time of presentation until past the time the dog is discharged from the hospital. In a previous study it was shown that this gradient persisted up to 3 weeks from the time of insult.(45) In that previous study the spinal cord lesion was induced with a balloon catheter introduced into the vertebral canal. There was no documented lateralization of the lesions and the thermography results showed a symmetrical pattern. In the current study the lateralization of the spinal cord lesions were documented by myelogram and/or CT and confirmed at the time of surgery. There was no significant difference in the temperatures from side to side to indicate the side of the lesion prior to surgery. There were occasional hot spots that were noticed visually on the thermograms in the area of the suspected lesion but their presence was inconsistent and they were diffuse enough that they provided no further information as to the site of the lesion that was not revealed with a proper neurological exam.

There was a significant increase in temperature measurements from day 0 to day 1 over all areas of the back. The likely explanation is that the animals were scanned on day 0 prior to any clipping of hair from the animal. Studies have shown that although the scanned temperatures on haired areas versus clipped areas are decreased the thermographic patterns are relatively unchanged.(37,42,51) The animals used in this study were client owned animals with acute neurological deficits requiring immediate attention. Clipping would have required waiting a minimum of 60 minutes for stable temperature readings.(42) Furthermore, scans should be performed prior to any medication or sedation to ensure consistent patterns.(37) The day 0 measurements had lower overall temperatures, but the patterns demonstrated were similar to the following days.

There was a correlation between lower temperatures of the pelvic region and higher grade neurological deficits at the time of presentation. This correlation was not present on any other day. Although an interesting finding, it appears that there is not an impact on the diagnosis or prognosis at this point in the animal's treatment.

The findings in this study suggest that although there are changes in temperature across the back in dachshunds with IVDD, they are not useful in a clinical setting. A thorough physical and neurological exam is more useful in localizing the spinal cord lesion and assessing prognosis for recovery than thermography. Although there were temperature changes across the backs of dachshunds with IVDD, thermography was not able to correlate with the neurological grade of the patient. Thermography was also unable to determine the lateralization of the lesion.

Conclusion

Thermography is a quick and non-invasive procedure that has found a variety of uses in human and veterinary medicine. Its use in veterinary medicine is primarily in equine and to a lesser extent food animal medicine. Its limited use in small animal medicine is most likely the result of the ease of manipulation and examination of the patient as well as the relative ease of other diagnostic methods as compared to large animals.

Although there were significant heat patterns detected in dachshunds with IVDD, these patterns did not correlate with lesion site or lateralization of the lesion. There was a correlation of neurological grade and temperature of the caudal ROI on day 3, but it would not appear to be useful in a clinical setting. The results of this study suggest that thermography is not a useful tool for the diagnosis or prognosis of IVDD in dogs.

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[a] FLIR P65, FLIR Systems Inc., Portland, OR
[b] FLIR ThermaCAM Researcher Pro 2.8 SR-1, FLIR Systems Inc., Portland, OR
[c] WINKS 4.80 Professional Ed., Texasoft, Cedarhill, TX

References

(1) Kamardin LN. [Thermography in the differential diagnosis of nodular goiter and thyroid cancer]. Vestnik khirurgii im. I.I. Grekova 1983;130(5):70.

(2) Vogel A. Using quantitative imaging techniques to assess vascularity in AIDS-related Kaposi's sarcoma. IEEE Engineering in medicine and biology society conference proceedings 2006;1:232.

(3) González FJ. Infrared imager requirements for breast cancer detection. IEEE Engineering in medicine and biology society conference proceedings 2007;2007:3312.

(4) Agostini V. Evaluation of different marker sets for motion artifact reduction in breast dynamic infrared imaging. IEEE Engineering in medicine and biology society conference proceedings 2007;2007:3377.

(5) Shah A. Determination of fertility interval with ovulation time estimation using differential skin surface temperature (DST) measurement. Fertility and sterility 1984;41(5):771.

(6) Gat Y. Physical examination may miss the diagnosis of bilateral varicocele: a comparative study of 4 diagnostic modalities. The Journal of urology 2004;172(4 Pt 1):1414.

(7) Lai HS. Role of thermography in the diagnosis of undescended testes. European urology 1998;33(2):209.

