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RISK FACTORS AND DETECTION OF LAMENESS USING INFRARED THERMOGRAPHY IN DAIRY COWS – A REVIEW*

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Abstract
Lameness in dairy cows is a worldwide problem, usually a consequence of hoof diseases. Hoof problems have a negative impact on animal health and welfare as well as the economy of the farm. Prevention and early diagnosis of lameness should prevent the development of the disease and consequent high costs of animal treatment. In this review, the most common causes of both infectious and noninfectious lesions are described. Susceptibility to lesions is primarily influenced by the quality of the horn. The quality of the horn is influenced by internal and external conditions such as hygiene, nutrition, hormonal changes during calving and lactation, the animal's age or genetic predisposition. The next part of this review summarizes the basic principles and possibilities of using infrared thermography in the early detection of lameness in dairy cows.

Key words: dairy cows, hoof lesions, infrared thermography, lameness

Lameness in dairy cows is currently a serious problem in the dairy industry and affects the health and welfare of animals (Westin et al., 2016). The prevalence of these diseases positively correlates with increasing milk yield (Potterton et al., 2012; Bicalho and Oikonomou, 2013). There is a growing number of breeds in the Czech Republic in which digital dermatitis and necrobacillosis occur (Šlosárková and Fleischer, 2009). Hoof problems have a negative impact on longevity, reproduction and dairy production (Hulsen, 2007; Blowey, 2012; Solano et al., 2016).

According to Thomsen et al. (2012) 90% of lameness in dairy cows is caused by hoof lesions. Lameness is debilitating and painful for the animal, has a multifactorial etiology and may be of infectious origin or caused by hoof injury. Hygiene and breeding technology are important factors in lameness (Keyserlingk et al., 2009). In

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particular the low level of hygiene and high humidity in the stables constitute ideal conditions for bacterial growth (Cook et al., 2012). Other factors include flooring, uncomfortable bedding, no access to pasture (Keyserlingk et al., 2009), nutrition, other diseases and genetic influences (Abuelo et al., 2016).

Early identification, immediate treatment of clinical signs and the initiation of specific steps in preventing lameness is very important for reducing lameness on the farm (García-Munoz et al., 2017). It is crucial to determine the cause of the disease and to distinguish whether it is an infection, a lesion caused by excessive grinding and trauma or laminitis. It is necessary to focus on the predominant cause and eliminate it (Nordlund et al., 2004). A low percentage of lameness reflects farm management, which should include regular antibacterial hoof baths, hoof trimming, suitable corridor surfaces, convenient bedding and clean stabling (García--Munoz et al., 2017). Diagnosis is usually determined during hoof trimming after the cow starts to limp (Alsaaod et al., 2015), which is economically inefficient (Hulsen, 2007).

There are several methods to diagnose hoof diseases. The most common methods are based on visual analysis of movement; however these are subjective (Rodríguez et al., 2015), there is no standard for evaluation and they are time consuming. On the other hand, they are cheap, noninvasive and easily applicable (Schlageter-Tello et al., 2014).

Movement and lameness can be assessed using relatively new automatic methods, which use a 3D vision monitor (Schlageter-Tello et al., 2018). The camera scans several points to obtain a 3-dimensional image of the cow and records motion changes (Pezzuolo et al., 2018). This approach ensures objectivity, unlike manual locomotion scoring (Van Hertem et al., 2018).

Another diagnostic method for hoof disease is infrared thermography, which uses the change in skin surface temperature in response to inflammatory changes (Alsaaod and Büscher, 2012). The disadvantage of this method is that it cannot be used for differential diagnostics. Studies have not confirmed temperature differences for individual diseases (Marti et al., 2015).

Lameness can also be detected using alternative methods, for example, pedometers, accelerometers (Schlageter-Tello et al., 2018), radiographic methods such as ultrasonography and scintigraphy. Radiographic methods usually complement infrared thermography: ultrasonography assesses size and morphology, whereas infrared thermography determines the location of the affected area. Scintigraphy is used to diagnose bone changes (LokeshBabu et al., 2018).

