An Analysis of Biofluids & Heat Transfer Mechanisms within the Canine Body to Determine the Usefulness of Thermal Imaging in Canine Osteopathy

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By

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There are some who guide you along a path and others who turn you away from one.

Abstract

Thermal imaging detects thermal radiation emitted from a body; recently, it has gained popularity as a tool for detecting thermal asymmetries and abnormalities in both humans and animals. There appears to be relevance in using this tool in canine osteopathy due to links between thermal generation and heat transfer processes that occur within the body, which alter the natural flow of biofluids, contributing to the development of somatic dysfunctions.

Assessment for somatic dysfunctions involves identifying areas of tenderness. However, biopsychosocial effects and sensory experiences can alter behavioural responses to touch. Due to this, relying on behavioural signals to detect areas of tenderness comes with risks.

Since thermal imaging is non-contact and an objectively quantitative mode of detecting temperature, it can potentially locate areas of thermal abnormality associated with tenderness. Thermal changes can occur due to neurologically driven vasoconstriction and vasodilation, which alters the mass flow rate of intravascular fluid in response to afferent feedback. They can also be associated with changes in local metabolic heat generation processes.

Bilateral asymmetry is a second identifying marker of somatic dysfunction, and thermal asymmetries are readily detected by thermal cameras. These thermal asymmetries may be linked to restrictions in motion, a third indicator of somatic dysfunction, which directly impacts the biomechanical system and can cause an imbalance of muscle engagement. Muscles that work harder require an increased flow of biofluids to provide nutrients; they may also generate more heat than the under-engaged muscles.

Tissue texture changes, a fourth indicator of somatic dysfunction, can be associated with changes in the flow of fluids, which impacts heat generation and transfer. So, to better understand the connection between thermal change and somatic dysfunction, this paper explores the movement of fluids around the body and heat transfer processes with the five models of osteopathy.

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Introduction

There is a fundamental concept in Osteopathy regarding the natural flow of bodily fluids, whereby impediments to this flow are linked to the causation of pathological diseases. This is because biofluids play an essential role in maintaining health on a cellular level.

Although the constitution of these fluids varies depending on their function and location within the system, their movement and mechanics play a unique role in thermoregulatory processes that affect heat emission from the body. This paper explores the interactions of thermal energy and fluid flow within the body. Furthermore, it draws conclusions on the benefit to Canine Osteopaths of detecting radiant thermal energy emitted by a canine's body through thermal imaging.

Osteopathy

The foundations of Osteopathy are attributed to Andrew Still (1828 – 1917), who gained medical training from his father and began practising as a physician around 1849 (Britannica, 2022). Still was fascinated, even from a young age, with gaining a deep understanding of human pathophysiology and promoting health from within the body (Still, 1899). This connection between pathologies and physiology would guide the establishment of Osteopathy.

Still strongly believed that many diseases stemmed from internal imbalances within the body (Still, 1899) and that rectifying anatomical deviations that **impeded the healthy flow of fluids within the body** was vital in alleviating many health issues (ATSU). This is why osteopathy strongly promotes health by improving structural alignment (Findley & Shalwala, 2013); this encourages symmetry and the removal of bodily restrictions. Thus, osteopathic treatments that optimise the body's natural ability to move fluids from one area to another create an efficient environment for the body's natural healing processes.

To guide osteopathic thought, Still created four leading principles: (1) **The body is a unit of interconnected systems**, (2) **The body is capable of repair and self-healing functions when the functioning of all systems is optimal or unimpeded**, (3) **Structure (anatomy) and function (physiology) are interdependent**, and (4) **When one area of the body is strained, compensatory issues can develop** (Findley & Shalwala, 2013).

These principles continue to play an essential role in contemporary Osteopathy, where the patient, rather than the presenting ailment, is the focus of their healthcare (Christian). Health is promoted through optimising the functioning of interconnected systems in the body, thus gaining a holistic approach to wellness (Christian). These interconnected systems can be summarised into five models: **biomechanical**, **neurological**, **respiratory-circulatory**, **metabolic-energetic** and **behavioural-biopsychosocial** (Lunghi & Fusco, 2017).

When considering the application of the Osteopathic principles to the five systems, it becomes clear why osteopaths consider the whole being rather than focus on treating a presenting symptom in isolation. Where one component of the body is not functioning in an optimal state, it has a broader effect on upstream or downstream processes or components. Strain may occur in areas of the body that must work harder to support the injured or diseased areas, resulting in secondary dysfunction due to compensation. If patient treatments are limited to treating a symptomatic area in isolation, there is an inherent risk that affected, asymptomatic areas would be left untreated. Asymptomatic does not mean there is no issue;

instead, it is the absence of detectable clinical signs – **which is limited by human skill and technology.**

Somatic Dysfunction

In describing these pathophysiological disease states within the body that impair or otherwise alter the body's normal functioning, Osteopaths use the term 'somatic dysfunctions' (Christian). Identifying somatic dysfunctions is a valuable tool as a diagnostic term (Christian) (Lunghi & Fusco, 2017); research has shown that the diagnosis of somatic dysfunction is a safe means of communication between healthcare professionals, resulting in improved patient care (Arcuri et al., 2022).

Currently, somatic dysfunctions are diagnosed through palpatory techniques and physical assessments performed by skilled professionals (Coates, 2018), such as osteopaths. This is then used to guide manual therapy treatments (Epstein, 2013). Animal Osteopaths assess the body for TART symptoms, that is; '**Tenderness**', '**Asymmetry**', '**Restriction of motion**', and '**Tissue texture changes**', then determine if these are acute or chronic conditions (Christian). Somatic dysfunctions are diagnosed when two or more TART symptoms occur (Christian).

In considering the link between somatic dysfunctions and impediments to the natural flow of biofluids within the body, it is essential to understand the function of these fluids and their natural movement. Biofluids can be generally classed as either **intracellular** (within the cell), accounting for approximately 40% of a canine's total body weight, or **extracellular** (outside the cells), approximately 20%. Extracellular fluids include intravascular fluid (blood plasma), interstitial fluid, lymphatic fluid and transcellular fluid (*Applied Physiology of Body Fluids in Dogs and Cats*, 2016).

Biofluids

The term 'fluid' is not restrictive to liquids; fluids are substances in either the liquid or gaseous phase. Unlike solids, they exhibit continuous deformation upon application of shear stress or tangential force (Cengel & Cimbala, 2010), which means they behave in specific ways that differ from solids. This continuous deformation allows fluids to transport heat energy in the form of **convection**, which will be discussed in greater detail throughout this paper.

The convective movement of biofluids also acts as a transportation medium for nutrients and wastes, a process essential in maintaining homeostasis (Pittman, 2011). The flow of these fluids, however, varies. In maintaining a state that promotes life, the body must constantly adapt to environmental stimuli; in meeting the fluctuating demands of individual cells, the dynamic process of homeostasis (Pittman, 2011) alters the flow of fluids around the body.

The flow of fluids, then, is an active component in the movement of heat around the body by convection and is also essential for metabolic processes, which generate heat. Therefore, there is an intrinsic link between the dynamic movement of biofluids and the generation and distribution of thermal energy around the body. When this is considered using osteopathic principles, it becomes apparent that thermal changes are associated with somatic dysfunction, where impediments to the natural flow of biofluids negatively affect the body's natural ability for self-healing and result in compensatory strain in other areas of the body.

In exploring the usefulness of thermal imaging to detect thermal changes associated with pathophysiological change, it is important to foster a deep understanding of the natural movement of fluids around the body.

Barrier Exchange Flow

The passive processes by which biofluids and other molecules flow between interstitial space and cells are **diffusion** and **filtration** (Marieb, 2015). Diffusion is the transition of particles across a semipermeable membrane from areas of high concentration to low concentration, tending towards concentration equilibrium (Marieb, 2015).

The kinetic energy of the particles drives this process; increased thermal energy accelerates the diffusion rate. In contrast, filtration is a process driven by **hydrostatic pressure** (see equation 6.0); the pressure gradient forces solutes through a membrane from areas of high pressure to low pressure, tending towards a pressure equilibrium (Marieb, 2015).