(8) Kukkonen TM. Thermography as a physiological measure of sexual arousal in both men and women. The journal of sexual medicine 2007;4(1):93.

(9) Woodard TL. Contribution of imaging to our understanding of sexual function and dysfunction. Advances in psychosomatic medicine 2008;29:150.

(10) Sherman RA. Thermographic correlates of chronic pain: analysis of 125 patients incorporating evaluations by a blind panel. Archives of physical medicine and rehabilitation 1987;68(5 Pt 1):273.

(11) Sherman RA. Relationships between near surface blood flow and altered sensations among spinal cord injured veterans. American journal of physical medicine 1986;65(6):281.

(12) Park J. The effectiveness of digital infrared thermographic imaging in patients with shoulder impingement syndrome. Journal of shoulder and elbow surgery 2007;16(5):548.

(13) Niehof SP. Reliability of observer assessment of thermographic images in complex regional pain syndrome type 1. Acta orthopaedica belgica 2007;73(1):31.

(14) Niehof SP. Thermography imaging during static and controlled thermoregulation in complex regional pain syndrome type 1: diagnostic value and involvement of the central sympathetic system. Biomedical engineering online 2006;5:30.

(15) Galvin EM. Thermographic temperature measurement compared with pinprick and cold sensation in predicting the effectiveness of regional blocks. Anesthesia analgesia 2006;102(2):598.

(16) YANG P P T,. LITERATURE SURVEY ON BIOMEDICAL APPLICATIONS OF THERMOGRAPHY. Bio-medical materials and engineering 1992;2(1):7.

(17) Spence VA. The relationship between temperature isotherms and skin blood flow in the ischemic limb. The Journal of surgical research 1984;36(3):278.

(18) Chikura B. Sparing of the thumb in Raynaud's phenomenon. Rheumatology 2008;47(2):219.

(19) Katz LM. Infrared imaging of trauma patients for detection of acute compartment syndrome of the leg. Critical care medicine 2008;36(6):1756.

(20) Suma H. Intraoperative coronary artery imaging with infrared camera in off-pump CABG. The Annals of thoracic surgery 2000;70(5):1741.

(21) Iwahashi H. New method of thermal coronary angiography for intraoperative patency control in off-pump and on-pump coronary artery bypass grafting. The Annals of thoracic surgery 2007;84(5):1504.

(22) Diamantopoulos L. Thermal heterogeneity within human atherosclerotic coronary arteries detected in vivo: A new method of detection by application of a special thermography catheter. Circulation 1999;99(15):1965.

(23) García-García HM. Diagnosis and treatment of coronary vulnerable plaques. Expert Review of Cardiovascular Therapy 2008;6(2):209.

(24) Kopsa H. Use of thermography in kidney transplantation: two year follow up study in 75 cases. Proceedings of the European Dialysis and Transplant Association 1979;16:383.

(25) de Weerd L. Intraoperative dynamic infrared thermography and free-flap surgery. Annals of plastic surgery 2006;57(3):279.

(26) Dunbar MR. Use of infrared thermography to detect signs of rabies infection in raccoons (Procyon lotor). Journal of Zoo and Wildlife Medicine 2006;37(4):518.

(27) Arenas AJ. An evaluation of the application of infrared thermal imaging to the tele-diagnosis of sarcoptic mange in the Spanish ibex (Capra pyrenaica). Veterinary parasitology 2002;109(1-2):111.

(28) Durrant BS. New technologies for the study of carnivore reproduction. Theriogenology 2006;66(6-7):1729.

(29) Kastberger G. Infrared imaging technology and biological applications. Behavior research methods, instruments, computers 2003;35(3):429.

(30) Röhlinger P. [Results of no-contact measurement of surface temperature in swine]. Archiv für experimentelle Veterinärmedizin 1980;34(5):759.

(31) Warriss PD. Estimating the body temperature of groups of pigs by thermal imaging. The Veterinary record 2006;158(10):331.

(32) Schaefer A. Early detection and prediction of infection using infrared thermography. Canadian journal of animal science 2004;84(1):73.

(33) Rainwater-Lovett . Detection of foot-and-mouth disease virus infected cattle using infrared thermography. The veterinary journal 2008.

(34) Eicher SD. Short communication: behavioral and physiological indicators of sensitivity or chronic pain following tail docking. Journal of dairy science 2006;89(8):3047.

