

Gross anatomy of dural venous sinuses in the one-humped camel (*Camelus dromedarius*, Linnaeus 1758)

H. JERBI^{1*}, K. ABID², N. VAZQUEZ³, W. PEREZ³

¹ Service d'Anatomie, Ecole Nationale De Médecine Vétérinaire Sidi Thabet, CP 2020, Université de La Manouba, Tunisie.

² Institut Supérieur Agronomique de Chott-Mariem, Université de Sousse, Tunisie

³ Área de Anatomía, Facultad de Veterinaria, Universidad de la República, Lasplacas 1620, 11600 Montevideo, Uruguay

*Corresponding author: Hassen_jerbi@yahoo.fr

Abstract – One-humped camel (*Camelus dromedarius*) have many anatomical adaptation mechanisms that help them to survive successfully in arid climates. Like many other desert ungulates, resorts to selective brain cooling when it is subject to heat stress partly with dural venous sinuses. In this study, we describe the macro anatomy and we measured the length and diameter of each dural venous sinuses. The dorsal system consisted of a single dorsal sagittal and straight sinus (sinus rectus) and paired transverse sinus (temporal and sigmoid sinuses). The ventral system includes the cavernous and intercavernous sinuses, basilar sinus, and petrosal sinuses. There was intracranial connection between them. The straight sinus emptied in the dorsal sagittal sinus shortly before the confluence of the sinuses. The cavernous sinus contained the rostral epidural rete mirabile. The basilar sinus was continued as the ventral internal vertebral plexus inside the vertebral canal. To conclude, we added information to literature in relation to topographic anatomy of the camel dural venous sinuses and showed this interesting structure with photographic documentation of dissections with latex injection in venous and arterial vessels.

Keywords: brain, encephalon, vascular system, camel

1. Introduction

The sinuses of the dura mater (*Sinus duraematrix*) are intercommunicating veins that drain the veins of the brain and veins of the skull wall (Barone 2011). They are irregular veins, without valves and always open; they lodge in the thickness of the dura or between it and the bones of the skull. The sinuses delegate through the ducts or holes of the cranial wall the emissary veins that are destined to the roots of the jugular veins. Absence of a tunica media in their walls and valves in their lumina were characteristics of these sinuses (Barone 2011). The dural sinuses are divided into dorsal and basilar systems.

Physiological studies on the function of these sinuses were realized by Baker and Hayward (1968) and Baker (1979). These authors postulated that venous nasal blood cools the arterial blood of the internal carotid artery that supplies the encephalon, thanks to countercurrent heat exchange. However, new researches documented that the sinuses not have a considerable role in protecting the brain against overheating under physiological conditions (Fuller et al. 2000; Fuller et al. 2011; Mitchell et al. 1997).

A new hypothesis on the function of these sinuses was caused by the discovery of the permeation of neuropeptides, or in the local destination transfer of pheromones that permeate from the venous blood out flowing from the nose into the arterial blood that supply to the brain (Krzyszowski et al. 2014). It has been postulated that physiological regulators, after reaching the hypothalamus and hypophysis in this way, initiated endocrine reactions associated with reproduction (Krzyszowski and Stefańczyk-Krzyszowska 2012; Krzyszowski et al. 1999; Krzyszowski et al. 2001; Krzyszowski et al., 2014; Stefańczyk-Krzyszowska et al., 2000). The countercurrent transfer of neurotransmitters is a part of a universal physiological regulatory system, called “the retrograde and destination transfer of hormones and other physiological regulators,” and it functions in humans and in animals (Krzyszowski and Stefańczyk-Krzyszowska 2012).



Several studies were conducted on the structure and function of the dural venous sinuses in different animal species, including camelids (Baker 1979; Barone 2011; El-Hagri et al. 1977; Smuts et al. 1987; Zguigalet al. 1991). The aim of this study was to describe gross anatomy of the dorsal dural venous sinuses in Dromedary and their extracranial connections with veins of head and neck. This would allow a better comprehension of their role on the selective brain cooling during heat stress that allows it to survive in harsh areas of the world, a fact mentioned in multiple studies (Bengoumi 2002; Elkhawad 1992; Elkhawad et al. 1990; Gebreyohaneset al. 2017; Soliman 2015).