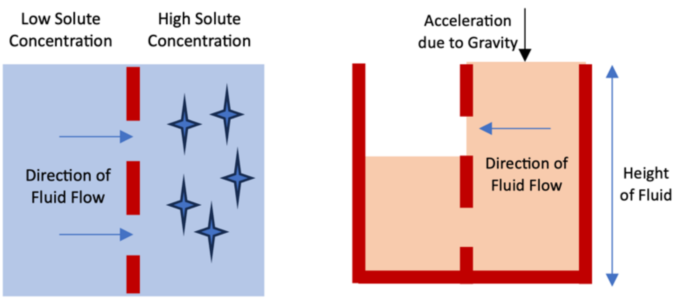

Figure 1.0: a) Osmosis b) Hydrostatic Pressure

Another means of transport is primary active transportation, known as solute pumping, which uses protein carriers or solute pumps, dependent on energy activation by ATP (adenosine triphosphate) (Marieb, 2015). The energy input from the hydrolysation of ATP releases thermal energy (Reis et al., 2002) and moves solutes across membranes in the direction opposing the concentration gradient (Marieb, 2015).

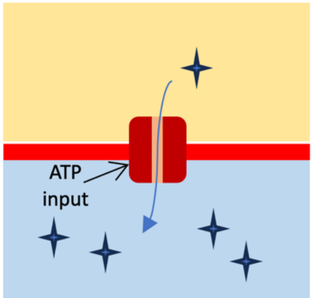

Figure 2.0: Active Transport

These barrier exchange flow systems are fundamental bodily processes that influence local heat generation and convection of thermal energy. This is relevant to thermal imaging, which detects temperature gradients across the body since dysfunctions that inhibit the flow or generation of heat will cause abnormalities in the local bodily temperature.

Extracellular Flow

Extracellular fluids, such as intravascular biofluids, play a significant role in the bulk transportation of thermal energy around the body and in dispersing excess heat into the environment. The amount of thermal energy transferred is directly proportional to the fluid mass flow rate; this is demonstrated in equation 1.0. When the mass flow rate is increased, there is an increase in heat transfer; conversely, a decrease in mass flow rate decreases heat transfer.

Equation 1.0: Rate of Heat Transfer (Fischer et al., 2010)

$$\dot{Q} = \dot{m} \times Cp \times \Delta T$$

$\dot{Q}$ = Thermal Energy (kW)

$\dot{m}$ = mass flow rate (kg/s)

Cp = specific heat capacity (kJ/kg/°C)

ΔT = Temperature difference (°C)

Where pathological changes affect or alter the mass flow rate of these fluids, thermal abnormalities or asymmetries can present. Thus, surface temperatures may be a relevant physiological indicator of somatic dysfunction.

Other extracellular fluids with less significant mass flow rates affect heat transfer in other ways. For instance, synovial fluid, a transcellular fluid found in joint capsules, acts as a lubricant, reducing friction between moving parts (LibreTexts). Friction releases thermal energy, so the synovial fluid decreases heat generation by reducing the friction in joint movements.

Fluid Mechanics

The dynamic movement of fluids around the body is essential for homeostasis; it also facilitates the convection of thermal energy around the body. To understand this flow of heat, the mechanics of biofluids is explored.

The heat transfer rate is directly proportional to the mass flow rate; thus, factors that alter the mass flow rate will affect the heat transfer rate. The general equation that describes this is given in equation 2.0.

Equation 2.0: Mass Flow Rate (Cengel & Cimbala, 2010)

$$\dot{m} = \rho . A . v_{avg}$$

$\dot{m}$ = Mass flow rate (kg/s)

ρ = Fluid Density (kg/m^3)

A = Cross-sectional area (m^2)

v_{avg} = Average velocity of fluid in cross-sectional area (m/s)

This equation shows that the mass flow rate can be altered where the fluid density, velocity or cross-sectional area changes. Flow type, viscosity, and turbulence affect velocity, whereas vessel uniformity affects the cross-sectional area. Figure 3.0 illustrates these different cases.

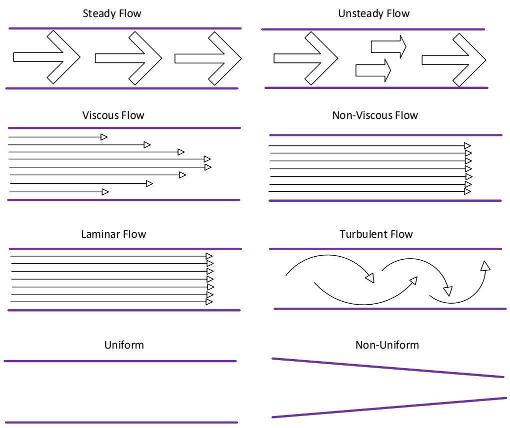

Figure 3.0: Fluid Flow Types

Unsteady flow

Many bodily systems rely on unsteady flow; fluctuations in mass flow rate define this flow type. The respiratory, cardiovascular, and lymphatic systems all function on the premise of an unsteady or pulsatile flow (Xin & Johnstone, 2023); this dynamic process allows the body to adapt to environmental conditions and maintain homeostasis.

A pumping or pulsating mechanism is needed for unsteady flow; this action can be attributed to the movements created by specialised tissues and the biomechanical system. The heart is a specialised muscle that acts as a positive-displacement pump; this type of pump pulls fluid into a closed volume area and then contracts to expel the fluid; one-way valves prevent fluid from flowing in the wrong direction (Cengel & Cimbala, 2010).

The amount of usable power transferred from the pump to the fluid is given in equation 3.0. However, the energy used by the biological pumping mechanisms is greater than the power transmitted to the fluid. This is due to irreversible losses associated with the biological processes of pumping fluids, such as friction and the metabolic release of thermal energy that powers the tissues.

Equation 3.0: Water horsepower (Cengel & Cimbala, 2010)

$$\dot{W} = \dot{m}gH$$

$\dot{W}$ = Power delivered to fluid (W)

$\dot{m}$ = mass flow rate (kg/s)

g = acceleration due to gravity (m/s^2)

H = Bernoulli head (m)

Bernoulli's head, in this equation, relates to fluid pressure, velocity, and hydrostatic pressure. This demonstrates the complex interactions that affect the mass flow rate of biofluids. When applied to the osteopathic principles, restrictions of motion or pathologies that alter pressure, velocity, or the amount of power delivered to the fluid affect the interconnected systems that rely on these fluids or strain the systems that work harder to move the fluids.

Viscosity

The property that defines resistance to flow is termed viscosity (Cengel & Cimbala, 2010); it can be thought of as its stickiness. Higher viscosity values indicate increased frictional forces between the layers of the biofluid and with the adjoining tissues; this is why viscosity is directly related to the pumping power required to move the fluid (Cengel & Cimbala, 2010), with increased viscosity values requiring a greater input force to move the fluid.

However, as temperature increases, the viscosity in liquids decreases, meaning they flow more freely (Cengel & Cimbala, 2010). Equation 4.0 demonstrates this dependency of viscosity on temperature in non-Newtonian liquids, of which blood is (Baieth, 2008).

Equation 4.0: Liquid Viscosity Equation (Cengel & Cimbala, 2010)

$$\mu = a.10^{b/(T-c)}$$

μ = Viscosity of liquid (kg/m.s)

T = Temperature (K)

a = experimentally determined constant ($N.s/m^2$)

b = experimentally determined constant (K)

c = experimentally determined constant (K)

Research in human studies has demonstrated a link exists between blood viscosity changes and pathologic conditions of clinical significance (Akers & Haidekker, 2005). This aligns with the fourth osteopathic principle since increased viscosity places greater demands on the interconnected systems that provide the mechanical pumping force required to overcome the larger internal frictional forces caused by the temperature-viscosity relationship.

This temperature dependence of viscosity is especially relevant to sporting dogs. Colder temperatures increase viscosity and thus the demands on the pumping systems; if the body is insufficiently warmed up, performance is not optimised. A correctly warmed-up body decreases the blood viscosity to an optimal flow rate; this is linked to performance advantages in human sport (Çinar et al., 2001). Thus, hypothermia in the distal limbs, such as seen in Figure 4.0 is likely a performance inhibitor and may act as a precursor to the development of somatic dysfunction when exercise occurs in this state.

