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Angioarchitecture of the nasal cavity and the carotid rete-cavernous sinus complex and their functional significance in the camel (Camelus dromedarius)

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Iowa State University, 1988

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Angioarchitecture of the nasal cavity and the carotid rete-cavernous sinus complex and their functional significance in the camel (*Camelus dromedarius*)

by

Hadhoum Zguigal

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1988

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DEDICATION

This work is dedicated to all the special people in my life:

To my mother and my sisters for their continuous support, especially my sister Amina, Zguigal and her husband Abdelhaq, Chahbar who encouraged me to continue my graduate studies;

To Aziza, Majid, and to my best friends Siham and Oussama.

INTRODUCTION

The camel is well suited to a desert environment and this adaptation is dependent upon many factors including: (1) diurnal rise in body temperature in hot weather conserving water; (2) a low metabolic rate reducing the need for water; (3) ability to recycle urea when limited amount of protein is available; and (4) ability of the nasal cavity to humidify the inspired air and to cool exhaled air reducing water loss (Gauthier-Pitters and Dagg, 1981). In addition, the hair provides insulation during hot ambient temperature and the sweat glands facilitate evaporative cooling. The camel produces little urine and dry feces which could be a device for conserving water. Schmidt-Nielsen et al. (1957, 1972 a,b) described some mechanisms that help camel to reduce utilization of water by storing metabolic heat and thus reducing the environmental heat gain. Body temperature fluctuations become obvious during deprivation from drinking water.

Langman et al. (1978) reported that heat and water exchange occurs within the conchae of the nose of the camel. The inspired air comes in contact with a large conchal surface for heat and water exchange facilitating control of brain temperature via the carotid rete. During the day the expired air temperature tends to approximate the rectal temperature but at night it approximates the ambient air temperature as there is no need for evaporative cooling and excess of heat can be dissipated without expending water.

Lately, many investigators are working with camels to understand precisely their desert adaptations, specifically the thermal regulation of the body, and respiration in heat stressed camels. In the literature, there are very few accounts on the blood supply of the head of the camel (Lesbre, 1903; Tayeb, 1951; Badawi et al., 1977; Hifney et al., 1981 a,b, 1982), but these works lack a detailed systematic description. Further, very limited references have been made in these studies especially to the blood supply of the nasal cavity, afferent vessels of the ophthalmic rete and the rostral epidural rete mirabile ("carotid rete"), and the venous pathways from the nasobuccal regions to the ophthalmic plexus and the cavernous sinus. Some of the structures above have been shown experimentally to play a significant role in the thermal regulation of the brain; for example in the dog (Magilton and Swift, 1967, 1968, 1969); in the goat (Jessen and Pongratz, 1979; Jessen et al., 1984); and in sheep (Baker and Hayward, 1967, 1968a,b; Young et al., 1976; Khamas and Ghoshal, 1982a,b; Krabill and Ghoshal, 1982, 1983; Ohale and Ghoshal, 1982a,b,c,d; Booth and Ghoshal, 1983).

The objectives of this study are the following:

(1) To describe the blood vessels of the head of the camel in general, complementing the existing literature with special emphasis on the arterial supply and venous drainage of the nasal cavity;

(2) To describe the formation and relationship of the ophthalmic rete to the ophthalmic plexus, and the carotid rete to the cavernous sinus, respectively;

(3) To describe the histomorphology of the nasal mucosa depicting the distribution and structure of blood vessels and their anastomoses, presence of intraarterial bolsters, distribution and type of nasal glands; and possible function of these structures in the thermal regulation of the brain; and

(4) To describe the structure of the carotid rete and the cavernous sinus complex and to relate this to their possible role in the brain temperature regulation.

This detailed anatomical description will serve as a basis for designing future experimental work on this species.

REVIEW OF LITERATURE

Gross Anatomy

The blood supply of the head of most domesticated animals has been studied by many authors. Getty (1975), Koch (1976), and Nickel et al. (1981) gave a complete description of the blood vessels of the head of the horse, ruminants, pig and carnivores; Barone and Tagand (1957) and Evans and Christensen (1979) described in detail the blood supply of the head of the horse and the dog, respectively; textbooks by Bourdelle and Bressou (1964, 1972) and Bressou (1978) were, however, not considered sufficiently complete to provide an adequate basis for experimental work. The cranial blood vessels of the ox are available in the textbook of Ellenberger and Baum (1943). Ghoshal et al. (1981) furnished considerable general information about the venous drainage of the head of the domestic animals. May (1967) described the normal arterial supply of the head and neck of the sheep and ox, and Hegner (1962) studied it in the dog. Concerning the blood supply of the head of the camel, there is a general paucity of information in textbooks, except a few selected publications. The blood supply to the head of the camel was studied briefly by Lesbre (1903) and Tayeb (1951), later, Kanan (1972), Badawi et al. (1977) and Hifney et al. (1981 a,b, 1982) described some cranial blood vessels of the camel in a general way.