2. Materials et Methods

2.1. Animal material: Ethics statement

This study involved the use of seven camel heads (4 males and 3 females) aged between 1 and 1.5 years. The specimens were slaughtered and handled in accordance with the local ethical board guidelines of école nationale de médecine vétérinaire Sidi Thabet of Tunisia. Each head was isolated immediately after slaughter by a section between the second and third cervical vertebrae.

2.2. Latex injection procedure

A first group of five heads was used to perform plan-by-plan classical progressive dissections and sagittal sections, that allowed the extraction of the encephalon within its connections to the dural venous sinuses. The head and the cranial extremity of the neck were injected with a 10 % formalin solution via cannulas placed in the right and left common carotid arteries and external jugular veins. Fixation takes 12 to 24 hours, and then, demineralized water was introduced through the same cannulas to wash the formalin salts. Between 60 and 100 ml of very diluted and red-colored latex neoprene was injected immediately after rinsing with demineralized water in both common carotid arteries. The injection of latex was conducted progressively with hand pressure, using 60 ml syringes, until the coloration of the little arterioles in the conjunctiva was visible. A very-diluted solution of blue colored latex neoprene was also manually injected in the venous system through cannulas placed in each external jugular vein. Cannulas were systematically placed in a way to bypass the venous valves system of the external jugular vein, commonly located next to the first cervical vertebrae, in order to achieve a satisfactory filling. We used near 400 ml of latex neoprene for each head, and the injection was systematically stopped at the appearance of resistance. Heads were then maintained at +4 °C during 24 hours, until the solidification of the injected latex was suitable. A dissection was conducted progressively, following precise muscular incisions and bone sections, to extract the encephalon still linked to its dorsal and ventral dural venous sinuses and the rostral epidural rete mirabile.

2.3. Vascular corrosion casting

In order to identify the organization of the dural venous sinuses network and to measure its dimensions, a second group composed of two heads, with no previous injection for conservation was used. The external jugular veins were carefully dissected and cannulated followed by manual injection of blue methyl methacrylate. The heads were stored at 4°C for 24 hours to allow polymerization of the injected resin. Maceration was performed with pepsin hydrochloric acid and amylase/protease solution at 50°C until all soft tissues were dissolved. Pictures were taken with a Nikon digital camera. Terms are used in agreement with the Nomina Anatomica Veterinaria (ICVGAN 2017).

3. Results and discussion

The veins of the brain were generally divided into 4 groups: dural venous sinus, diploic veins, emissary veins and cerebral veins.

The dorsal sagittal sinus (*Sinus sagittalis dorsalis*) (Fig.1) was the longest dural sinus with 12.0 cm in length and 0.5 cm in width. In cross section, it had a shape of a triangle with the base oriented dorsally. At the rostro-dorsal surface of the brain, this sinus was thin and single. It ran caudo-dorsally along the median plane and was bifurcated forming a rich plexus between the cerebellum and the cerebrum. It received the diploic veins, five to six dorsal cerebral veins and, near the caudal extremity, the straight sinus.