(35) Paulrud CO. Infrared thermography and ultrasonography to indirectly monitor the influence of liner type and overmilking on teat tissue recovery. Acta Veterinaria Scandinavica 2005;46(3):137.

(36) Nikkhah A. Short Communication: Infrared Thermography and Visual Examination of Hooves of Dairy Cows in Two Stages of Lactation. Journal of dairy science 2005;88(8):2749.

(37) Turner . Diagnostic thermography. The Veterinary clinics of North America. Equine practice 2001;17(1):95.

(38) Eddy AL. The role of thermography in the management of equine lameness. The veterinary journal 2001;162(3):172.

(39) Correlation between contact thermography and ultrasonography in the evaluation of experimentally-induced superficial flexor tendonitis. Proceedings American Association of Equine Practitioners; 1987.

(40) Graf von Schweinitz D. Thermographic diagnostics in equine back pain. The Veterinary clinics of North America. Equine practice 1999;15(1):161.

(41) Steiss J. Coccygeal muscle injury in English Pointers (limber tail). Journal of veterinary internal medicine 1999;13(6):540.

(42) Loughin CA. Evaluation of thermographic imaging of the limbs of healthy dogs. American journal of veterinary research 2007;68(10):1064.

(43) Sherman RA. Differences between trunk heat patterns shown by complete and incomplete spinal cord injured veterans. Paraplegia 1987;25(6):466.

(44) Broseta J. Influence of spinal cord stimulation on peripheral blood flow. Applied neurophysiology 1985;48(1-6):367.

(45) Kim W, Kim M, Kim SY, Sea K, Nam T. Use of digital infrared thermography on experimental spinal cord compression in dogs. Journal of Veterinary Clinics 2005;22(4):302.

(46) Kazakos G. Duration and severity of clinical signs as prognostic indicators in 30 dogs with thoracolumbar disk disease after surgical decompression. Journal of veterinary medicine. Series A 2005;52(3):147.

(47) Ferreira A. Thoracolumbar disc disease in 71 paraplegic dogs: influence of rate of onset and duration of clinical signs on treatment results. The Journal of small animal practice 2002;43(4):158.

(48) Davis GJ. Prognostic indicators for time to ambulation after surgical decompression in nonambulatory dogs with acute thoracolumbar disk extrusions: 112 Cases. Veterinary surgery 2002;31(6):513.

(49) Scott H. Laminectomy for 34 dogs with thoracolumbar intervertebral disc disease and loss of deep pain perception. The Journal of small animal practice 1999;40(9):417.

(50) Ito D. Prognostic value of magnetic resonance imaging in dogs with paraplegia caused by thoracolumbar intervertebral disk extrusion: 77 cases (2000-2003). Journal of the American Veterinary Medical Association 2005;227(9):1454.

(51) Tunley BV. Reliability and repeatability of thermographic examination and the normal thermographic image of the thoracolumbar region in the horse. Equine Veterinary Journal 2004;36(4):306.

Appendix A - All means

	Day 0					
	Mean Temp	Thoracic Mean	Lumbar Mean	Pelvic Mean	Left Mean	Right Mean
Dog 1	33.65	33.25	34.03	33.67	33.74	33.56
Dog 2	28.71	28.50	28.89	28.75	28.80	28.63
Dog 3	31.25	31.36	31.42	30.97	31.50	31.00
Dog 4	31.71	31.14	32.36	31.64	31.61	31.81
Dog 5	33.31	33.22	33.97	32.72	33.11	33.50
Dog 6	30.84	30.78	31.64	30.11	30.74	30.94
Dog 7	31.43	30.97	31.78	31.53	31.22	31.63
Dog 8	31.89	32.44	31.86	31.36	31.80	31.98
Dog 9	30.56	30.78	30.42	30.47	30.69	30.43
Dog 10	32.03	31.94	32.33	31.81	31.85	32.20
Dog 11	30.57	30.78	30.89	30.06	30.37	30.78
Dog 12	33.50	34.03	33.67	32.81	33.63	33.37
Dog 13	31.46	31.69	31.97	30.72	31.24	31.69

