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Thermographic Anatomical Investigation of Forelimb in Healthy British Horses

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Abstract: This study was conducted to document Infrared Thermographic (IRT) views of the anatomical regions on the forelimbs of 20 adult male British horses and to analyze them for the use in veterinary medicine. The highest, lowest and mean temperature values measured were displayed as tables and a schema. IRT views were obtained out of the regions from the scapular region throughout the distal phalangeal region using the camera adjusted to 0.99 emission and 8-38°C temperature values. The maximum and minimum temperature values determined on the forelimbs in this study were 33.7 and 13.6°C, respectively. The results measured showed that the temperature in general decreased as descending distally. Similarly, temperature values were higher on the medial and palmar aspects of the regions as compared to those of the lateral and dorsal sides, respectively. Statistically significant differences were determined bilaterally on the six out of 16 regions. Generally, the values were significantly higher in the left side. Temperature differences in symmetric anatomical regions did not exceed 0.8°C. These temperature values measured on the symmetric regions of the left forelimbs in British horses in the study could be called normal or nonpathological asymmetry. Overall, the results found in this study may be useful for further researches on the related topics concerning the preparation of thermographic mappings of various anatomical sites.

Key words: Anatomy, horse, forelimb, thermography, regions

INTRODUCTION

Infrared Thermography (IRT) is a method which measures infrared temperature dispersed out of objects with very high sensitivity. Since 1968, basic thermography has been used in 71 studies as a diagnostic and treatment tool in several issues including animal welfare, joint diseases, arthritis, laminitis and pain in general (McCafferty, 2007).

Nowadays, IRT is applied in the treatment of the diseases, along with the preventive medicine and diagnose (Embaby *et al*., 2002). Thermography is becoming increasingly popular as an aid to assist with the diagnosis of injuries in horses (Otilia *et al*., 2006). In veterinary medicine, several studies have been conducted on thermographic diagnose of clinical problems such as various inflammations like laminitis (Eddy *et al*., 2001; Levet *et al*., 2009; Purohit and McCoy, 1980; Turner, 1996; Turner, 2001; Turner *et al*., 2001).

By the use of IRT, unilateral problems can be determined by comparing the differences that occur on the other side. Yet, changes on the thermal curve can be a determinant for bilateral problems (Purohit *et al*., 2007).

A study has shown that the temperature measured on any given region of the leg with acute tendinitis in horses is 1.5°C higher than that of the same region in healthy status (Otilia *et al*., 2006).

Similar studies have been reported regarding the importance of asymmetry (Eddy *et al*., 2001; Oerlemans *et al*., 1999; Otilia *et al*., 2006; Yanmaz *et al*., 2007). Number of researchers have reported bilateral symmetrical temperatures (Simon *et al*., 2006) where as some others did not account the symmetry (Autio *et al*., 2007; Johnson *et al*., 2011; Tunley and Henson, 2004). Abnormal or asymmetrical temperature distributions have been used as indicators of underlying problems with blood circulation or inflammatory responses (McCafferty, 2007).

In horses, thermal changes can be observed in the regional blood circulation after local anesthesia and neurectomy applications (Van Hoogmoed and Snyder, 2002). There were no significant differences in temperatures between thermograms obtained before exercise and 45 min after stopping the exercise (Simon *et al*., 2006). In horses, anaesthesia with mepivacainne HCL performed on the digits of the forelimb,

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leads to less vasodilatation, ending up with low artifact ratio (Holmes *et al*., 2003). A study done on ponies has suggested that medium temperature should be <18°C for vasodilators and earlier 20°C for vasoconstrictors (McCafferty, 2007). A study has determined the thermographic changes by IRT in different horses at various temperatures (0, -9, -16 and -23°C) (Autio *et al*., 2007). Since, thermography applications may result in various artifacts it needs to be performed and analyzed by experts (Cetinkaya and Demirutku, 2012).