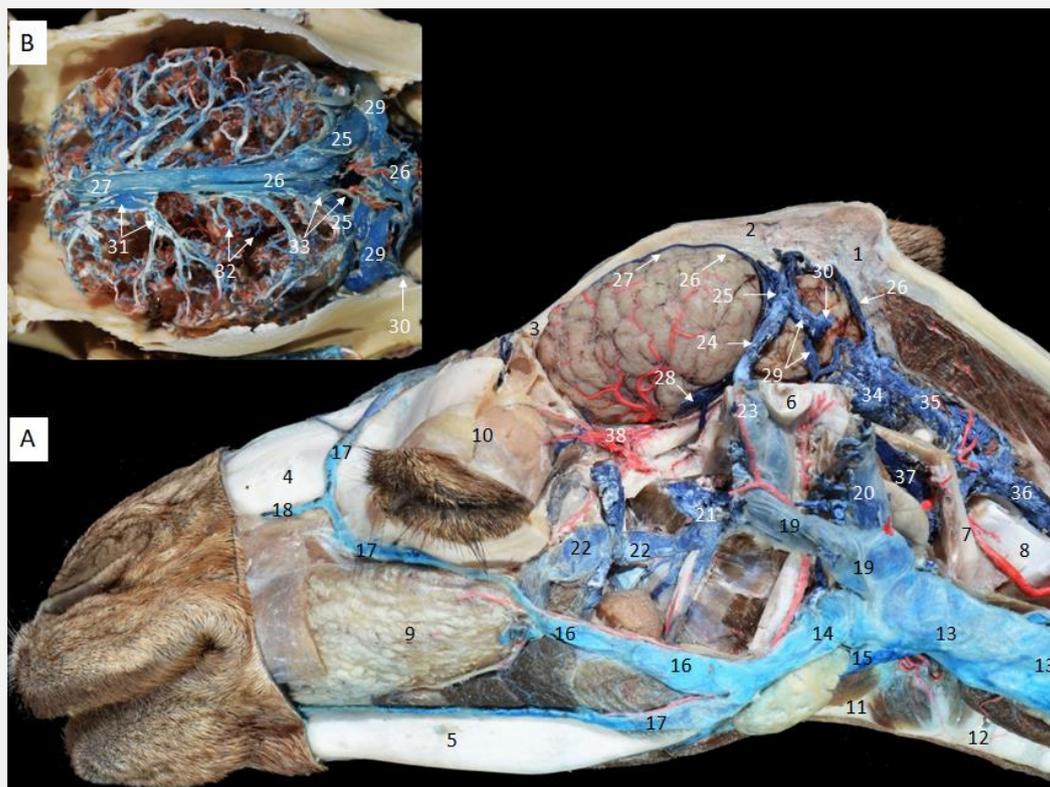


Fig. 1. Venous of the head of the dromedary camel with dural venous sinuses *in situ*

(A) Superficial and deep layer, latex injection, lateral view. (B) Corrosion cast, dorsal view. 1: Occipital bone; 2: Parietal bone; 3: Frontal bone; 4: Maxillary bone; 5: Mandible; 6: External acoustic meatus; 7: Atlas; 8: Axis; 9: Buccal salivary glands; 10: Eyeball and lacrimal gland; 11: Larynx; 12: Trachea; 13: External jugular vein; 14: Linguofacial vein; 15: Lingual vein; 16: Facial vein; 17: Angularis oculi vein; 18: Dorsal nasal vein; 19: Retromandibular vein; 20: Caudal auricular vein; 21: Maxillary vein; 22: Buccal sinus; 23: Emissary vein of the retroarticular foramen; 24: Temporal sinus; 25: Transverse sinus; 26: Confluence of sinus; 27: Dorsal sagittal sinus; 28: Dorsal petrosal sinus; 29: Sigmoid sinus; 30: Emissary vein of the condylar foramen; 31: Lateral lacuna; 32: Meningeal vein; 33: Dorsal cerebral vein; 34: Basilar sinus; 35: Occiput atlóidien venous plexus; 36: Internal vertebral venous plexus; 37: Occipital vein; 38: Rostral epidural rete mirabile.