	Day 1					
	Mean Temp	Thoracic Mean	Lumbar Mean	Pelvic Mean	Left Mean	Right Mean
Dog 1	33.70	33.81	34.22	33.08	33.80	33.61
Dog 2	32.50	32.97	33.08	31.44	32.67	32.33
Dog 3	31.94	32.11	32.06	31.67	31.83	32.06
Dog 4	32.01	32.83	32.36	30.83	31.85	32.17
Dog 5	31.00	31.36	30.97	30.67	31.04	30.96
Dog 6	33.24	33.33	33.19	33.19	32.85	33.63
Dog 7	30.87	30.86	30.72	31.03	30.76	30.98
Dog 8	32.08	32.08	31.94	32.22	32.24	31.93
Dog 9	32.28	32.53	32.11	32.19	32.56	32.00
Dog 10	32.19	32.33	32.19	32.03	32.24	32.13
Dog 11	32.56	32.72	32.42	32.53	32.50	32.61
Dog 12	34.37	34.72	34.47	33.92	34.39	34.35
Dog 13	32.82	32.78	33.00	32.69	32.89	32.76

	Day 2					
	Mean Temp	Thoracic Mean	Lumbar Mean	Pelvic Mean	Left Mean	Right Mean
Dog 1	35.10	35.31	35.36	34.64	35.02	35.19
Dog 2	34.32	34.64	34.47	33.86	34.31	34.33
Dog 3	32.35	33.06	32.47	31.53	32.19	32.52
Dog 4	33.56	33.92	34.03	32.75	33.52	33.61
Dog 5	33.17	33.81	33.42	32.28	33.19	33.15
Dog 6	33.58	34.14	33.36	33.25	33.83	33.33
Dog 7	32.33	33.11	32.22	31.67	32.39	32.28
Dog 8	34.03	34.14	34.00	33.94	34.13	33.93
Dog 9	32.27	32.03	32.58	32.19	32.31	32.22
Dog 10	28.91	29.83	28.56	28.33	28.91	28.91
Dog 11	33.69	33.75	33.94	33.36	33.98	33.39
Dog 12						
Dog 13						

	Day 4					
	Mean Temp	Thoracic Mean	Lumbar Mean	Pelvic Mean	Left Mean	Right Mean
Dog 1	36.86	37.39	36.97	36.22	36.83	36.89
Dog 2	33.78	34.03	34.67	32.64	33.54	34.02
Dog 3	31.82	32.28	31.83	31.36	31.80	31.85
Dog 4	34.41	35.00	34.92	33.31	34.30	34.52
Dog 5	33.76	34.22	34.33	32.72	33.70	33.81
Dog 6	31.80	32.58	32.22	30.58	32.24	31.35
Dog 7	31.28	32.08	31.11	30.64	31.24	31.31
Dog 8	31.96	32.31	31.86	31.72	32.13	31.80
Dog 9						
Dog 10						
Dog 11						
Dog 12						
Dog 13						

	Day 5					
	Mean Temp	Thoracic Mean	Lumbar Mean	Pelvic Mean	Left Mean	Right Mean
Dog 1	35.11	35.31	36.19	33.83	35.02	35.20
Dog 2	31.66	32.56	32.75	29.67	31.61	31.70
Dog 3	32.62	33.06	33.14	31.67	32.33	32.91
Dog 4	33.66	34.69	33.89	32.39	33.56	33.76
Dog 5						
Dog 6						
Dog 7						
Dog 8						
Dog 9						
Dog 10						
Dog 11						
Dog 12						
Dog 13						

Appendix B - Comparison between days

Mean Temperature for entire back

Day	Mean Temperature	S.D.
0	31.61	1.36
1	32.43	0.97
2	33.03	1.63
3	32.56	0.93
4	33.21	1.87
5	33.26	1.48

Mean Temperature for thoracic region

Day	Mean Temperature	S.D.
0	31.61	1.43
1	32.65	0.99
2	33.43	1.47
3	32.95	1.00
4	33.74	1.83
5	33.90	1.31

Mean Temperature for lumbar region

Day	Mean Temperature	S.D.
0	31.94	1.44
1	32.52	1.09
2	33.13	1.78
3	32.83	1.00
4	33.49	2.03
5	33.99	1.54