Economic losses are caused not only by lower milk production, but also by the disruption of the animal's overall health. There is a reduction in live weight (Němeček, 2009) and decline or disappearance of symptoms of estrus. It also increases the costs of treatment and care of affected animals and unsuccessfully treated animals are frequently removed. Other losses result from depletion of milk for human consumption during treatment due to the protection period, and from the increased risk of other health complications, e.g. bedsores, throbbing and inflammation of the joints (Šlosárková and Fleischer, 2009).

Hoof lesions

The occurrence of lame cows can be as high as 50% in problematic breeds in the Czech Republic, of which 85–90% is caused by claw and surrounding skin disorders (Šlosárková and Fleischer, 2009). Diseases can be divided into three categories. The first affects hoof horn (hemorrhages, white line disease, ulcers, penetration of a foreign object, horizontal and vertical fissures, necrosis), the second relates to bones (disorders of coffin or navicular bone) and the third category affects skin (hyperplasia, digital dermatitis, interdigital necrobacillosis) (Blowey, 2012). The most susceptible are high-yield dairy cows (Foditsh et al., 2016). The lesions may be of infectious or non-infectious origin. Infections more frequently affect the skin of the limbs (Solano et al., 2016) and are more often caused by *Fusobacterium necrophorum* and several types of Treponema (in the case of digital dermatitis) (Cook and Nordlund, 2009). Non-infectious lesions affect the hoof horn and are associated with metabolic and hormonal changes during calving, low body condition, excessive horn growth or exposure to hard surfaces (Solano et al., 2016). This is a multifactorial disease caused by internal and external influences. Internal influences include, for example, breed, genetic predisposition, pathologically formed hooves or the age of the animal. External conditions that may affect the health of the hooves may include breeding technology, environment, nutrition, metabolic diseases or veterinary prevention (Šlosárková et al., 2001). Heifers constitute a high risk category, having very weak connective tissue during calving (Huxley, 2012).

If lameness and hoof lesions occur during the first lactation, they will likely reappear during subsequent lactations (Foditsh et al., 2016). The thickness of the digital cushion is also important (Bicalho and Oikonomou, 2013), as it reduces the compression of the hoof junction and the risk of lesions (Foditsh et al., 2016). The thickness of the digital cushion correlates positively with the body condition score, which decreases during the first months of lactation (Bicalho and Oikonomou, 2013). The thickness of the digital cushion gradually decreases after calving, which is associated with dynamic changes in the condition of high-yield dairy cows where the highest prevalence of ulceration is at the peak of lactation (Lean et al., 2013).

Many countries implement electronic systems for recording hoof diseases and claw disorders in dairy cows. Descriptions and records of hoof diseases are included, and this data can improve the health and welfare of dairy cattle. Claw disorders are defined in the ICAR Claw Health Atlas including photos (Egger-Danner et al., 2017).

Predilection sites for hoof diseases

The rate of horn growth is approximately 5 mm per month (Blowey, 2012). Without sufficient abrasion, pathological forms of hooves can be developed, resulting in a non-physiological distribution of claw pressure and non-physiological pressure on the deep finger flexor (König and Liebich, 2002). Increasing pressure on the corium can destroy dermal papillae and disrupt horn formation, thus increasing the risk of ulceration (Alsaaod et al., 2015).

The typical location of the Rusterholz ulcer is between the proximal and distal section of the heel. A horn of very different hardness is encountered in this area, and due to the physicochemical material properties, microscopic cracks occur more

frequently, which is the beginning of a larger disruption of the claw horn (König and Liebich, 2002). Rusterholz ulcers are often the result of horn overgrowth when there is an acute angle in the hooves. Through the softer horn of the hoof, the corium is easily traumatized (Šlosárková et al., 2001). Rusterholz ulcers appear more often on the lateral finger of the hind limb (Alsaaod et al., 2015), the reason being that the lateral claw bone partially lies on the sole, while the medial claw is more tightly attached to the wall, causing less pressure on the sole (Blowey, 2012). On the contrary, ulcers occur less frequently on front limbs and, when so, more often on the medial finger (Alsaaod et al., 2015). The predilection point for ascending infections of the white line disease is determined by heterogeneity and very wide marrow areas of terminal papillas (König and Liebich, 2002).