The transverse sinus (*Sinus transversus*) (Fig.1) was paired and located inside the membranous tentorium of the cerebellum. This sinus continued to direct to the dorsal sagittal sinus and occasionally receives a few branches of the straight sinus. It passed through the occipital bone and lodges in a specific transverse groove. Each sinus, in its intraosseous course, was composed of 3 to 4 veins and formed a pampiniform plexus. It was about 2-3 cm in length. It ends up dividing into temporal and sigmoid sinuses. The temporal sinus (*Sinus temporalis*) (Fig.1) was larger than sigmoid sinus. With a circular section, it measured 7 cm in length and 1 cm in diameter. Near to the temporal canal usually it received the caudal deep temporal vein and it passed through this canal. It emerged as the emissary vein of the retroarticular foramen and joined to the maxillary vein and pterygoid plexus. The sigmoid sinus (*Sinus sigmoideus*) (Fig.1) was the caudal branch of the division of the transverse sinus. It was S shaped and had about 5 cm in length and 0.2 cm in diameter. It joined the emissary vein of the condylar foramen to finally empty in the occipital vein and basilar sinus.

The straight sinus (*Sinus rectus*) (Fig.2) was brief and often triangular in cross section. It had about 4-5 cm in length and 0.5-1 cm in diameter. This sinus was formed at the level of the splenium of corpus callosum by the confluence of the great cerebral veins ventrally and the vein of the corpus callosum and ventral sagittal sinus dorsally. The straight sinus ascended along the median plane between the two cerebral hemispheres and usually emptied directly in the dorsal sagittal venous sinus (5 cases). Sometimes it drained into the confluence of sinus, or in the transverse sinus (2 cases).

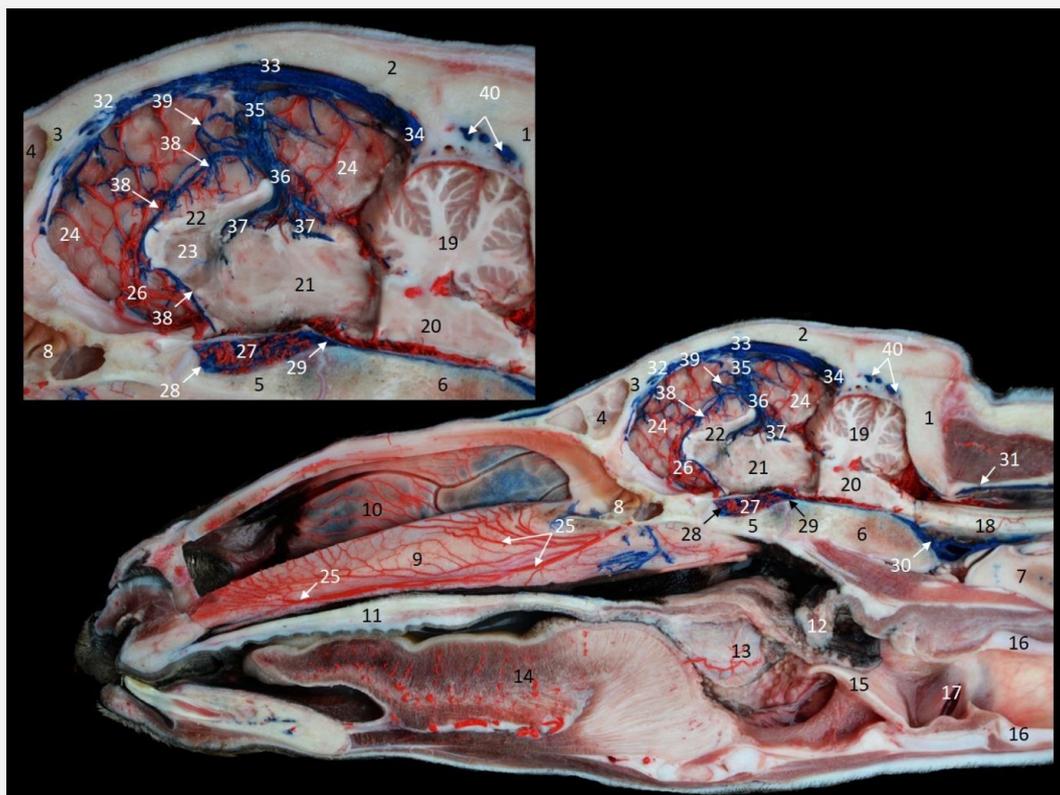


Fig. 2. Dorsal dural venous sinuses, sagittal section of the head at the median plane.