Mean Temperature for pelvic region

Day	Mean Temperature	S.D.
0	31.28	1.32
1	32.12	0.98
2	32.53	1.70
3	31.88	0.91
4	32.40	1.83
5	31.89	1.73

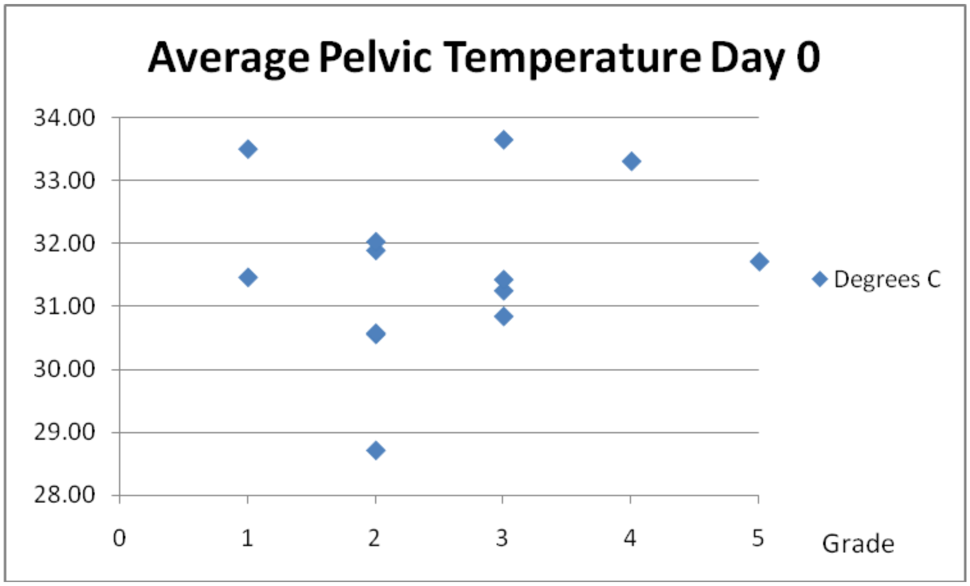
Mean Temperature for left region

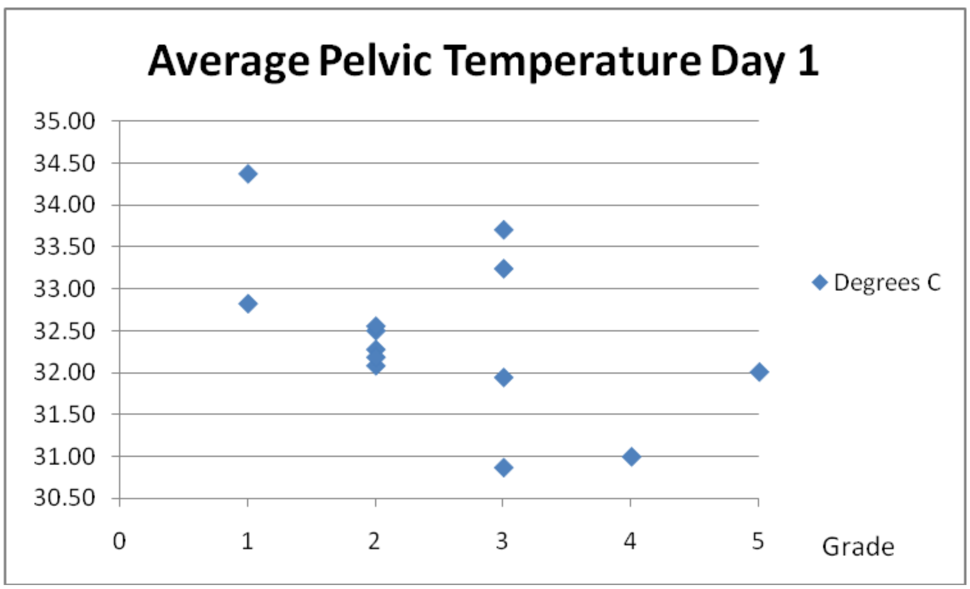
Day	Mean Temperature	S.D.
0	31.56	1.36
1	32.43	0.99
2	33.07	1.65
3	32.62	0.95
4	33.22	1.80
5	33.13	1.49