Thermographic mapping of horses and a related scale have not been done yet. True diagnose on behalf of experience and symmetry may not always be achieved. It needs to be performed with proper standards. With this in mind this study aimed to combine topographic anatomical data with thermographic findings in horses thus pointing out usability of IRT in veterinary medicine. The results of this study could be a critical data for establishing a standard by the use of temperature values measured in these regions.

MATERIALS AND METHODS

The forelimb regions in horses (Fig. 1a) include the shoulder joint region, triceps region, axillary region, brachial region, region of the elbow joint, antebrachial (forearm) region, carpal region, metacarpal region, metacarpo phalangeal region, proximal phalangeal region, proximal inter phalangeal region, middle phalangeal (coronal) region, distal inter phalangeal region and distal phalangeal region (Dursun, 2001; Dyce *et al*., 2010; Schaller, 2007). Also distal inter phalangeal region, distal phalangeal region and the anatomical structures found thereby (os sesamoideum distale, bursa podotrochlearis, extensor and flexor tendons) could not be visualized by IRT. For these regions, a thermographic map was formed upon the findings of the divisions of the hoof capsule (capsulaungulae). The findings were evaluated on three different bases as paries (hoof wall), solea (sole) and pulvinus (frog). The scapular region was also included to obtain the full thermography of the forelimbin this study (Fig. 1b).

IRT visualization of the topographical regions in the forelimbs of the 20 healthy, male adult British horses were acquired using a surface thermography (FLIR ThermaCAM™ E45). The findings were analyzed by the use of Data ThermaCAM Reporter 2000 Pro.Dec.02.Ed. With this program, maximum, minimum and mean temperature values in a certain region can be measured (Fig. 2a). Data from the right and left sides (Table 1) were statistically compared using Paired sample test and were evaluated by Pearson correlation analysis.

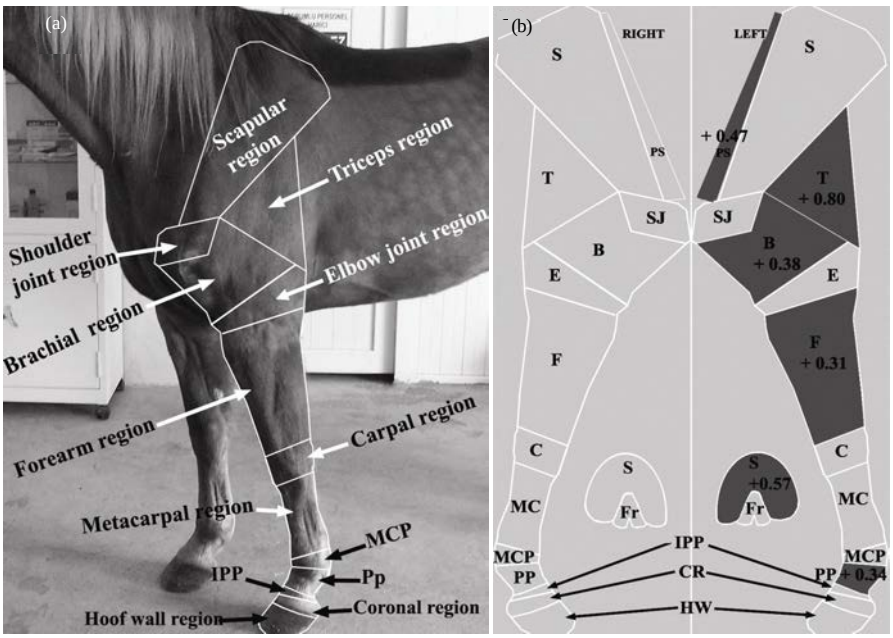

Fig. 1: a) The forelimb regions; b) Schematic lateral view of the forearms; Dark areas: statistically warmer regions by bilaterally symmetrical. Regions; S: Scapular, Ps: Prescapular, SJ: Shoulder Joint, T: Triceps, B: Brachial, E: Elbow joint, C: Carpal, MC: Metacarpal, MCP: Meta Carpo Phalangeal, PP: Proximal Phalangeal, IPP: Proximal inter phalangeal, CR: Coronal, HW: Hoof Wall, S: Sole, Fr: Frog. The difference in celcius