1: External occipital protuberance; 2: Parietal bone; 3: Frontal bone; 4: Frontal sinus; 5: Sphenoid bone; 6: Occipital condyle; 7: Atlas; 8: Ethmoid conchae; 9: Nasal septum; 10: Nasal concha; 11: Hard palate; 12: Soft palate; 13: Diverticulum of the soft palate; 14: Body of tongue; 15: Epiglottic cartilage; 16: Cricoid cartilage; 17: Laryngeal ventricle; 18: Spinal cord; 19: Cerebellum; 20: Midbrain; 21: Thalamus; 22: Corpus callosum; 23: Fornix; 24: Right cerebral hemisphere; 25: Sphenopalatine artery (septal branches); 26: Anastomosis of rostral cerebral arteries; 27: Cavemous sinus and epidural rostral rete; 28: Rostral intercavernous sinus; 29: Caudal intercavernous sinus; 30: Basilar venous plexus; 31: Occiput atloïdien venous plexus; 32: Dorsal sagittal sinus; 33: Confluence of sinus; 34: Transverse sinus; 35: Straight sinus; 36: Great cerebral veins; 37: Internal cerebral veins; 38: Vein of the corpus callosum; 39: Ventral sagittal sinus; 40: Temporal sinus and the emissary vein of the retroarticular foramen.

The cavernous sinus (*Sinus cavernosus*) (Fig.3) was H shaped and was composed of two lobes. With a plexiform aspect, it was surrounding the rostral epidural rete mirabile and the internal carotid artery. It was located on both sides of the hypophysis cerebri on the basisphenoid bone and related to the piriform lobe and the pons of the encephalon. Each lobe measures 6 cm in length and 3 cm in width and were transversally connected via very fine rostral intercavernous sinus and a well-developed caudal intercavernous sinus. Each sinus communicated rostrally with the ophthalmic plexus and caudally with the basilar plexus and the ventral petrosal sinus.