Horn quality

The horn is a barrier against ascending infection. If this barrier is disturbed by pathogenic microorganisms, purulent inflammation may occur. Poor bedding hygiene can interfere with this barrier and horn integrity because high slurry concentration dissolves intercellular cement. Urea in bedding selectively destroys the cells' keratin and produces a dyskeratotic horn, characterized by a lack of keratin and excess intercellular cement. This dyskeratotic horn is very sensitive to bacterial decomposition.

The horn quality may also be influenced by nutrition: a lower supply of nutrients leads to the production of poor-quality horn and increased sensitivity to chemical, physical or microbial effects (Tomlinson et al., 2004). Other causes may be insufficient vascular supply to the corium due to lack of movement, and permanent load or anatomical anomalies, which reduce the nutritional supply of the epidermis through diffusion, thereby reducing the quality of the epidermal product of the horn (König and Liebich, 2002).

At the start of lactation, insulin sensitivity is reduced, which may inhibit the formation of keratin due to suppression of glucose and amino acid absorption. Excessive feeding during a dry period induces hyperinsulinemia and hyperglycemia in early lactation, which are classic signs of insulin resistance. This phenomenon leads to the production of poor-quality horn at the beginning of lactation and can cause laminitis. Increased steroid hormones and prolactin during pregnancy also reduce production of growth factors and inhibit keratin synthesis.

Glucocorticoids, especially stress-induced cortisol, affect the maturation of keratinocytes and negatively affect the metabolism of glucose, proteins and fats. Dairy cows with higher milk production may not be able to produce enough protein, especially at the beginning of lactation. Insufficient protein in developing keratinocytes can result in the production of poor-quality horn and predispose the cow to lameness. At the beginning of lactation, calcium requirements are also increased, which is necessary for the formation of the horn. Requirements grow with increasing parity (Tomlinson et al., 2004).

In older and heavier animals, horn cracks may appear, caused by the horn becoming dry and brittle and losing flexibility. This can also be due to a deficiency of some microelements, such as selenium, copper or zinc. Cracks can be of genetic origin as well. In animals with healthy hooves, cracks may appear after exposure to stress.

Prevention includes supplementation of minerals and biotin. If the cracks are too deep, the deeper tissues may become infected and cause lameness. Hooves that grow too much tend to crack and split (Thomas, 2009).

Effect of the environment on hoof horn quality in dairy cows

The hoof horn grows faster in summer and is harder than in colder periods. Dry air causes harder, but more brittle horn. Wet and warm weather, on the other hand, is conducive to the proliferation of rotting microflora (Novák et al., 2003), causing diseases of the interdigital space and heels (Nordlund et al., 2004). The most inappropriate housing technology, with the highest incidence of limb disease, are litterless stables with a slat floor. Movement in feces softens the horn and excessively abrades it (Novák et al., 2003). Dirty hooves indicate a large amount of excrement. Waste removal facilities play an important role in ensuring a clean and dry environment (Hulsen, 2007). Animals react to higher concentrations of stagnant gases, high relative humidity in winter and high temperature in summer by restricting movement, reducing metabolism, reducing feed intake and consequently reducing milk production. The breeder usually compensates by increasing concentrated feeds, which may cause subclinical metabolic acidosis and laminitis (Novák et al., 2003).