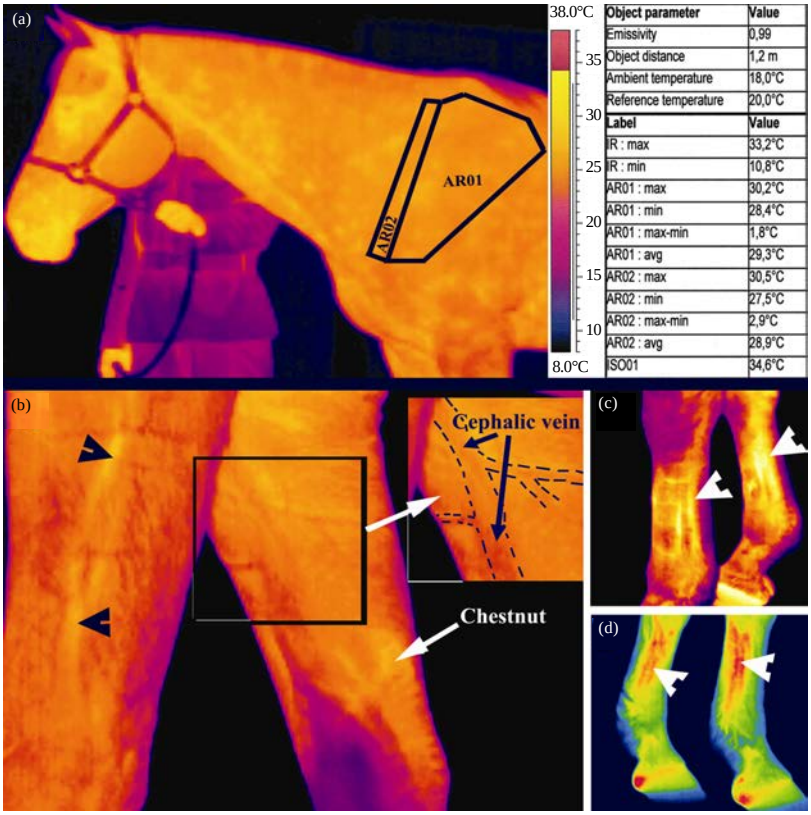

Fig. 2: a) Thermal view of the left side of the horse, a sample report on the scapular region prepared by ThermaCAM Reporter 2000 Pro; AR01: prescapular area; AR02: scapular region; Max: the highest temperature on bounded area; Min: the lowest temperature on bounded area; Avg: mean temperature on bounded area; max.-min.: temperature distance between the highest and the lowest; b) left view of the forearm; Black arrow heads: thermal reflection of the cranial interosseous artery. Thermal view of the metacarpal region; c) left side, d) right side; White arrow heads: thermal reflections of flexor tendons and arteries lies in the groove between tendons

Table 1: The mean regional temperatures data from the right and left front limbs (°C)