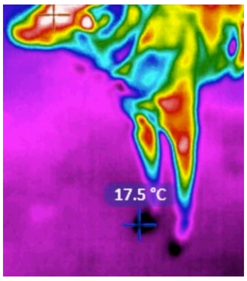

Figure 4.0: Hypothermia in Distal Forelimbs of Canine During Warmup

The interactions of hypothermic temperature on blood viscosity in dogs has been studied. It found that blood viscosity increased as body temperature was lowered; specifically, body temperature was lowered from 37°C to 25°C, with viscosity progressively increasing to 173% to that of the original value (Chen & Chien, 1978). Furthermore, the study found that blood cell concentration within the bloodstream increased due to the loss of plasma. Thus, temperature significantly affects the mechanics and composition of intervascular fluid.

Viscosity also plays a significant role in the biomechanics of joints; synovial fluid, the transcellular fluid found in joint capsules, is a viscous liquid affected by temperature. Increases in local temperature decrease viscosity, making the joints slide more easily. In pathologies such as arthritis, joint stability can be reduced due to inflammation heating the fluid and combined with an overproduction of fluid stretching the synovium (Konstantakos, 2016).

Since viscosity, a temperature-dependent property (equation 4.0), affects the mass flow rate (equation 2.0), it also affects how much work energy (equation 3.0) is required to facilitate fluid flow. When applied to the osteopathic principles, non-ideal temperatures would cause other body areas to work harder and negatively affect the body's natural repair functions due to altered flow. Thus, assessing the body for adverse or abnormal temperature gradients may aid the Canine Osteopath in detecting pathologies or their precursory signs.

Laminar & Turbulent flow:

Laminar flow is defined by layers within the fluid moving smoothly at the same rate and in regular patterns (Cengel & Cimbala, 2010). In contrast, turbulent flow is a more chaotic movement of particles with irregular fluctuation or mixing (Cengel & Cimbala, 2010). Turbulence occurs due to obstructions and high velocities, increases in turbulence promote conditions favourable for heat transfer to occur more readily (Cengel & Boles, 2007).

Previously, blood flow was considered laminar; however, newer models consider it a multi-harmonic pulsatile flow (Saqr et al., 2020), which can be either turbulent or laminar, with the presence of turbulence not necessarily indicating a pathological disease (Saqr et al., 2020). However, in regions of excessive or abnormal turbulence, damage to the single cell layer of endothelial cells, which line blood vessels, can occur, leading to local inflammation and a thrombus or clot formation (C et al., 2022).

Since excessive turbulence increases heat transfer between the fluid and vessel and, when abnormal, is linked to pathologies, local temperature measurements may help detect areas affected by dysfunction. When considering the third osteopathic principle, where structure and function are interdependent, thermal abnormalities may be linked to issues with fluid flow or issues with the vessels that contain it.

Uniform & Non-uniform flow:

Uniform flow describes a flow in which parameters and characteristics are constant along the pathway (Cengel & Boles, 2007). Within the body, generally, the pathways of most biofluids will be considered non-uniform as branching and vessel diameter changes occur along their length.

However, let us consider that, in general, there should be significant symmetry across the left and right halves of the body. Flow parameters and characteristics along these paths of symmetry should be symmetrically consistent, even without uniformity of the entire system. That is to say that comparisons might be made across the halves of the body rather than along the length of a specific vessel.

Asymmetry is one of the indicators of somatic dysfunction (Christian). When there is asymmetry in the mass flow of biofluids, there is also asymmetry in the localised transfer of heat, which was established earlier. Thus, thermal asymmetries may be indicative of dysfunction. However, thermal differences along a pathway may be present without dysfunction due to the non-uniformity of vessels along pathways.

Fluid Compression & Pressure:

Compressible flow refers to fluid flows where a change in density occurs (Cengel & Cimbala, 2010); a decrease in volume or an increase in fluid causes density to increase. In contrast, pressure refers to the magnitude of force exerted on a vessel's walls. While compression is linked to the movement of lymphatic fluid (Zamir et al., 2010), pressure is linked to barrier exchange interactions within the body through hydrostatic pressure.

The mass flow rate of fluids into and out of capillaries is driven by osmatic (or oncotic) pressure and hydrostatic pressure (Learning). Both processes play a vital role in the inflammation process (Ferguson, 1988), associated with increased localised heat.

The gradient of solute particles between the interstitial spaces and the capillaries creates osmatic pressure. Naturally, this should cause the fluid to flow into the capillaries due to the higher solvent concentration within the capillaries. However, pathologies that affect the chemical composition of the interstitial and capillary fluid will affect this process (Ferguson, 1988).

The osmatic pressure equation shows that osmatic pressure is directly proportional to temperature. As temperature increases, the osmatic pressure increases, facilitating a higher fluid flow rate across the membranes.

Equation 5.0: Osmatic pressure equation (Nagy, 2019)

$$\pi = i.c.R.T$$

π = Osmatic pressure

i = Van't Hoff index

c = Molar concentration of solute

R = Ideal gas constant

T = Temperature

In contrast, hydrostatic pressure causes fluid to move from the capillaries into the interstitial spaces. This occurs because there is pressure exerted by the fluid against the boundaries containing it; this forces the fluid to flow through microscopic gaps within the capillaries. The equation that governs the hydrostatic process is given in Equation 6.0.

Equation 6.0: Hydrostatic pressure (Fischer et al., 2010)

$$P_{fluid} = \rho g h$$

P_{fluid} = Hydrostatic Pressure (Pa)

ρ = density of liquid (kg/m^3)

g = acceleration due to gravity (m/s^2)

h = depth of liquid (m)

Within the initial phase of acute inflammation, there is a net increase of heat transferred into the local area due to increased blood flow due to vasodilation (Marieb, 2015). Capillary permeability is also increased, which causes an increase in the concentration of solutes, such as proteins and large molecules within the interstitial tissue (Ferguson, 1988). This results in a drop in oncotic pressure; thus, fluid is retained in the interstitial tissue spaces, causing swelling.

This swelling results in tissue tightening, which can continue until the tissue reaches its compliance maxima. The compliance of tissue affects how quickly the pressure will build up in relation to the volume of fluid (Klabunde, 2023); this is shown in Figure 5.0. Since tissue compliance creates hydrostatic pressure, greater tissue compliance results in larger volumes of fluid filling cavities.

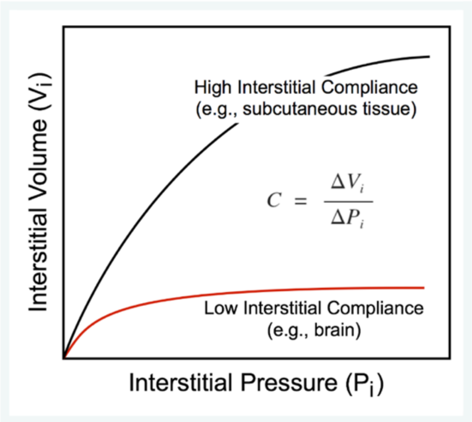

Figure 5.0: Interstitial Pressure vs Interstitial Volume Graph (Klabunde, 2023)

Palpatory detection of the magnitude and location of inflammation and swelling is subjective and limited by the skill of the Canine Osteopath. However, human studies have demonstrated the usefulness of thermal imaging in providing an objective means of detecting and monitoring changes associated with inflammation (Ramirez-GarciaLuna et al., 2022).

Bioheat Transfer

This section considers heat transfer mechanisms and how they relate to the biological processes that maintain homeostasis in the canine body. Thermoregulatory processes are biological in nature, these work in conjunction with the properties of thermodynamics. This is important because thermal imaging detects radiant heat emitted from the body, which is impacted by physiology, altering the location and magnitude of heat radiation that is transferred out of the body.

Heat transfer is the transmission of thermal energy from one system or area to another. Naturally, the flow is from hotter objects to cooler ones, and the net heat transfer tends toward zero as temperature equilibrium between the two systems is reached (Cengel & Cimbala, 2010).