A suitable type of surface in stables is required to maintain good hoof health in dairy cows (Haufe et al., 2012). The surface must not be too smooth, wet or dirty because of the risk of slipping, which can lead to changes in interdigital space (microcracks, thylomas) (Šlosárková et al., 2001). On the contrary, too rough a surface can cause severe horn abrasion, excessive shortening of hooves and inflammation (Bicalho and Oikonomou, 2013). Small cutting wounds in the skin of the lower extremities allow microorganisms from the environment to penetrate, causing pathological lesions (Šlosárková et al., 2001). Excessive abrasion of the hoof horn occurs in stables with rough concrete floors and long distances to and from the milking parlor (Nordlund et al., 2004). An uneven and ruptured surface can cause horn and skin damage, which may be connected with an increased incidence of necrobacillosis (Novák et al., 2003). The use of rubber flooring improves the movement of animals (they move more quickly, having boosted confidence, and take longer steps) and reduce the risk of slippage compared to concrete surfaces (Cook and Nordlund, 2009; Rajapaksha et al., 2015). Haufe et al. (2012) rebutted the hypothesis that the use of rubber floors could reduce the incidence of hoof lesions. The influence of the material used was minimal. Dairy cows spend more time standing and walking on these floors than on concrete, which increases the prevalence of infectious hoof diseases (digital dermatitis) (Boyle et al., 2007; Haufe et al., 2012). Walking on the soft surface also caused excessive horn growth (Bicalho and Oikonomou, 2013). A suitable environment is in the pasture, where the ground is soft and optimally rough and where there are few bacteria that could have a negative impact on the health of the hooves (Hulsen, 2007).

Cow stalls must be comfortable because the cows spend 11–14 hours per day lying (Bicalho and Oikonomou, 2013). It is beneficial to have 10% more stalls than cows, so the animals do not spend so much time looking for a free stall (Blowey, 2012). It is important that dairy cows spend more time lying than standing, because

longer periods of standing increase the load on hooves and increase the risk of lesions (Cook and Nordlund, 2009). Long-standing animals exert more pressure on the hooves, which may cause physical damage and hemorrhaging. In addition, an animal that has been standing for a long time may have edemas, which can affect horn growth (Blowey, 2012).

The most frequent form of housing for dairy cows is free-boxing stalls (Šlosárková et al., 2001) and it has been found that dairy cows prefer a deep sand bed. On farms with this technology a lower incidence of lameness was observed (Bicalho and Oikonomou, 2013). From the point of view of microclimate, effective ventilation is important. Dairy cows produce about 60 l of water per day (urine, excretion, breathing and sweating) and insufficient ventilation can lead to heat accumulation and heat stress (Blowey, 2012).

Effects of nutrition on hoof horn quality in dairy cows

Nutrition is a key factor for healthy horn growth. Nutritional deficiencies can lead to the development of weak and fragile horn, more susceptible to cracks and infections (Thomas, 2009). Hoof diseases can be caused by abrupt changes in feed composition, which in turn cause changes in the rumen microflora composition, starting decarboxylation processes and production of volatile fatty acids and lactic acid (Šlosárková et al., 2001). It is important to always make gradual changes in the composition of feed rations and offer cows enough hay for proper rumination (Blowey, 2012).

Indigestion caused by ingesting poor-quality feeds can disrupt the synthesis of microbial protein and group B vitamins (biotin). Microbial protein is an indispensable source of methionine, which is the basis for the hoof horn (Šlosárková et al., 2001). Biotin assures the integrity of keratinized tissue, is important for lipid production in intercellular matter and, together with zinc and copper, makes it possible to produce a durable horn (Lean et al., 2013). Insufficient biotin has a negative effect on the quality of the horn and causes cracks in the hoof horn.

Concentrated feed and lack of effective fiber cause rumen acidosis and subsequent metabolic acidosis, which is a major factor in the onset of the hoof diseases (Hulsen, 2007). Such feed results in rumen microflora changes: there is an increase predominantly in bacteria producing lactic acid, which causes rumen pH decrease. The result is a change in the digestive process of proteins, in which histamine is formed and the desirable rumen microflora dies and endotoxins are produced. Histamine and endotoxins can be produced in the digestive tract because of poor quality feed, especially rotten silage or moldy feeds (Šlosárková et al., 2001). Endotoxins are lipopolysaccharides released from the cell walls of gram-negative bacteria during lysis (Lean et al., 2013). Endotoxins stimulate the release of histamine, which affects blood vessels, resulting in an insufficient blood supply to the corium of the hoof and therefore in an inadequate supply of oxygen and amino acids necessary for horn formation (Blowey, 2012). Additionally, these substances retard epithelial regeneration (Lean et al., 2013) and activate enzymes that cause degradation of the collagen fibers of the suspension apparatus, causing the displacement and sinking of the distal phalanx (Bicalho and Oikonomou, 2013). In addition to these changes, metabolic

acidosis disrupts the metabolism of calcium and phosphorus, which is manifested in lactating animals by reduced calcium absorption, leading to the development of osteoporosis, which affects the coffin bone. Another problem may be excess proteins in feed, which results in faster horn growth and a poor ratio of cysteine and methionine, which is connected to the production of softer horn (Šlosárková et al., 2001).