Scapular region		Prescapular groove		Shoulder joint region		Triceps region		Brachial region		Elbow joint region		Forearm region		Carpal region	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
29.2	29.7	29.5	30.5	29.0	29.5	29.1	29.4	29.1	29.1	28.0	28.1	28.9	29.2	19.8	18.8
30.9	31.0	29.9	30.3	30.8	30.9	30.9	31.1	31.0	31.1	27.5	27.6	30.4	30.9	26.4	26.4
27.9	27.6	30.5	30.2	27.8	27.8	27.3	27.5	27.3	27.5	27.9	28.1	26.8	27.0	24.9	25.2
29.1	30.5	30.3	30.3	29.3	28.9	29.1	29.5	29.0	29.7	26.9	27.2	28.7	28.8	25.5	25.6
30.3	30.3	30.4	29.6	28.6	28.1	29.6	29.6	29.6	29.5	28.4	27.5	29.4	29.6	26.7	26.8
30.4	30.9	30.3	29.6	30.6	31.1	31.1	31.1	30.9	31.0	28.3	27	25.5	27.0	28.8	28.5
28.1	28.1	28.2	28.1	28.6	28.4	27.3	27.6	28.0	27.9	26.9	26.5	27.6	27.9	27.9	29.5
30.0	29.7	29.6	29.4	30.3	29.9	25.6	26.4	27.6	26.4	27.7	28.1	28.0	28.5	21.6	23.3
28.8	29.6	30.8	32.5	30.0	29.8	27.6	29.2	29.6	29.3	28.2	28.7	27.9	28.1	27.9	29.5
26.4	25.8	30.2	32.8	27.5	26.9	27.3	28.2	28.0	29.2	27.8	28.6	26.9	26.9	26.3	26.2
25.4	24.3	29.7	30.4	26.8	26.2	27.7	30.4	28.3	29.2	29.9	29.4	29.4	29.9	25.9	25.6
28.7	29.1	29.4	30.6	29.9	29.8	26.5	27.9	27.7	28.3	26.1	26.2	23.7	23.7	26.6	25.8
28.9	29.0	28.6	30.7	30.1	30.2	27.1	29.3	27.4	29.2	28.3	29.1	28.0	28.4	25.9	25.6
28.8	28.5	29.9	30.8	29.2	29.0	30.7	30.9	30.8	30.9	29.5	28.8	29.2	29.5	25.5	25.2
28.0	28.1	30.2	29.3	28.0	28.2	29.8	29.7	28.9	29.9	27.3	26.7	28.4	28.7	25.7	25.9
28.7	30.1	28.2	28.3	29.9	30.1	27.5	28.3	28.9	30.0	26.1	25.0	27.0	27.3	20.1	19.6
28.1	28.1	29.8	30.1	28.0	28.5	28.1	28.5	29.1	30.1	30.2	30.3	29.4	29.7	26.3	26.4
29.6	29.6	29.6	30.6	28.5	28.6	26.6	28.4	29.7	30.1	29.6	29.1	27.4	27.1	25.2	25.6
30.9	31.7	28.5	29.1	33.0	32.9	28.5	29.9	28.4	28.3	28.3	29.4	28.2	28.5	25.3	25.4
28.2	27.6	29.6	29.4	31.0	31.4	29.1	29.5	28.9	29.1	28.2	28.1	27.6	28	27.1	27.2