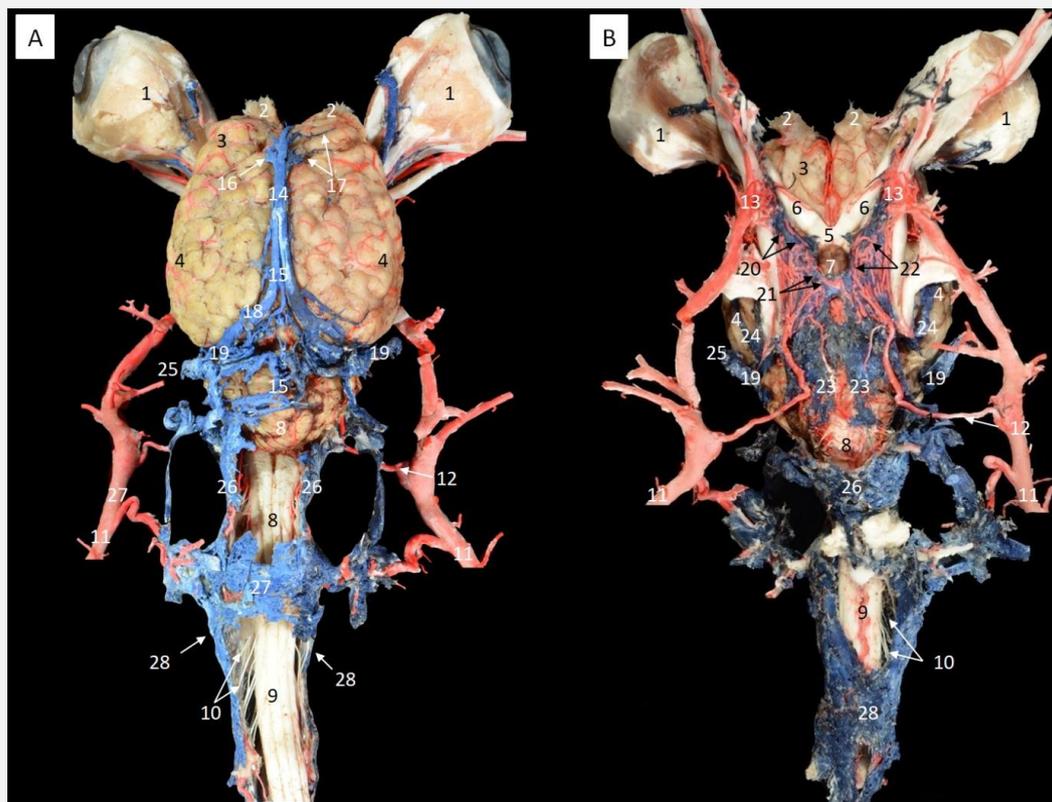


Fig. 3. Dural venous sinuses, encephalon of the one-humped camel with the arterial and venous vascular tributaries. (A) Dorsal view. (B) Ventral view. 1: Eyeball and lacrimal gland; 2: Olfactory tract; 3: Telemcephalon; 4: Cerebral hemisphere; 5: Optic chiasm; 6: Optic nerve; 7: Hypophysis pituitary; 8: Cerebellum; 9: Spinal cord; 10: Spinal nerves; 11: Common carotid artery; 12: Internal carotid artery. 13: Rostral epidural rete mirabile; 14: Dorsal sagittal sinus; 15: Confluence of sinus; 16: Lateral lacuna; 17: Dorsal cerebral vein; 18: Transverse sinus; 19: Temporal sinus; 20: Rostral intercavernous sinus; 21: Caudal intercavernous sinus; 22: Cavernous sinus with rostral epidural rete mirabile; 23: Ventral petrosal sinus; 24: Dorsal petrosal sinus; 25: Emissary vein of the retroarticularforman; 26: Basilar sinus; 27: Occiput atloidien venous plexus; 28: Internal vertebral venous plexus

The basilar sinus (*Sinus basilaris*) (Fig.3) was a voluminous mass with a spongy aspect occupying the basilar part of the occipital bone. It was composed of two lobes connected ventrally by the well-developed ventral interbasilar sinus; however, the dorsal interbasilar sinus was vestigial. It was extended transversely with its counterpart of the opposite side occupying the foramen magnum. It continued caudally and ventrally as the ventral internal vertebral plexus. The basilar sinus was released to the occipital vein by the emissary vein of the hypoglossal canal and dorso-laterally, it received the sigmoid sinus and the condylar and diploic veins.

The petrosal sinus (*Sinus petrosus*) (Fig.3) had two parts, dorsal and ventral. The dorsal was the rostral extension of the transverse sinus. It had 8 cm in length and 0.5 cm in wide. It was located opposite to the lateral aspect of the pyramid. It was connected to the cavernous sinus and the caudal intercavernous sinus. Several veins drained this sinus such the ventral cerebral vein and the meningeal veins. However, the ventral petrosal sinus was located between basilar and cavernous sinuses. It was very thin and attached to the basilar part of the occipital bone. It was enclosed in thick dura mater. It had 2 cm of length and 0.5 cm in wide.

According to our knowledge, this is an anatomical description of dural sinuses of the dromedary camel with excellent photographic documentation and measures of sinuses, which facilitates a comparison with other descriptions from the literature.

In most animals and especially in the camel, there are intracranial connections between the dorsal and ventral systems of the dural venous sinus, however, in the horse this anastomosis is absent (Zguigal et al. 1991). The dorsal sagittal sinus of the camel, like the horse and unlike ox and dog, is amply divided

by a septum or fibrous bands and bifurcates rostral to the tentorium (Barone 2011; Smuts et al. 1987). Moustafa et al. (1981), reported the presence of a ventral sagittal sinus in the camel, this observation is confirmed in our dissections while Zguigal et al. (1991) they could not identify this structure.