Minerals such as zinc, copper, selenium, manganese, vitamins (especially A, D and biotin) and fatty acids affect horn quality (Thomas, 2009). Zinc, sulfur and trace elements increase the hardness of the horn (Blowey, 2012). Zinc is important for the formation of hooves, it has a catalytic, structural and regulatory function in keratinization. Furthermore, it regulates calmodulin, which is responsible for the transfer of calcium ions to the cytosol of keratinized cells, an important final step in the development of keratinocytes (Lean et al., 2013). Zinc deficiency also often plays a role in the development of inflammatory processes on the skin and horn, such as dermatitis digitalis (Šlosárková et al., 2001). Selenium protects and maintains the intercellular mass of keratinocytes, which is rich in lipids. Vitamins A, D and E are important for horn structure and quality. Vitamin A is involved in the differentiation of keratinized cells. Vitamin D is a regulator of calcium metabolism and has a positive effect on keratinization. Vitamin E is soluble in fat and maintains cell membranes and intercellular matter in the horn (Lean et al., 2013).

Nutrition affects the body's immune system, indirectly contributing to the development of infectious hoof diseases. This is especially important in early lactation, at which time there are raised levels of glucocorticoids, which are substances that have significant immunosuppressive effects. Energy deficiency at the beginning of lactation often causes ketosis. The ketone bodies negatively affect the function of white blood cells. A negative influence on the immune system is also present in animals with metabolic acidosis.

It is necessary to properly prepare cows for calving, to maintain optimal body condition, to avoid changing the feed suddenly before calving, but gradually over a two to three week period preceding birth, and to maintain the appropriate amount of structural fiber (Šlosárková et al., 2001). Dairy cows should have a body condition score (BCS) of 2.5–3 during the dry period, and maintain this condition until calving, because overfed cows are more susceptible to developing metabolic problems (Blowey, 2012).

Effects of calving and lactation on hoof horn quality in dairy cows

Hoof horn is very brittle and susceptible to contusions during calving. The cause may be stress induced by changes in feed, changes in the environment, or by the formation of a larger group of animals. Another theory is that sulfuric amino acids, necessary for keratin production, are increasingly consumed for milk production, and therefore low quality horn is produced. Keratinized cells are separated, the space between them being filled with blood, bacteria and amorphous residues. The hoof structures are thinner and the infection can penetrate into the corium.

Two weeks before calving there is an increased production of relaxin which promotes a higher flexibility of the suspension apparatus and greater movement of the coffin bone. This phenomenon lasts until about two weeks after birth (Blowey,

2012). These physiological and metabolic changes around calving have the same effect on connective tissue as endotoxins. Their impact decreases the integrity of the horn and increases the risk of ulceration (Lean et al., 2013; Abuelo et al., 2016). An increased pro-oxidative state around calving potentially increases the production of pro-inflammatory mediators (Abuelo et al., 2016). Cases of digital and interdigital dermatitis often appear after calving. This is probably due to a combination of immunosuppression and increased time spent standing. Changes in blood circulation cause fluid accumulation in the corium and other structures, resulting in the production of a softer horn, hemorrhages, horn separation or ulceration (Blowey, 2012).

Diagnostics of lameness in dairy cows

Lameness disrupts the vertical symmetry of animals. Lame cows walk much slower than healthy ones. Lameness imposes costs for the farmer, so it is important to recognize the lame cow in time (Thorup et al., 2014). In healthy animals, each limb bears a certain weight, which is distributed optimally when the cow is standing on all four limbs. When one limb is raised during walking, weight is distributed among the other limbs. In lame cows there is a change of body position. Lame cows have problems getting up and down and use their head as a counterweight to relieve painful limbs (Hulsen, 2007). Pain is associated with arching of the spine and shortening of gait length (Nordlund et al., 2004). Other non-specific symptoms of lameness may be reduced feed intake and lower interaction with other animals (Nechanitzky et al., 2016). Most hoof lesions are detected during preventive hoof trimming. However, this is carried out usually only twice per year, so this method of detecting hoof lesions is not effective and an alternative is needed (Thomsen et al., 2012).