Insulation

Insulation is one factor that prevents heat loss from the system; it is particularly important in canine patients. Coat variations, including type and length, occur across different canine breeds, which provide differing insulation levels. Research has found a statistical significance in heat radiation emitted by dogs with different coat variations, that is, short, long, curly, and double coats (Brundage & Kwon, 2022). These researchers also found that coat directions and thicknesses differed along the dog's body, which affected heat emission. Thus, a deep understanding of heat transfer processes and coat variation is essential when analysing thermal radiation emitted from the canine body.

Thermal Gradient

The coat is not the only consideration when assessing the thermal profile of a dog. It is essential to understand typical temperature gradients, as this reduces incorrect conclusions from thermal imaging.

The organs in the abdominal region generate more than one-third of the body's heat (Krönert & Pleschka, 1976); this creates a temperature gradient throughout the body. The canine body constantly balances heat load and dissipation, maintaining a dynamic process of homeostasis instead of being in thermal equilibrium. These bodily temperatures should be maintained within the range of +5°C to -15°C from the normal temperature of the blood, as this is required for cellular life (Larson & Carithers, 1985).

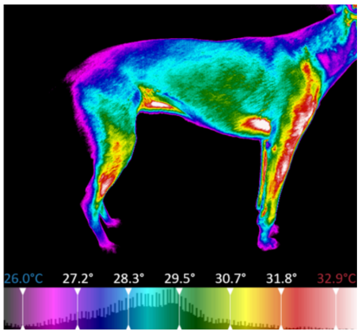

Figure 6.0: Thermal Imaging: Coat Variations

Figure 6.0 shows patterns of reduced radiant heat emission over the dorsal aspect of the cervical-thoracic junction; this corresponds to increases in coat length and thickness. There are also patterns of increased radiant heat emission in the armpit and groin area where the coat is sparse.

Energy Transfer

The modes in which energy transfer processes occur across a boundary are **heat**, **work** and **mass flow** (Cengel & Boles, 2007), all of which are important in a biological sense. The biomechanical model is primarily associated with work, the metabolic system with heat, and the circulatory systems with mass flow. However, when we consider canine locomotion, which results from work done by the biomechanical system, it is apparent that the underlying complex interactions of the metabolic, circulatory, and neurological processes also play a role in heat transfer within the body. This aligns with the first osteopathic principle, where the body is a series of interconnected systems.

To maintain cellular health and homeostasis, the heat generated by metabolic processes must be moved away, and cooler areas of the body must be heated to prevent hypothermia. The heat transfer processes that govern thermoregulation in the body are a complex interaction of **convection**, **conduction**, **radiation**, and **evaporative cooling**. Of these, the mass transfer of biofluids within the circulatory system plays a significant role since it promotes the bulk transfer of thermal energy and nutrients necessary for metabolism by convection.

Convection

Convection is the process of heat transfer due to the movement of the fluid medium. This can occur within the fluid due to temperature differences creating a flow of mass or due to external forces creating flow within the fluid (Cengel & Boles, 2007). This mode of heat transfer relies heavily on surface area and the temperature difference between the surface and fluid, which is demonstrated in equation 7.0:

Equation 7.0: Convective Heat Transfer (Cengel & Boles, 2007)

$$\dot{Q} = hA(T_s - T_b)$$

$\dot{Q}$ =The rate of heat transfer by convection (W)

h= convective heat transfer coefficient ($W/(m^2.^oC)$)

A = surface area (m^2)

T_s= surface temperature (^oC)

T_b = bulk fluid temperature (^oC)

Convection plays a significant role in thermoregulatory processes; it facilitates the bulk flow of heat. This heat transfer occurs in conjunction with the convective delivery of nutrients and the removal of wastes that are necessary for metabolic processes, which generate heat. It also acts outside the body, with the ambient air convecting heat away from the body.

Conduction

Conduction is the process of heat transfer through solid mediums or across boundaries. It occurs due to a temperature differential and is affected by the material's thermal conductivity, surface area and thickness (Cengel & Boles, 2007). Conduction occurs within the body's tissue and between the body and the external environment. Heat is exchanged with the environment by conduction when the body contacts a surface, such as the ground, and a temperature gradient exists.

The amount of heat transferred through conduction increases when there is a more significant temperature difference between the two adjoining areas. This is important in inflammation processes as the increased heat will move by conduction to the body's surface, where it can be dissipated into the environment.

Conversely, heat loss through conduction also plays a significant role in maintaining homeostasis. When heat loss to the environment exceeds heat input or generation, the body must adapt to maintain thermal homeostasis.

The equation that defines conductive heat transfer is known as Fourier's Law and is given below:

Equation 8.0: Conductive Heat Transfer (Cengel & Boles, 2007)

$$Q = \left(\frac{k}{s}\right) A.dT$$

Q = Heat transfer (W)

k = Thermal conductivity (W/m °C)

s = Material thickness (m)

A = Area (m2)

dT = Temperature gradient (°C)

Radiation

Radiation is the transmission of heat energy by infrared energy waves; this does not require a medium to travel through and travels at the speed of light (Cengel & Boles, 2007). Radiation energy can be absorbed within living tissue, creating a warming sensation; this occurs when basking in the sun. Living bodies also emit thermal energy; however, since radiation occurs in the infrared spectrum of light, we cannot see it.

Thermal imaging cameras are designed to detect thermal radiation emitted or reflected by the surface of an object. The thermal camera used to create the images in this paper has a spectrum band of 7 µm to 14 µm, which is in the long wave band of the infrared spectrum.

The amount of thermal energy emitted by a body is directly proportional to the heat transfer rate by radiation. The equation that describes this is given below:

Equation 9.0: Radiation Heat Transfer (Cengel & Boles, 2007)

$$\dot{Q} = \varepsilon \sigma A T_s^4$$

$\dot{Q}$ = The rate of heat transfer by radiation (W)

ε = emissivity of the surface

σ = Stefan-Boltzmann constant ($W/m^2.K^4$)

A = Surface Area (m^2)

T_s = surface temperature (K)

Applying thermal imaging makes it possible to see which areas of the body emit more heat. Combined with an understanding of the above equation, canine osteopaths may better determine which systems are involved in causing or leading to somatic dysfunction. In the absence of external influences, the presence of abnormally low heat emission is likely associated with restrictions preventing heat transfer into the area or local heat generation. Conversely, abnormally high heat emission is likely associated with local inflammation or increased metabolic demand, such as in compensatory strain.

Evaporative Cooling

Evaporative cooling is the loss of heat energy due to the combined effects of convection and a phase change. Energy is required to transform the liquid into a gaseous phase; this energy loss is called the latent heat of vaporisation and depends on the temperature or pressure at which the process occurs (Cengel & Boles, 2007).

This type of cooling is used by dogs when they pant; heat is transferred to the moist tissue in the oral cavity, which is further exchanged into the environment. To determine how much heat is lost through this process, the following equation can be applied:

Equation 10.0: Evaporative Cooling

$$Q = L_v m + mc\Delta T$$

Q = heat loss by evaporative cooling

L_{vap} = latent heat of vaporisation

m = mass

c = specific heat capacity

ΔT = temperature gradient

Heat loss by evaporation relies on converting saliva and respiratory secretions into water vapour (Ewart, 2020). Impediments to producing these fluids, restrictions that reduce the opening of the oral cavity, or genetics such as brachycephalic breeds that result in a shorter snout will decrease the amount of heat dissipation into the environment. According to osteopathic principles, this negatively affects the dog's ability to cool themselves and will cause strain in other areas due to the potential for excess heat load.

Fluid flow, therefore, plays a significant role in the thermoregulation processes in canines. By considering the neurological model's involvement in the 'autonomic reflex that regulates saliva production' (Marieb, 2015), in conjunction with motion restrictions of the jaw, Canine Osteopaths will be better able to aid dogs affected with heat dissipation issues.

Heat exchange

Two critical heat exchange systems in the canine body play a significant role in regulating the internal temperature. The first regulates the brain's temperature, and the second regulates heat loss through the limbs.