Table 1: Continue

Metacarpal region		Metacarpo-phalangeal region		Proximal phalangeal region		Proximal interphalan-geal region		Coronal region		Hoof wall		Sole		Frog	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
26.2	25.8	25.1	24.7	20.8	20.9	23.9	23.7	29.9	29.4	27.3	26.6	23.4	24.1	23.3	21.9
24.6	24.4	24.1	23.9	22.9	23.1	25.0	24.3	30.2	29.5	27.1	29.0	25.8	25.8	22.8	22.4
25.3	24.8	24.0	23.5	20.9	21.3	24.8	24.5	29.7	29.2	29.4	29.6	25.9	24.9	23.2	23.8
23.3	22.4	23.4	22.7	23.9	24.1	23.7	23.2	30.0	29.5	26.7	26.5	21.8	22.9	29.5	28.0
25.4	24.9	24.1	23.6	21.1	21.3	24.6	24.0	31.6	31.0	26.8	27.9	22.8	24.1	28.8	27.5
24.1	23.4	22.9	22.1	26.0	25.4	25.9	24.5	30.1	29.4	27.2	26.8	23.6	24.1	26.8	27.2
24.9	24.4	24.5	24.0	25.4	25.9	25.3	25.1	29.4	29.0	23.5	23.1	23.8	24.5	23.2	21.6
18.0	17.4	17.1	17.0	22.0	21.8	23.4	24.1	30.4	29.9	27.4	27.4	25.0	25.7	22.4	21.7
18.0	17.3	16.6	16.5	21.1	21.8	25.5	23.8	29.4	29.7	28.0	28.2	23.6	24.3	23.1	23.7
24.7	24.4	22.5	22.3	21.2	21.3	16.8	16.1	30.8	30.7	27.7	28.1	22.7	23.2	30.1	28.9
23.2	22.6	22.9	22.6	25.3	25.9	22.0	22.7	30.1	30.6	25.6	25.4	23.5	23.8	28.9	30.1
22.3	21.9	22.0	22.5	26.8	28.0	24.5	24.7	29.7	30.2	26.9	26.4	23.7	24.4	26.8	27.4
22.8	23.3	21.1	20.7	25.5	26.3	23.3	23.8	28.8	29.3	27.3	26.7	23.1	24.5	23.6	24.0
23.7	24.0	21.0	21.5	24.6	25.1	24.0	24.4	28.1	28.0	23.6	22.9	22.8	23.6	24.6	26.7
23.2	23.7	21.7	21.8	26.2	26.5	21.5	23.6	28.7	29.1	27.3	27.2	23.8	23.9	21.5	21.6
22.4	23.2	22.0	22.3	20.0	20.3	24.7	25.2	28.4	29.2	21.2	21.6	23.4	24.0	22.1	21.9
23.0	23.5	21.6	21.8	20.3	20.7	26.1	26.5	29.8	29.6	24.2	23.5	24.4	24.4	21.6	21.2
21.5	22.0	15.7	15.7	20.5	21.0	25.0	25.5	28.3	28.4	28.8	28.5	21.7	22.7	22.2	22.5
23.1	24.1	26.5	27.0	23.9	24.6	23.7	23.9	28.9	28.7	29.5	29.2	23.6	24.1	23.7	24.0
22.6	22.4	24.4	24.5	25.8	25.7	22.6	22.9	30.8	30.2	29.0	29.1	22.5	23.2	21.5	21.8

R: Right, L: Left

Minimum and maximum temperature values were set to 8 and 38°C, respectively while the emission value of the thermal camera was 0.99. IRT visualization was performed at a closed and wide area where no direct air circulation affected animals. The animals were at rest fully and the regions were clean and dry. Thermography was performed 120 cm far from the animals in a room with high ceilings in the afternoon at 15:00-17:30. The altitude was 1300 m and environment temperature was 18°C.

RESULTS

The mean temperature value on the forelimbs was 26.5°C. The highest value was obtained from the scapular region as 33.7°C while the lowest level was 13.6°C from the distal phalangeal region. The mean temperature values on the right and left forelimb's regions were shown in (Table 1 and 2) the highest and lowest temperature values given in Table 3.

The mean temperature values on the prescapular grooves and triceps, brachial, forearm, proximal phalangeal and solear regions were higher on the left side (Fig. 1b). Overall, the mean temperature values were statistically higher on the left side.

Anatomical structures possessing surface reflection in this region were the prescapular groove (warmer) and spina scapula (colder). But no significant reflection was seen on the localization of the superficial cervical lymph nodes.

The left axillar region was hotter than the right one, the mean value being 30.5°C while the lowest and highest values being 24.0 and 33.7°C, respectively. The temperature value of the lateral pectoral groove was particularly higher. The course of the medially located cephalic vein was eminent (2°C) colder thermally on the forearm region. Besides, the mean temperature value measured medially right on the chestnut was 29.5°C (Fig. 2b).

Thermo graphical reflection of the second and third palmar metacarpal arteries and third common palmar digital artery at particular was observed on the palmar aspect of the metacarpal region (Fig. 2c and d). The mean temperature value of the sole was 23.8°C. This value for the corpus sole was 22.3°C. The mean temperature values of the medial crus of sole and lateral crus of sole were measured as 25.8 and 25.4°C, respectively.