The most common methods for detection of lameness include visual analysis of motion (Rodríguez et al., 2015), where the symptoms of pain and swelling must be recognized (Hulsen, 2007). Locomotion scoring is a very subjective method. According to one study (Orman and Endres, 2016), a single assessor rated 56% of the cases with the same locomotion score over three consecutive days. With two evaluators, the same locomotion score was given in only 37% over the same period.

Objectivity can be attained through locomotion scoring based on 3-dimensional computer vision, which emulates human observation and analyzes parameters of movement and behavior through sensors and mathematical algorithms (Schlageter-Tello et al., 2018). Lameness detection is based on the spinal arch (Hansen et al., 2018). The 3-D system is capable of automatically classifying cows as lame or non-lame (Schlageter-Tello et al., 2018; Van Hertem et al., 2018).

Radiographic methods like ultrasonography and scintigraphy used for measurement of internal structures such as horn thickness and thickness of underlying soft tissues are also used in the diagnosis of lameness. Many changes to these structures, however, are permanent and it is difficult to ascertain whether a particular change is responsible for lameness (LokeshBabu et al., 2018). Dairy cows with a low body condition score (BCS) and thin soft tissue in the foot have a higher risk of both horn injury and ulcers. Determination of soft tissue thickness in early lactation may be useful for prediction of sole ulcers (Toholj et al., 2014). It is also possible to use temperature phenomena where the affected limb has a higher temperature before

color changes on the skin, lesions and lameness occur (Nikkhah et al., 2005). This phenomenon is utilized by the infrared thermography method described below.

The use of infrared thermography in the diagnosis of hoof lesions in dairy cows

Infrared thermography is a non-invasive, non-radiation, rapidly evolving diagnostic method (Hildebrandt et al., 2010) that measures the surface temperature and represents it as a color scale (Alsaaod et al., 2013). It is used to detect local temperature abnormalities on the skin surface by capturing infrared radiation that can be directly correlated with the surface temperature of a part of the body (Hildebrandt et al., 2010). The hoof with a lesion has a higher surface temperature than a healthy one (Bobić et al., 2017). This phenomene we can see in Figure 1.

Figure 1. The thermogram shows temperature differences between the cow's hind limbs. Clearly the left limb is considerably warmer than the right one. Therefore, it can be concluded that a lesion is present in the left limb

Infrared thermography is applied in human and veterinary medicine (Alsaaod and Büscher, 2012). It has been used in veterinary medicine since the 1960s in equine orthopedics (Westermann et al., 2013), for early detection of estrus in farm animals and for detection of dairy mastitis, viral diseases and diarrhea in calves (Alsaaod and Büscher, 2012). In human medicine, it is used in neurology, urology, muscular fever and breast cancer (Hildebrand et al., 2010). It is useful to place the equipment in a parlor or weighing scales to diagnose hoof lesions. The thermocamera should always be at the same angle and distance from the monitored animal and thermograms made at the same time of day. Measurements should be carried out on site without direct sunlight and draft (LokeshBabu et al., 2018).

Basic principles of infrared thermography

The camera detects the infrared radiation emitted by the body surface, resulting in a thermogram of the measurements (Westermann et al., 2013). The thermogram is

a quantitative and qualitative temperature map of the body surface that may correlated with various pathological processes in the blood stream (Hildebrandt et al., 2010).