During exercises, the temperature of the canine brain drops from that of an alert resting state due to a counter-current heat exchange (Baker & Chapman, 1977). The cool veinous blood returning from the mouth and nose runs in an opposite direction adjacent to the warm arterial blood that supplies the brain (Baker & Chapman, 1977), which allows the warmer arterial blood to transfer heat to the cooler vein, resulting in cooler blood flow to the brain.

Blood returning from the snout is cooled by the transfer of thermal energy into the environment through convection and evaporative cooling processes. The moist environment of the oral and nasal passages facilitates evaporative cooling. However, the body also adjusts the blood mass flow rate into the lingual region in response to the ambient temperature (Krönert & Pleschka, 1976). In addition to the jaw mechanics, this optimises the body's ability to conserve or dissipate heat, thus regulating brain temperature.

Figure 7.0: Canine Airway and Vascular Structure

In image 8.0, it is possible to see the increased radiant thermal energy being emitted around the eyes and from the internal structures of the mouth. This is where heat generation and transfer readily occur. In contrast, the nose appears hypothermic; this area is not associated with large amounts of heat generation, and there is likely a reduced heat transfer rate into the area when resting to promote heat conservation. Thus, it would be expected that the temperature of the nose would tend towards equilibrium with the environment. However, in these images, an area of the nose appears cooler than the environment, this may be caused by the evaporative cooling effect removing thermal energy through the phase change of fluid into water vapour.

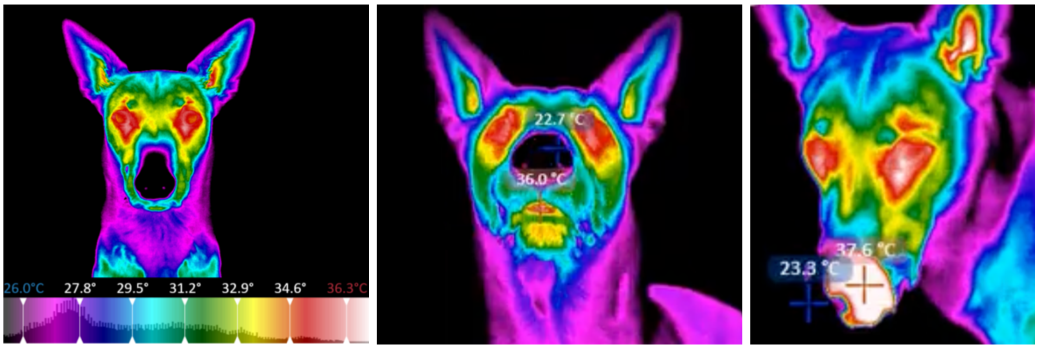

Figure 8.0: Thermal Image of Canine Face a) Front View b) Front View with chin raised c) Oblique Front View with Tongue Licking Lips

Another counter-current heat exchange has also been observed in the distal limbs of canines, although the studies focused on how they conserved heat in arctic regions (Henshaw et al., 1972). Breeds active in hot weather, such as the Australian working dog breeds, may benefit from an increased distance between the arteries and veins in the distal limbs to disperse heat more readily into the environment; there appears to be a gap in knowledge as to whether breed affects the limb heat exchange system.

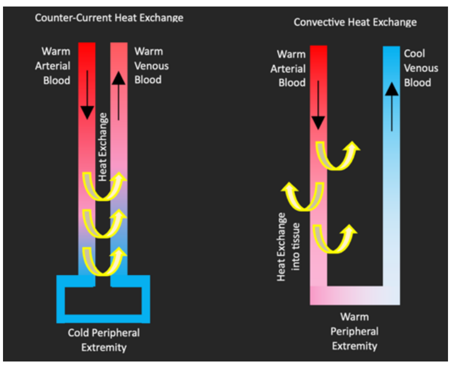

Figure 9.0: a) Count-Current Heat Exchange b) Convective Heat Exchange

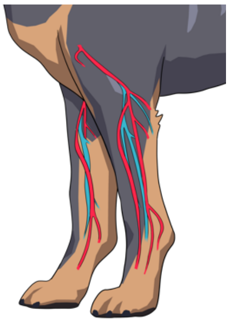

Figure 10.0: Vascular System in Canine Forelimbs

The effectiveness of heat transfer processes within and out of the body is vital in maintaining life and is intrinsically linked to the mass flow of biofluids. In the next chapter, the five models of osteopathy will be explored in greater detail to establish further the link between heat transfer, impediments to the natural flow of bodily fluids and pathological states that lead to somatic dysfunctions.

Five Models of Osteopathy

Biomechanical

The biomechanical model considers energy transfer through the work process. This model is indirectly linked to heat generation since the activation of skeletal muscles, required in conducting work, generates heat due to metabolic processes. The work produced by this system is a function of force and displacement. In its simplest form, under a constant force, the equation that describes this is given below.

Equation 11.0: Mechanical Work Equation (Ozkaya et al., 2016)

$$W = F.d.\cos(\theta)$$

W = work (J)

F = Force (N)

d = displacement distance (m)

θ = angle (deg)

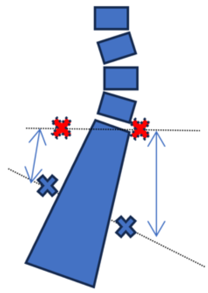

Figure 11.0: Mechanical Work Differs Across Distances Require

This equation, however, is for mechanical work and does not consider the metabolic processes that generate the energy needed for movement, such as locomotion, to occur. Therefore, it is not an accurate reflection of the total energy requirements used by the dog in locomotion.

However, it helps aid an understanding that structural misalignments or restrictions alter the magnitude of work conducted by areas of the body. Where work is asymmetrical across the body, there will also be asymmetry in the generation and movement of thermal energy in the activated muscles.

Increased demands on over-engaged muscles require a greater bioenergetic input from metabolism; this increases the localised demand for oxygen and nutrients. In response to these demands, vasodilation increases the mass flow rate of intravascular fluid (Ramanlal R, 2023). Therefore, there is an increase in local temperature due to the thermal energy produced by the metabolic process and the increased heat transfer by convection through vasodilation.

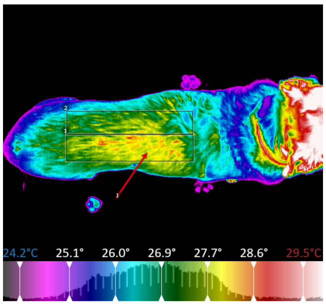

Figure 12.0: Thermal Asymmetry: Dorsal Aspect of Canine Thorax

Chronically under-used, diseased or injured muscles experience less biomechanical movement and reduced flow of biofluids, leading to the local fascia becoming dehydrated and less elastic (MacDonald et al., 2013). Fibrous fascial adhesions are likely to form under those conditions and are known to cause pain and restrictions of motion (MacDonald et al., 2013). This is significant because thermal asymmetries may be precursory signs of changes in fascia.

In this sense, over-engaged muscles would appear warmer in thermal imaging, and under-engaged muscles appear cooler in temperature. Knowing which areas of the body are generating and receiving insufficient thermal energy is important because when the local bodily temperature drops below 32^{o}C, the elastic modulus of muscles is increased, making them stiffer and more prone to tearing under high energy input loads, such as high acceleration movements (Scott et al., 2016).

Hypothermic areas of the body are then more likely to suffer facia adhesions and muscle injuries. Although it is well known that muscle injuries lead to performance declines, dysfunctions in the fascia also contribute to performance declines and the development of pain disorders (Kodama et al., 2023).

Canine Osteopaths consider the body as a series of interconnected systems and understand that when one area of the body is strained, other areas will need to compensate. So, the knowledge of any thermal asymmetries or marked temperature abnormalities will be beneficial. Reducing the likelihood of compensatory injuries is done by the detection of and holistic treatment of somatic dysfunctions, which are linked to thermal asymmetries or abnormalities.

The canine in Figure 13.0 had received non-osteopathic treatment for hindlimb lameness with unremarkable X-rays. However, the thermal imaging shows a distinct pattern of hypothermia through the left carpus and metacarpal area. This demonstrates the use of thermal imaging in aiding the canine osteopath to gain a more holistic understanding of the dog's physiological state and provides a visual means to educate the owner on the fourth osteopathic principle.