Intracavernous sinuses of the camel are disposed as in the calf (Godynickiet al. 1981), there are two intracavernous sinuses, rostral and caudal which resulted in the formation of the circular sinus located around hypophysis pituitary. Smuts et al. (1987) did not mention the existence of rostral intercavernous sinus in camel. In sheep, goat and horse only the caudal intercavernous sinus is present (Barone 2011; Khamas 1983).

Large tributaries of the confluence sinus and the dorsal petrosal sinus connected the transverse sinus to the cavernous sinus and the rostral and caudal intercavernous sinus, this connection is present in cows and sheep and absent in pigs (Ghoshal et al. 1986; Hoffmann et al. 2014). Jerbi et al. (2016) reported that the cavernous sinus contained the rostral epidural rete mirabile in the camel, as in ruminants and pig, and the venous plexuses were intermingled with carotid rete branches.

In all species, including the camel, except the horse, the dorsal petrosal sinus was lodged within the membranous cerebellar tentorium (Barone 2011; Smuts et al. 1987; Zguigal et al. 1991). The ventral petrosal sinus is especially plexiform in camel like in cows, it lay ventral to the cavernous sinus.

In future research is necessary understand the physiological importance of these structures, especially in the diffusion of pheromones, hormones and neurotransmitters, topics never explored in these species.

4. Conclusion

Dural venous sinuses are arranged into two systems, dorsal and ventral. The patterns of the dural venous sinuses in one-humped camel differs from the patterns described in other species of the Artiodactyla order. The presence of ventral sagittal sinus, the division of the dorsal sagittal sinus by a septum and the constant existence of rostral intercavernous sinus are the major anatomical particularity of dural venous sinuses in the one-humped camel.

Acknowledgements

The authors would like to appreciate Doctor Caroline Larrouilh (<http://www.proudhorseconnections.com/>) for this interest and his help in the study.

5. References

- Baker MA, Hayward JN (1968)** The influence of the nasal mucosa and the carotid rete upon hypothalamic temperature in sheep. *J Physiol* 198: 561-579.
- Baker MA (1979)** A Brain-cooling System in Mammals. *Scientific American* 240:130-139.
- Barone R (2011)** Anatomie comparée des mammifères domestiques : Angiologie, tome 5. Paris.
- Bengoumi M, Faye B (2002)** Adaptation du dromadaire à la déshydratation. *Science et changements planétaires/Sécheresse* 13: 121-129.
- EL-Hagri MAA, EL-Gindy EM, Moustafa MS, El-Khaligi GEM (1976)** The cerebral meninges of one-humped camel (*Camelus dromedarius*). *J. Egyptian Vet. Med. Ass* 36: 5-9.
- Elkhawad AO, Al-Zaid NS, Bou-Resli MN (1990)** Facial vessels of desert camel (*Camelus dromedarius*): role in brain cooling. *Am J Physiol* 258: 602-607.
- Elkhawad AO (1992)** Selective brain cooling in desert animals: the camel (*Camelus dromedarius*). *Comp Biochem Physiol Comp Physiol* 101:195-201.
- Fuller A, Maloney SK, Kamerman PR, Mitchell G (2000)** Absence of selective brain cooling in free-ranging zebras in their natural habitat. *Exp Physiol* 85: 209-217.
- Fuller A, Hetem RS, Meyer LC, Maloney SK (2011)** Angularis oculi vein blood flow modulates the magnitude but not the control of selective brain cooling in sheep. *Am J Physiol Regul, Integr. Comp Physiol* 300: 1409-1417.
- Gebreyohanes MG, Assen AM (2017)** Adaptation mechanisms of camels (*Camelus dromedarius*) for desert environment : A review. *J Vet Sci Technol* 8: 1-5.
- Ghoshal NG, Zguigal H (1986)** Dural sinuses in the pig and their extracranial venous connections. *Am J Vet Res* 47:1165-9.
- Godynicki VS, Schwarz S, Radke B (1981)** Mikromorphologische Untersuchungen am Rete mirabile epiduraie rostrale und am Sinus cavernosus des Schafes (*Ovis aries*). *Anat. Histol. Embryol* 10:227-237.