Infrared radiation is an electromagnetic wave with wavelength between 0.75 μm and 1 mm. It is also referred to as thermal radiation. All matter whose temperature is higher than absolute zero (0 K) generates infrared radiation. The thermal radiation of random bodies depends primarily on the temperature of the source: when the temperature increases, the total energy increases and the generated spectrum is enriched by the shorter wavelengths (Drastich, 2001). Thermocameras receive electromagnetic radiation and convert it to an electrical signal. These signals are displayed on a gray scale that represents the true thermal values (Hildebrandt et al., 2010). The basic components of the thermal camera are the lens, optical-mechanical positioning unit (scanner), clones, filters and detector. The objective consists of lenses with an antireflective layer. The clones affect the image quality and measurement of the signal radiation itself. The filters allow a rough selection of the displayed temperature interval when selecting the spectral interval. The infrared rays are concentrated into the detector, where they are converted into other forms of energy, usually an electrical analogue signal, which is processed in the infrared image channel (Drastich, 2001).

Infrared cameras generate images that depict radiated energy with a particular wavelength (Hildebrandt et al., 2010). A thermogram can be used to detect deviations from the expected temperature on the limb or differences between the limbs, thereby identifying areas affected by inflammation. It has been shown that there are almost no temperature differences between the right and left extremities of one animal. Some authors have reported that a difference ≥1°C may indicate a pathological process. It is important to always evaluate the pictures in combination with a detailed anamnesis and clinical examination. Two different animals never have the same temperature, so it is important to compare the contralateral limb (Westermann et al., 2013).

Advantages and disadvantages of infrared thermography in the diagnosis of lameness in dairy cows

Infrared thermography is a noninvasive method for early detection of lesions before the occurrence of clinical symptoms. It has a high rate of success, especially in combination with other diagnostic methods (LokeshBabu et al., 2018). The equipment is easy to operate with minimal risk of injury to the animal or farmer (Westermann et al., 2013). For these reasons thermography is a suitable diagnostic tool. However, individual animal variability combined with thermoregulation limits its interpretation, so it is important to combine this method with other diagnostic techniques (Hildebrandt et al., 2010), usually with radiographic methods. It helps determine the exact location of the lesion and identifies animals with anomalies for further clinical examination (LokeshBabu et al., 2018). Anatomy, physiology, morphology, and pathophysiology are important for proper diagnosis (Hildebrandt et al., 2010). The normal thermal pattern is determined by topography of vessels and anatomical structures (Westermann et al., 2013). The aim of this method is to facilitate diagnosis, not replace current diagnostic procedures (Hildebrandt et al., 2010).

Table 1. Application of infrared thermography as a diagnostic tool in cattle

Author	Cattle category	Type of infrared camera	Region of animal	Type of foot lesion observed
Alsaaod et al. (2014)	Dairy cows	Ti25 Termal Imager	Foot	Digital dermatitis
Alsaaod and Büscher (2012)	Dairy cows	JenopticVarioCAM	Hooves and hind limbs	Hooves with lesions
Bobić et al. (2017)	Dairy cows	FLIR and 7	Hooves	Sole ulcer, inter-digital hyperplasia, dermatitis digitalis
Gloster et al. (2011)	Cattle	TIR1 imager	Feet and eye	Foot-and-mouth disease
Marti et al. (2015)	Beef cattle	FLIR i40	Hooves	Foot rot, digital dermatitis
Montanholi et al. (2015)	Beef and dairy cattle	FLIR i40, FLIR T250, FLIR SC2000	Feet, flank, eye, hind area, lumbar region, trunk, snout, ear	?
Nikkhah et al. (2005)	Dairy cows	FLIR Inframetric 760	Hooves	Healthy hooves
Oikonomou et al. (2014)	Dairy cows	E30Box	Hind feet	Sole ulcer
Orman and Endres (2016)	Dairy cows	HIS 3000 AS	Hind feet	White line disease, sole ulcer, digital dermatitis
Renn et al. (2014)	Dairy cows	FLIR e40bx	Limbs	?
Wilhelm et al. (2014)	Dairy cows	ThermaCam E300	Hooves	Subclinical laminitis