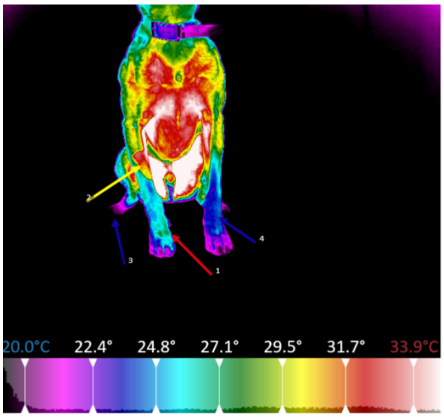

Figure 13.0: Thermal Asymmetry in Canine Carpi and Metacarpi

Neurological

The neurological model considers the functioning of the nervous system. It is responsible for sensing and transmitting information through the afferent nerves up to the central nervous system, which processes the information and then initiates the transmission of information through the efferent nerves to effector organs, causing an action to occur (Marieb, 2015). Because the nervous system detects sensory information and controls functions, it is intrinsically linked to heat generation and transfer processes throughout the body.

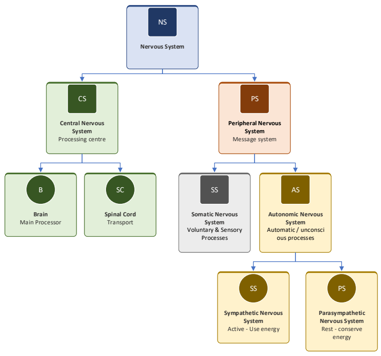

Figure 14.0: Neurological System

Using a pulse of charged particles, termed an action potential, signals are transmitted along the length of the neuron's axon to or from the central nervous system, which is responsible for processing the information (Marieb, 2015). Due to the interconnectedness of the bodily systems, where dysfunctions impede this neurological communication, there will be a resultant alteration in the animal's physiology.

Alterations in physiology that result in patterns of thermal asymmetry are linked to the nervous system. This is because the autonomic and somatic nervous systems play a role in heat generation and transfer processes. Figure 15.0 shows the different structures and functions of the somatic and autonomic nerves. Although these systems play different roles, the sympathetic and parasympathetic nervous systems can work antagonistically, synergistically, or independently to maintain thermal homeostasis by regulating the complex functions of the autonomic effector organs (Sheng & Zhu, 2018).

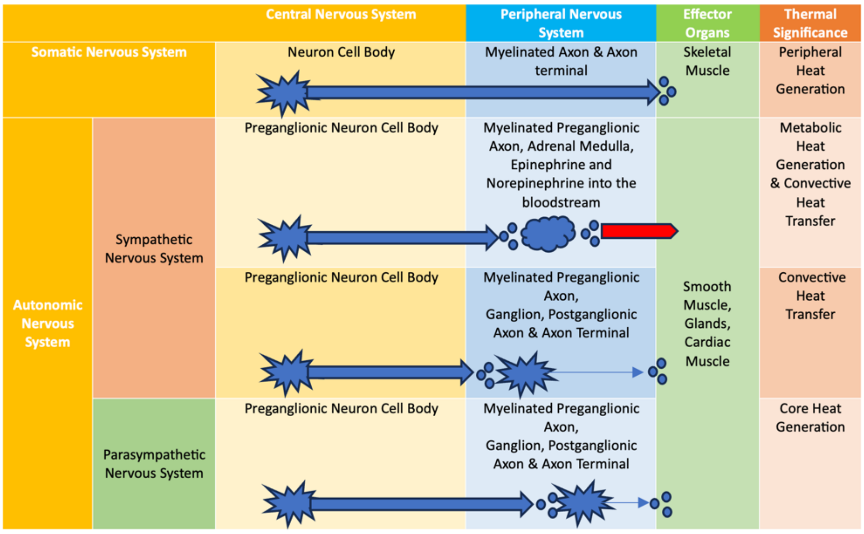

Figure 15.0: Comparison of Autonomic and Somatic Effector Nerves

The effector organs of the somatic nervous system are skeletal muscles, which generate heat through metabolic processes. In contrast, the autonomic nervous system regulates the mass flow rate of intravascular fluid, which alters convective heat transfer through vasoconstriction and vasodilation (Sheng & Zhu, 2018). This system is also responsible for signalling smooth muscle tissue, which causes heat generation through metabolism; these tissues are predominantly found in organs within the body's core region. It plays a third function by signalling the synthesis of norepinephrine and epinephrine in the adrenal medulla; this contributes to heat generation by increasing the rate of metabolism (Osilla et al., 2023) and heat transfer by affecting heart rate.

When considering neurological dysfunctions, the body can be viewed in regions according to innervation. Dermatomes are areas of skin, hypodermis, and superficial fascia innervated by a single cutaneous branch of a spinal nerve (Stecco et al., 2019); canine dermatomes are illustrated in Figure 16.0. In comparison, myotomes denote a group of muscles innervated by a specific nerve root (Gaskell, 2013). Further, areas of deep fascia, which are supplied by a single nerve root, are termed fasciatomes and follow force lines associated with motion (Stecco et al., 2019).

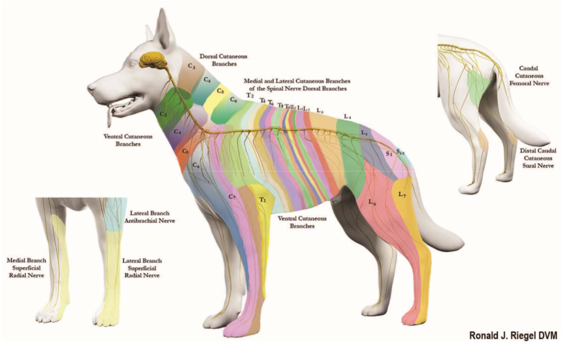

Figure 16.0: Canine Dermatome Diagram

Different pain sensations are associated with faciatome and dermatome pathologies, with localised pain linked to a dermatome and radiating pain linked to a fasciatome (Stecco et al., 2019). Since animals cannot describe their pain to us, thermal imaging may help detect thermal asymmetries linked with pain, and the resulting patterns may help in ascertaining if the somatic dysfunction is surface level, deep fascia, or muscle groups. It would be expected that pathologies in these different regions would display different thermal patterns.

In addition to determining the location and systems involved in a dysfunction, thermal imaging may also help determine the severity of nerve injury. Complete peripheral nerve injury is linked with increased convective heat flow due to a loss of function in the autonomic nervous system, which increases the mass flow rate of intravascular fluid (Gaskell, 2013). Whereas incomplete peripheral nerve injury showed localised areas of hypothermia caused by vasoconstriction, which reduced the mass flow rate of intravascular fluid (Gaskell, 2013).

Where systemic thermal abnormalities inappropriate to the environment present, such as excessive or insufficient heat generation, the links to the metabolic or biopsychosocial models should also be explored. These models are highly linked to the nervous system through the hypothalamus in the central nervous system, which processes thermal regulation information (Romanucci & Salda, 2013). This brain region is also part of the limbic system that processes emotions (Gavrilova et al., 1975). It controls the release of epinephrine and norepinephrine from the adrenal medulla, which adjusts metabolic and heart rate.

Thus, the nervous system plays a complex yet vital role in local and systemic thermal regulation, conveying information and making decisions to maintain thermal homeostasis.

Respiratory Circulatory Model

The structure and function of the respiratory circulatory model play important yet different roles in thermal regulation. This system is intrinsically linked to heat transfer processes due to its role in the convection of heat through the movement of intravascular fluids; it is also indirectly linked to heat generation as it provides oxygen delivery and waste removal services necessary for metabolism. Further, the structure of this system directly impacts the mass flow rate of extracellular biofluids contained within the system; this impacts the conduction of heat across the vessel barrier into the surrounding tissue.

The vessels of this system form the structure that permits biofluids to flow in predefined pathways, allowing heat convection to occur with the fluid flow. The flow rate, which affects the amount of heat transfer, is impacted by the properties of the fluid and the physical structures: viscosity, turbulence, the power delivered to fluid, cross-sectional area of the vessels, the distance between vessels and phase changes that occur between moist environment and the ambient air.