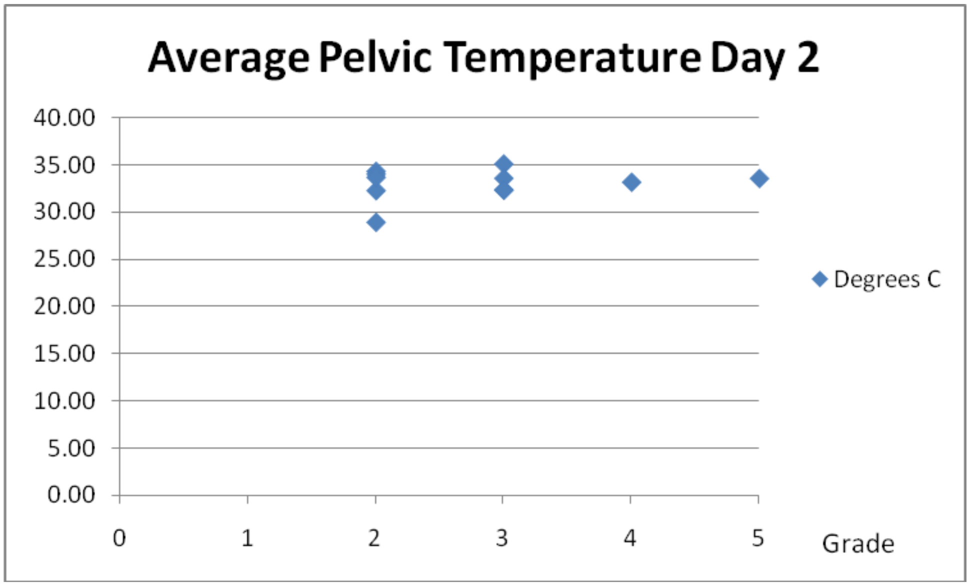
Mean Temperature for right region

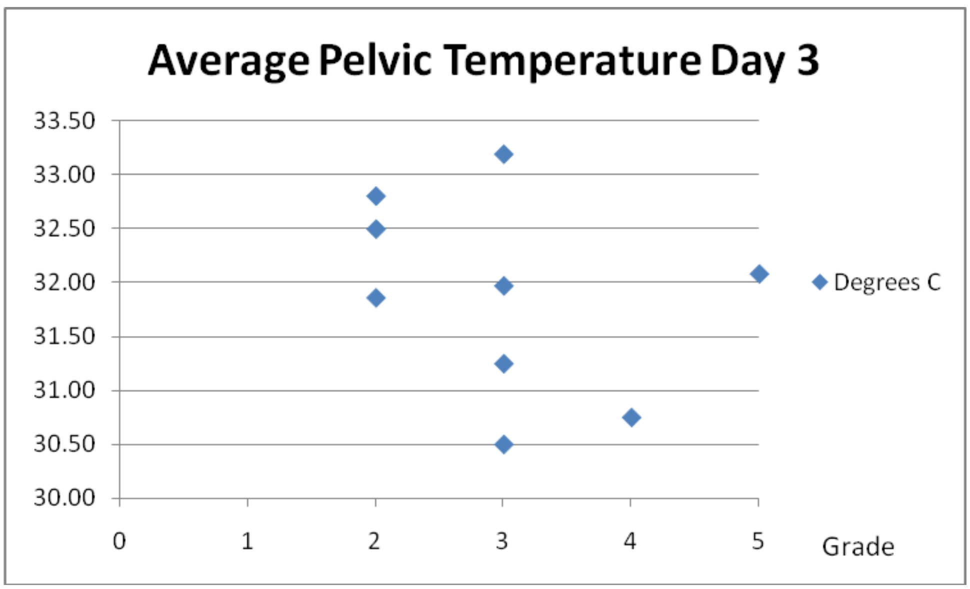
Day	Mean Temperature	S.D.
0	31.66	1.38
1	32.42	0.99
2	32.99	1.62
3	32.49	0.94
4	33.19	1.97
5	33.39	1.47