The accuracy of thermography is influenced by ambient temperature and other current environmental conditions such as solar radiation and air flow (Alsaaod and Büscher, 2012; Westermann et al., 2013), scanned object size, background radiation and air transparency (Drastich, 2001) that can affect the dynamics of blood circulation and temperature control of the body and thus make it difficult to interpret the thermogram (Alsaaod et al., 2015). The vegetative and central nervous system and endocrine system affect the surface temperature of the body. These internal factors are individual and may show physiological or pathological changes that can affect the surface temperature, for example venous flow disorders, local changes in heat production or changes in thermal conductivity (Drastich, 2001). Body temperature changes during the day, changes are related to the state of vigilance (temperature decrease during sleeping), food intake, daytime, ovarian cycle (Boďa et al., 1990), physical activity, pregnancy or lactation phase (Montanholi et al., 2015). The constant temperature of the animal is maintained by the thermoregulation mechanism despite significant environmental temperature fluctuations (Boďa et al., 1990). The physiological temperature in dairy cattle ranges from 38 to 39.3°C (Reece, 2011). Heat in an organism is created by the chemical thermoregulatory processes as a con-

sequence of the metabolism of fats, carbohydrates and proteins contained in food (Boďa et al., 1990). Heat production must be in balance with heat output through radiation, heat conductivity, water evaporation in the airways and on the skin surface, and to a lesser extent through urine and feces. Heat output is controlled by vasomotor activity (Reece, 2011).

The thermogram is affected by dirt that covers the animal and impairs the normal emissions of infrared radiation from the body surface. Image quality can also be affected by the distance from which it is captured (Montanholi et al., 2015). Infrared thermography sometimes gives false positive results. The choice of thermocamera is very important. High-quality thermocameras are expensive, but cheaper models are available. However, such devices have lower image quality and resolution (Lokesh-Babu et al., 2018). Therefore, it is necessary to select suitable equipment for thermographic measurements (Montanholi et al., 2015).

Ambient temperature is important for medicinal thermography: a neutral environment does not significantly stimulate the body's autoregulatory mechanisms. Thermal energy losses from the skin's surface are only affected by residual evaporation, convection and radiation (IR) (Drastich, 2001). If the thermoregulatory center of the posterior hypothalamus receives pulses from the cold receptors, vasoconstriction occurs, thereby reducing heat output through the body surface. At the same time, chemical thermoregulation is activated through sympathetic fibers (Boďa et al., 1990). A warm environment stimulates heat receptors, vasodilatation and increased circulation. At higher temperatures there is intense sweating associated with evaporation, which causes a change in the skin's surface emissivity, degrading the image of the surface thermal relief (Drastich, 2001).

Surface temperature can be increased by inflammation caused by infection (Alsaaod et al., 2013). Increased temperature is one of the manifestations of inflammation; it is a consequence of biochemical, physicochemical and mechanical changes in the inflammatory bearing (Boďa et al., 1990). Infrared thermography can be used for the detection of hoof lesions by comparing the affected limb with the contralateral limb (Alsaaod et al., 2013; Orman and Endres, 2016). Temperature changes are often detectable before visual changes occur, so this method is suitable for early diagnosis of limb disease. Disease can be diagnosed before the animals feel pain and lameness sets in (Alsaaod et al., 2015). Unfortunately, this method fails to distinguish between individual diseases (Stokes et al., 2012; LokeshBabu et al., 2018), but the combination of infrared thermography with clinical controls could be an effective prevention of laminitis and other hoof diseases (Alsaaod and Büscher, 2012), as we can see in Table 1.

Conclusions

Early identification, immediate treatment of clinical signs and the initiation of specific lameness prevention procedures on the farm is very important in reducing lameness. A low percentage of lameness reflects farm management which should include regular antibacterial hoof baths, hoof trimming, suitable corridor surfaces, comfortable stalls and clean housing. Infrared thermography is an objective diagnostic method for hoof lesions based on measurement of the surface temperature

of limbs. It enables early diagnosis depending on the increase in surface temperature during inflammation. The interpretation of thermograms is very important. The measured temperature is very individual, depending on biological factors. The outcome can also be affected by other technological and environmental factors. The disadvantage of infrared thermography is that it cannot be used for differential diagnostics. It is good in combination with further examinations. Nonetheless infrared thermography has great potential as a diagnostic method for lameness in dairy cows which could be automated.

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