Although mass flow rate is directly proportional to convective heat transfer, fluids such as lymphatic fluid, which flow at rates around 5ml/h (Michael et al., 1979), will likely play an insignificant role in heat transfer. Instead, the bulk flow rate of the intravascular fluid convects heat away from the core, bringing it to the surface where excess heat can be emitted into the environment, and cells can be maintained at a temperature optimal for life.

Understanding how heat moves around the body through the circulatory system can aid Canine Osteopaths in their treatment, aiming to foster an environment in the body that tends towards thermal symmetry and monitoring the healing processes of injuries.

Disruptions in the circulatory system happen in injuries; an example can be seen in Figure 17.0. The patient displayed unexpected thermal abnormalities in the neck region, likely associated with a non-puncturing bite injury and an expected thermal abnormality in the left hind limb. However, it was reported that palpation was not well in the area of injury; thus, thermal imaging may be of use to monitor the site and aid as a safe means of diagnosing somatic dysfunction, which can be easily communication with the Veterinarian.

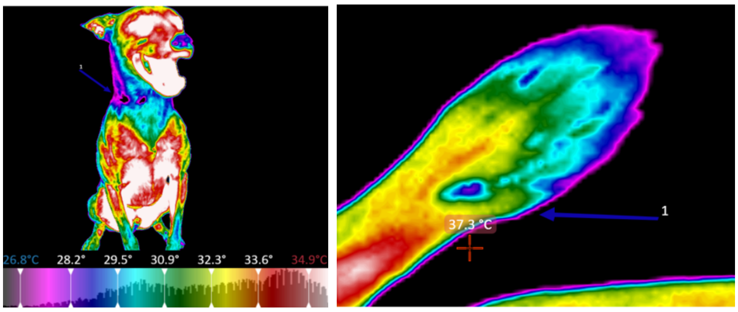

Figure 17.0: a) Local hypothermia on the R lateral side of the neck b) Local hypothermia LPL metatarsal region digit II/III

Metabolic Energetic

The metabolic-energetic model considers the consumption, production, storage, and conversion of energy within the body. This model is directly involved in heat generation because inefficiencies in the chemical reactions necessary to generate work energy release a significant amount of thermal energy (Millis & Levine, 2014).

Metabolic thermal energy is predominantly generated in the liver, brain, heart, and by skeletal muscles during exercise (Osilla et al., 2023), with 33% of a dog's total bodily heat production created by the abdominal organs (Krönert & Pleschka, 1976). This heat is moved away from the core towards the skin to maintain homeostasis; this is done by convection via the circulatory system, conduction through adjoining tissue and radiation, which is absorbed by nearby tissue and fluid and further, the heat is dissipated into the environment.

The sympathetic nervous system and hormones regulate the metabolic rate; it is further impacted by activity, size, pathologies, and state of mind. For instance, smaller dogs have a lower basal metabolic rate; however, they exhibit a higher mass-specific metabolic rate

(Middleton et al., 2017), which may be attributed to their higher surface-area-to-volume ratio which promotes the dissipation of heat into the environment.

How the animal perceives their environment also impacts the metabolic rate. In response to physical or emotional stressors, catecholamine hormones are released by the adrenal medulla into the bloodstream (Marieb, 2015). They increase the heart rate, blood pressure, circulating glucose and oxygen intake (Marieb, 2015), allowing the body to move away from perceived dangers.

In addition to the catecholamine hormones norepinephrine and epinephrine, thyroid hormone also affects metabolic rate (Hinderer et al., 2023). The release of thyroid hormones is controlled by the hypothalamus and the pituitary gland (Hinderer et al., 2023). Dogs are susceptible to the metabolic disorder hypothyroidism; this pathology reduces metabolic rate, leading to weight gain and lethargy (Peterson, 2022). This reduction in metabolic rate would likely be associated with a generalised decrease in the emission of thermal radiation.

Metabolic heat energy is released during the hydrolysis of adenosine triphosphate (ATP) (Kenny & Flouris, 2014), which provides energy to muscles; this is the oxidation process of carbohydrate and fatty acids within the mitochondria of muscle fibres (Kenny & Flouris, 2014). During exercise, ATP can also be synthesised anaerobically; however, this plays a less significant role in heat generation since the process can only be maintained for short durations and produces less thermal energy (Krustrup et al., 2003)

Pathologies that affect the metabolic system can be caused by nutrient deficiencies or altered enzyme functionality (Allen, 2022). Shifts in the dominant type of metabolism are also linked with pathologies, such as cancer (Jiménez et al., 2023). Pathologies related to the metabolic system directly impact energy production and, therefore, heat generation. It is unclear, though, how systemic metabolic pathologies would affect the thermal profile, and further studies of temperature variations may shed light on the effectiveness of thermal imaging in this regard.

However, in certain extreme cases, emotional state or environmental stimuli can trigger a metabolic pathology termed malignant hyperthermia, which raises the body temperature and can lead to death (Lin, 2018). In this disease, severe muscle contractions and a sudden and abnormal increase in body temperature are accompanied by symptoms in the respiratory-circulatory system (Lin, 2018), which requires immediate veterinarian assistance.

Thus, although the metabolic system generates thermal energy, detecting thermal asymmetries or abnormalities related to metabolic processes is likely more relevant to canine osteopaths when pathologies of the biomechanical or neurological systems are dominant. Localised thermal abnormalities or asymmetries are likely easier to discern on thermal imaging than are systemic metabolic dysfunctions.

Biopsychosocial model

The biopsychosocial model considers aspects of the dog's biology, psychology and social experiences that impact their thoughts, emotions and outward behaviour. It is directly and indirectly linked to body heat generation and transfer processes. Where genetic factors such as structure directly impact heat transfer and heat generation, psychological and social factors can impact the nervous system. This indirectly affects the convection of heat energy through the circulatory system and the metabolic generation of thermal energy, as discussed earlier.

It is generally well-understood that past experiences and present thoughts significantly impact present emotions. The previous social experiences dogs are exposed to form thought patterns and emotions that lead to an unconscious or autonomic response, preparing the body to act according to perception. In pursuit of homeostasis, the metabolic rate and intravascular fluid mass flow rate adapt based on the dog's emotion and perception of their environment. Ideally, the body should respond appropriately to environmental stimuli and recover shortly afterwards, returning to normal thermoregulatory processes. However, where past social-emotional experiences heighten, prolong or distort the body's response, there will be a resultant impact on other systems, leading to strain or pathologic disease states.

The flow of biofluid within the body changes in response to psychological interpretation. Heart rate increases are driven sympathetically and occur in heightened emotional stress states such as fight or flight; conversely, the parasympathetic nervous system decreases the heart rate in the inhibited state of freeze (Roelofs, 2017). These physiological responses to environmental or psychological stressors are designed to cope over a short-term period; otherwise, the overstimulation or inhibition of bodily functions that alter the natural flow of biofluids may lead to dysfunctions.

It has been shown that humans suffering from chronic pain can have an overstimulation of vasoconstriction due to psychological pain anxiety (Veluswamy et al., 2017). The interoception of patients with fibromyalgia, which causes pain and bodily restrictions, was reduced, resulting in decreased internal awareness (Valenzuela-Moguillansky et al., 2017). However, their exteroception was enhanced, leading them to believe their body was more extensive than their actual dimensions (Valenzuela-Moguillansky et al., 2017). This concept is interesting when considering dogs suffering from chronic pain because vasoconstriction associated with pain or pain anxiety changes the mass flow rate of biofluids, and an overestimation of bodily size may correlate to the need for a larger perceived space around them to feel safe.

Dogs that do not feel safe and are in pain may resort to biting; research has shown that dog bites are prevalent in veterinarian practices within Australia (Fritschi et al., 2006). Biting, although dangerous, is a form of canine communication, and biopsychosocial factors can influence how dogs communicate. When undiagnosed muscular skeletal pain is present, some dogs may display behavioural indications low on the ladder of aggression, such as lip licking or turning their head during palpation. Others may resort to biting without displaying these lower-level signals; this can be caused by handlers inadvertently ignoring lower-level signs of aggression or directly teaching dogs to suppress their outward behavioural indicators of aggression (Mills et al., 2020).