The mean temperature value of the frog was 24.4°C. The coldest (15.5°C) areas of the frog were the apical aspects of the medial branch of frog, lateral branch of frog and apex of frog whereas the hottest (31.1°C) areas were the bases of the medial furrow of frog, lateral furrow of frog and central groove (frog c-left). The mean temperature value of the heel bulbs was also measured as 30.1°C. There were 7-8°C temperature differences among the anatomical peculiarities of frog. These structures were arranged as medial branch of frog (22.4°C) lateral branch of frog (22.6°C) apex of frog (23.2°C) medial furrow of frog (27.9°C) lateral furrow of frog (29.1°C) and frog c-left (29.8°C).

Result of Pearson correlation analysis determinated a strong correlation amongs capular and shoulder joint regions, triceps and forearm regions, metacarpal and metacar pophalangeal regions. Correlation is found to be 0.690, 0.783 and 0.757 for these regions, respectively ($p<0.01$). Besides, significant (mean value of 0.92) positive correlation was observed between all (16 regions) bilateral symmetric regions.

Table 2: Maximum-minimum regional temperatures and symmetrical comparison of the mean temperatures data (n = 20)

Regions	Max. (°C)	Min. (°C)	Directions	Mean±SEM (°C)	Left-right comparison (p-values)
Scapular region	33.7	23.3	Right	28.82±0.30	0.320
			Left	28.97±0.40	
Prescapular groove	33.6	27.6	Right	29.66±0.17	0.039
			Left	30.13±0.26	
Shoulder joint region	33.6	23.8	Right	29.34±0.32	0.666
			Left	29.31±0.35	
Triceps region	32.3	24.4	Right	28.32±0.34	0.000
			Left	29.12±0.28	
Brachial region	32.3	26.3	Right	28.91±0.25	0.020
			Left	29.29±0.26	
Elbowjoint region	31.5	23.9	Right	28.05±0.25	0.592
			Left	27.97±0.28	
Forearm region	31.8	17.4	Right	27.92±0.33	0.010
			Left	28.23±0.34	
Carpal region	29.1	16.7	Right	25.47±0.53	0.421
			Left	25.60±0.59	
Metacarpal region	28.2	13.6	Right	23.11±0.47	0.359
			Left	22.99±0.48	
Metacarpo-phalangeal region	28.3	14.3	Right	22.16±0.63	0.174
			Left	22.03±0.62	
Proximal phalangeal region	28.8	15.1	Right	23.21±0.52	0.010
			Left	23.55±0.54	
Proximal interphalangeal region	29.1	14.3	Right	23.81±0.45	0.958
			Left	23.82±0.45	
Middle phalangeal region (coronal)	30.9	25.6	Right	29.65±0.20	0.254
			Left	29.53±0.16	
Hoof wall (paries)	30.3	13.8	Right	26.72±0.47	0.784
			Left	26.68±0.51	
Sole (solea)	30.3	15.2	Right	23.54±0.24	0.000
			Left	24.11±0.17	
Frog (cuneus)	31.6	15.5	Right	24.48±0.64	0.685
			Left	24.39±0.64	
Whole leg (all 16 regions)	33.7	13.6	Right	26.45±0.15	0.005
			Left	26.60±0.13	

Table 3: Mean regional temperatures on medial, lateral, dorsal and palmar sides of the manus

Regions	Medial	Lateral	Dorsal	Palmar
Carpal region	25.9°C±0.53	24.8°C±0.50	24.4°C±0.44	28.2°C±0.25
Metacarpal region	23.1°C±0.48	22.7°C±0.47	22.2°C±0.39	23.5°C±0.21
Metacarpo-phalangeal region	23.8°C±0.62	22.3°C±0.51	21.9°C±0.65	21.1°C±0.43
Proximal phalangeal region	23.9°C±0.54	23.6°C±0.52	22.1°C±0.45	23.6°C±0.37
Coronal region	29.9°C±0.20	29.8°C±0.36	29.4°C±0.25	30.2°C±0.16