- Hoffmann A, Stoffel MH, Nitzsche B, Lobsien D, Seeger J, Schneider H, Boltze J. (2014)** The ovine cerebral venous system: comparative anatomy, visualization, and implications for translational research. *PLoS One* 9: e92990.
- International Committee on Veterinary Gross Anatomical Nomenclature (ICVGAN) (2017)** *Nomina Anatomica Veterinaria*. 6th ed. Knoxville, Editorial Committee Hannover, Columbia, Gent, Sapporo.
- Jerbi H, Khaldi S, Perez W (2016)** Morphometric Study of the Rostral Epidural Rete Mirabile in the Dromedary (*Camelus dromedarius*, Linnaeus 1758). *Int J Morphol* 34:1429-1435.
- Khamas WA (1983)** Morphologic studies of the carotid rete-cavernous sinus complex and its functional significance in sheep and goat. Theses Iowa State University.
- Krzymowski T, Grzegorzewski W, Stefańczyk-Krzymowska S, Skipor J, Wąsowska B (1999)** Humoral pathway for transfer of the boar pheromone, androstenol, from the nasal mucosa to the brain and hypophysis of gilts. *Theriogenology* 52: 1225-1240.
- Krzymowski T, Stefańczyk-Krzymowska S, Grzegorzewski W, Skipor J, Wąsowska B (2001)** A possible humoral pathway for priming action of the male pheromone androstenol on female pigs. In: Marchlewska-koj A, Lepri JJ., Muller-Schwarze D (ed) *Chemical Signals invertebrates* 9 ed. Kluwer Academic Plenum Publisher, New York, pp. 117-124
- Krzymowski T, Stefańczyk-Krzymowska S (2012)** Local retrograde and destination transfer of physiological regulators as an important regulatory system and its role: Facts and hypothesis. *J Physiol Pharmacol* 63: 3-14.
- Krzymowski T, Stefańczyk-Krzymowska S, Muszak J, Gilun P, Koziorowski M (2014)** Cavernous sinus and its mysterious physiological functions: facts and hypotheses. *Acta Biologica Cracoviensis Zoologia* 55/56: 7-15.
- Mitchell D, Maloney SK, Laburn HP, Knight MH., Kuhnen G, Jessen C. (1997).** Activity, blood temperature and brain temperature of free-ranging springbok. *J Comp Physiol* 167: 335-343.
- Moustafa MS, EL-Hagri MAA, khidr IM (1981)** Veins of the head and neck of the dromedary camel (*Camelus dromedarius*). IV. Sinuses durae matris. Proceedings of the sixth european anatomical congress. *Acta Anat.* III (1-2), 102, Basel, Switzerland.
- Smuts MMS, Bezuidenhout (1987)** *Anatomy of the dromedary*. Oxford University Press. UK.
- Soliman MK (2015)** Functional anatomical adaptations of dromedary (*Camelus dromedarius*) and ecological evolutionary impact in KSA. International conference on plant, marine and environmental sciences. Kuala Lumpur, Malaysia.
- Stefańczyk-Krzymowska S, Krzymowski T, Grzegorzewski W, Wąsowska B, Skipor, J (2000)** Humoral pathway for local transfer of the priming pheromone androstenol from the nasal cavity to the brain and hypophysis in anaesthetized gilts. *Exp Physiol* 85: 801-809.
- Zguigal H, Ghoshal NG (1991)** Dural sinuses in the camel and their extracranial venous connections. *Anat Histol Embryol.* 20:253-260.