Thus, understanding where areas of pain are located and underlying biopsychosocial factors that impact behaviour are essential considerations for canine osteopaths. In the absence of dogs being able to describe where their pain is and the potential for behavioural signs to be impacted by learning, thermal imaging may serve as a new level of communication since it quantitatively displays the current physiological thermal profile of the dog, which is impacted by the mass flow rate of fluids and metabolic heat generation.

Studies have suggested that thermal imaging may help detect patterns of surface temperature changes associated with emotions (Ioannou et al., 2014) and sympathetic stress states in human (Engert et al., 2014). However, a study that used thermal imaging to detect temperature rises in the eye of greyhounds due to stress and arousal found that environmental and biological factors influence the results (Elias et al., 2021). Thus, thermal imaging to determine emotions or stress in dogs has yet to be fully developed and requires further research.

Anecdotally, in practice settings, the distal limb temperature of dogs appears to have some correlation with emotional states. For instance, Figure 17.0 (a) displays a greyhound with a mild temperature gradient from the crus to the metatarsals, compared with (b) a slightly more anxious greyhound who exhibited a more significant temperature gradient, promoting the conservation of heat loss through the distal limbs. Since these dogs had similar coat types and were from the same environment, the temperature differences are likely a physiological response to internal sensory or emotional differences.

Although using thermal imaging to detect the emotional states of canines requires more research, the physiological responses to past, present, and future events should form part of a canine osteopath's consideration when treating a patient.

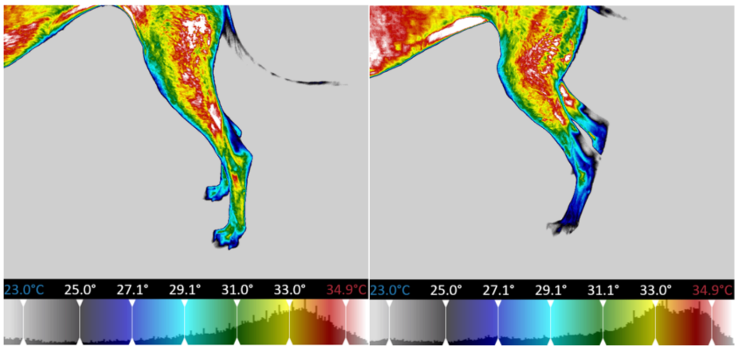

Figure 18.0: a) Mild temperature gradient in distal hind limbs b) Restricted heat loss in distal limbs

Applied Thermal Imaging

Thermal imaging uses a specialised camera that detects thermal radiation. These energetic frequencies have a wavelength in the infrared light spectrum; these can be emitted or reflected from an object's outer surface. It is a non-destructive and non-invasive means of detecting temperature. Ideally, the thermal imaging should be passive; that is, the target temperature is not changed by conducting the thermal imaging. However, if the process causes a stress response in the animal, the thermal profile may reflect an altered physiological state associated with the increased stress.

The images obtained through thermal imaging are quantitative; they reflect the thermal energy emitted by the canine body, creating a physiological heat map of the dog's present state. Further development of standardised interpretation is likely needed since temperature variations are associated with bodily regions and coat types (Brundage & Kwon, 2022). However, in non-pathological states, bilateral thermal symmetry should be observed in coat types other than curly coats, as these can produce asymmetrical patterning due to the direction and growth of the hair (Brundage & Kwon, 2022).

Using thermal imaging to detect thermal asymmetries is superior to using palpatory skills. Reliance on temperature determination via the practitioner's hands is a subjective means of assessment. Studies have shown that the quality of temperature perception from the human hand is reduced when “thermal stimulation is accompanied by dynamic tactile stimulation, as during haptic exploration” (Green, 2009), which is relevant since osteopathic palpatory assessments require the use of dynamic touch to detect tissue quality (LCAO, 2023).

Detecting thermal asymmetries with thermal imaging is likely a positive addition to canine osteopathic practices. It is a screening tool, valid for the early detection of musculoskeletal and neurological pathologies (Turner, 2001) that has demonstrated use in detecting changes associated with pathologies such as canine bone tumours (Sung et al., 2019), sports injuries (Hildebrandt et al., 2010), canid spinal pathologies (Mazzotta et al., 2022), cervical intervertebral disc herniation (Zhang et al., 1999), and pain (Pérez-Concha et al., 2023). It is limited, however, as a functional test, providing quantitative physiological information in a non-diagnostic manner. This is not necessarily problematic since it is out of scope and not the role of Canine Osteopaths to make medical diagnoses.

When applied thoughtfully and systematically, thermography may aid Canine Osteopaths in their osteopathic assessment. In understanding the location of thermal asymmetries, detecting somatic dysfunctions becomes easier since one of the T.A.R.T symptoms of somatic dysfunction becomes objectively visible. The thermal changes associated with dysfunction are discernible in thermal imaging before being perceivable in a typical physical examination (Turner, 2001). The visual images may also serve as a valuable means of communication with the animal's owner and medical veterinarian. Further, this extra layer of non-contact assessment may be helpful in cases where behaviours are subtle, extreme or altered due to pain or learning.

Further limitations in the applied use of this technology are associated with the hardware and operator. The resolution of the thermal images, dictated by the camera model, has some statistical significance in image repeatability (VainionpÄÄ et al., 2012). Thermographer skill and interpretation also play a role in the usefulness of thermal imaging. Where bilateral images are dis-similar in angle or distance, care should be taken in making interpretations of symmetry. Temperature acclimatisation periods are also suggested to avoid non-significant findings caused by environmental factors, such as sun exposure or resting on one half of the body.

Where external temperature influences are reduced or eliminated, the bodily temperature variations, as explored in this paper, are created by the complex involvement of the biological systems. Metabolic processes cause heat generation, and the convection of biofluids within the circulatory system facilitates bulk heat transfer. Understanding how thermal patterns arise and are impacted by the different bodily systems, combined with knowing where thermal abnormality or asymmetry are located utilising a visual tool, may make thermal imaging a valuable tool in canine osteopathy.

Applying a Canine Osteopath's deep anatomical knowledge, which considers the interactions of the neurological and musculoskeletal systems, to thermal imaging may aid in their physical and observational assessment for somatic dysfunction or detection of compensatory strain. Finding health remains an objective of the canine osteopath; to do so, there needs to be a deep understanding of physiology and how to affect positive change in the body by influencing the muscular-skeletal system. The strategic use of thermal imaging to locate and monitor thermal asymmetries may aid in achieving that objective.

Conclusion

The origins of Osteopathy were founded on the belief that impediments to the natural flow of bodily fluids affected the body's ability to conduct self-repair functions, leading to disease states. Identifying and treating these dysfunctional areas are fundamental to the osteopathic practice.

Where pathological disease states alter the mass flow rate of circulatory biofluids or the metabolic rate, the heat transfer and generation processes are directly affected. The circulation of intravascular fluid directly affects the convection of heat throughout the body, and metabolic processes release thermal energy that must be transferred around the body and into the environment to maintain homeostasis.

Thermal abnormalities and asymmetries within the body may be associated with dysfunction related to altered biomechanics, neurological dysfunction, circulatory constrictions, changes in metabolism, and biopsychosocial impacts. Local areas of thermal change may be associated with areas of tenderness, asymmetry, restriction of motion and tissue texture changes, which are symptoms the Canine Osteopath actively assesses for.

Research supports the application of thermal imaging to detect local thermal abnormalities or asymmetries objectively. The thermal abnormalities may present before the expression of performance-inhibiting symptoms becomes apparent. However, detecting emotional states or systemic thermal changes requires further research.

The role of the Canine Osteopath is to consider the whole patient and should seek to improve the natural flow of biofluids and create bilateral symmetry, which is directly linked to heat flow and heat generation. Canine osteopathic assessments do not offer a medical diagnosis; however, they determine areas of somatic dysfunction, which aligns with the abilities and application of thermal imaging.

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