DISCUSSION

IRT is reported to be a useful tool on measuring surface temperature of domestic mammals and wild animals (McCafferty, 2007). Recent studies (Autio *et al*., 2007; Johnson *et al*., 2011; Tunley and Henson, 2004; Otilia *et al*., 2006; Yanmaz *et al*., 2007) have also indicated usage of thermography in veterinary medicine. Likewise this study has verified distinctive characteristics of thermography in horses.

Literature has shown that side or regional temperature variations are essential on diagnose of related pathologies (Purohit *et al*., 2007). The study has stressed that both need to be considered since the results have revealed regional characteristic changes.

In a study, regarding thermo graphic measurements on the eye, the temperature difference between the right and left sides were ignored (Van Hoogmoed and Snyder, 2002). In another study, the researcher indicated that there a high degree of right leg to left leg symmetry to the was infrared emission of the horse which has also been shown in humans (Purohit and McCoy, 1980). On the otherhand, in the study it is determined that thermographic values of the forelimbs were significantly higher in the left side.

If there is a 1°C difference between two anatomically symmetric regions it indicates inflammation in this region (Head and Dyson, 2001; Turner, 1996). Otilia *et al*. (2006) observed >1°C temperature increase on the left forelimb of a thoroughbred with chronic tendinitis using thermography whereas 2°C temperature increase were observed on the metacarpo phalangeal joint of the left forelimb of this Arabian stallion. In the study, anatomical temperature differences in symmetric regions did not exceed 1°C. These temperature values (maximum 0.8°C)

measured on the symmetric regions of the left forelimbs in British horses in the study could be called normal or nonpathological asymmetry.

Embaby *et al.* (2002) have found that the temperature value of the coronary band is 1-2°C higher than that of the ungula. Purohit and McCoy (1980) has indicated that the hottest area of the leg is the coronary band. Likewise in the study, the coronary region temperature values were 2.9°C higher than the values of the hoof wall.

Topographic locations of anatomical structures affect the thermography results. In the study, arteries gave higher temperature visualization while veins were cooler than their surroundings. Temperature difference was positively up to 4°C on the cranial interosseous artery (Fig. 2b). Another striking data was that the temperature value measured particularly on the superficially running component of the cephalic vein was 2°C lower than that on its surroundings (Fig. 2b). It is naturally due to the temperature difference between the arterial and venous blood.

In the study, the IR findings have suggested that higher temperature values on the dorsal and dorsomedial aspects of the carpal region are due to the dorsal carpal rete and the radial artery and its branches, respectively. The highest temperature value was measured on the palmar aspect of the carpal region that may be because of the medial palmar artery running in between the flexor tendons.

The temperature increase on the metacarpo phalangeal region at dorsopalmar direction was probably due to the presence of medial and lateral palmar digital arteries lying on the collateral ligaments of the sesamoid bones. The lowest temperature value was measured on the exact palmar surface of this region which may be due to the presence of the longer and thick hairs thereby. Turner (1996, 2001) also mentioned artefacts of hair length in thermography.

The temperature value of the palmar aspect of the proximal interphalangeal region was higher than its surroundings because of the superficial lying of the lateral and medial third proprial palmar digital arteries. Thermographically measuring of the parietal plexus and laminar tissue under the hoof wall displayed as lines. The white line (zonaalba) of the sole was particularly eminent due to its 0.5°C higher temperature value. The temperature value of lateral and medial crus sole in all the animals included in the study was higher than that of a corpus sole.

CONCLUSION

Upon using thermography this study has acquired some data and a different perspective on the thermal temperature mapping of the forelimbs in British horses.

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