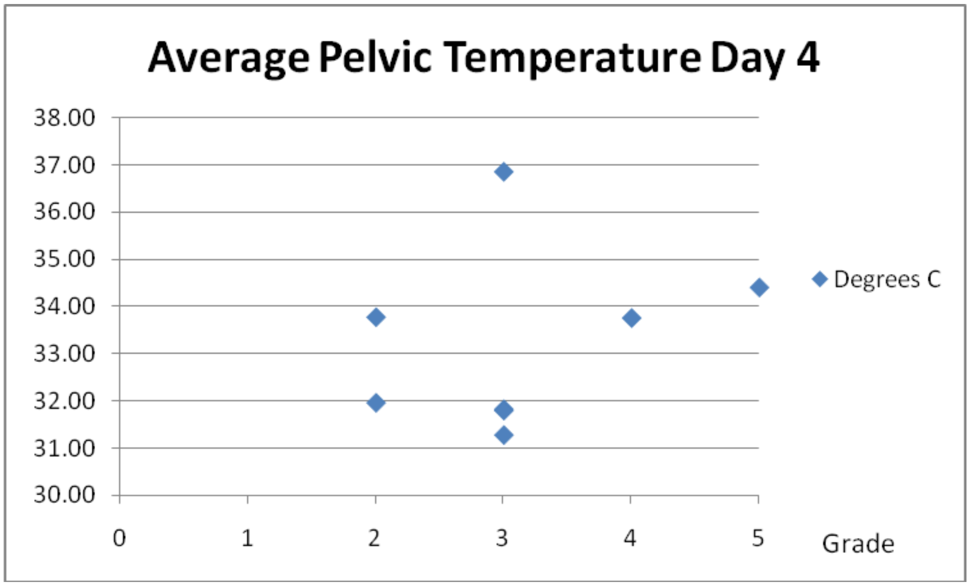
Appendix C - Pelvic temperature and neurological signs

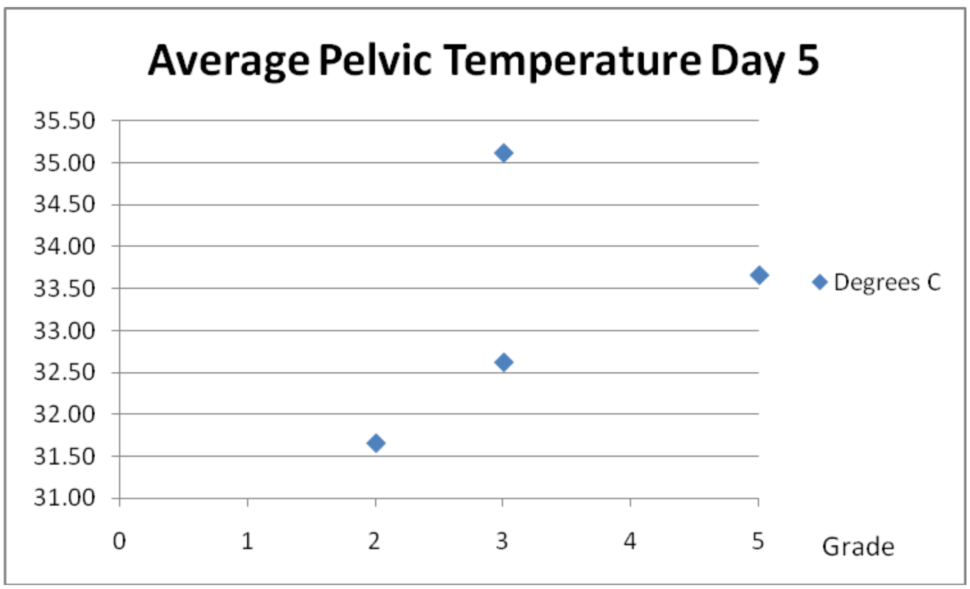





Average Pelvic Temperature Day 2
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
1
2
3
4
5
Grade
Degrees C


Average Pelvic Temperature Day 3
33.50
33.00
32.50
32.00
31.50
31.00
30.50
30.00
0
1
2
3
4
5
Grade
Degrees C


Average Pelvic Temperature Day 4
38.00
37.00
36.00
35.00
34.00
33.00
32.00
31.00
30.00
0
1
2
3
4
5
Grade
Degrees C


Average Pelvic Temperature Day 5
35.50
35.00
34.50
34.00
33.50
33.00
32.50
32.00
31.50
31.00
0
1
2
3
4
5
Grade
Degrees C