General blood supply of the head

Arteries The blood supply of the head is derived from the common carotid artery lying inside a bony groove bounded by the transverse processes of cervical vertebrae. The common carotid artery bifurcates, lateral to the stylohyoid bone, into the external carotid and the maxillary (Tayeb, 1951). During its course in the neck, the common carotid gives off the occipital, condylar and lingual arteries. The course and branching of the external carotid artery are further studied by Tayeb (1951), and Benkoukous (1983). According to these authors, the external carotid artery lies on the lateral surface of the stylohyoid bone, deep to the parotid gland. It gives rise to a common trunk of the caudal auricular and the caudal meningeal arteries. The terminal branches of the external carotid artery are the superficial temporal and the facial; the superficial temporal artery resembles the same vessel of the horse (Tayeb, 1951). The facial artery courses along the deep face of the parotid gland and appears superficial to the masseter muscle. At first it passes deep to the facial vein and then the facial artery is related to the parotid duct dorsally and the facial vein ventrally.

The maxillary artery continues the course of the external carotid (Badawi et al., 1977; Benkoukous, 1983) beyond the origin of the superficial temporal. It passes between the pharynx and the pterygopalatine fossa, and extends inside the infraorbital canal. It gives off the following branches: 1) The inferior alveolar artery passes between the medial and lateral pterygoid muscles (Tayeb, 1951), or within the medial and lateral pterygoid muscle (Badawi et al., 1977). It detaches the caudal deep temporal artery. The rostral deep temporal passes caudally through the round foramen to contribute to the rostral epidural rete mirabile.

Badawi et al. (1977) and Benkoukous (1983) described the blood supply to the brain of the camel. According to these authors, the arterial blood supply to the brain is derived from the internal carotid artery, the rostral epidural rete branches arising from the maxillary, and the caudal epidural rete branches of the external ophthalmic. The cerebral arterial circle receives afferents from several branches of the rostral epidural rete mirabile to which the internal carotid artery is connected via the caudal communicating artery. From this arterial circle arises the caudal cerebral artery that, in turn, gives off the caudal communicating artery. The middle cerebral and rostral choroidal arteries arise from the rostral cerebral artery.

Veins The venous drainage of the head has been described briefly by Tayeb (1951) and, in general, by Hifney et al. (1981 a,b; 1982) and Arifi (1986). These authors did not, however, describe the venous drainage of the nasal cavity, and the connections between this area and the cranial cavity, and the possible functional .relationship between the carotid rete-cavernous sinus complex.

The facial vein arises from the external jugular and courses superficially to the masseter and buccinator muscles. It is crossed by the dorsal buccal branch of the facial nerve, and releases several branches: 1) The masseteric branch and the superficial inferior labial vein supply the depressor labii inferioris muscle; 2) The deep inferior labial vein ramifies within the lower lip; 3) The veins of the ventral and dorsal buccal glands; 4) The deep and superficial superior labial veins drain the upper lip; and 5) The terminal branches of the facial are the dorsal nasal and the angularis oculi veins. The latter joins the dorsal external ophthalmic vein (Tayeb, 1951; Hifney et al., 1981a; and Arifi, 1986).

The deep facial vein is located between the buccinator and masseter muscles. It receives branches from the ophthalmic plexus, and the descending palatine vein that releases the major palatine, the minor palatine and the sphenopalatine veins.

The maxillary vein is the second terminal branch of the external jugular (Hifney et al., 1982; and Arifi, 1986). It is located medial to the mandible and receives the caudal auricular vein that is formed by the confluence of the stylomastoid vein, and the medial, lateral, and intermediate auricular veins. The superficial temporal vein joins the maxillary after receiving the rostral auricular vein. The emissary vein of the retroarticular foramen joins the maxillary vein at the ventral end of the jugular process.

Specific blood supply to the nasal cavity

The nasal cavity of different species, including man, has been extensively studied because of its complexity, vascularity, and its role in the regulation of the brain temperature. It is provided with protection gainst desication and penetration of foreign particles. Dawes and Prichard (1953) mentioned the presence of valves in veins at the nasal tip of the dog, but not in the veins of the nasal mucosa rostral to the middle nasal concha. Gillilan and Markesbery (1963) showed that the venous plexus of the nasal cavity of the cat is connected with the deep and superficial veins of the face, as well as the dural sinuses. Dawes and Prichard (1953) found an arterial network in the nasal mucosa of the pig, goat and sheep. Scott (1954) described a high degree of vasculature in the nasal cavity of the deer, horse, kangaroo, lemur, and new world monkey. Batson (1954) observed a venous network in the human nasal mucosa and mentioned the absence of valves in the veins of the head and the nasal cavity. Popovic (1967) reported that there were no differences in the origin, distribution, and topographic relationship of either arteries or veins in the nasal cavity of the apparently healthy pig at different ages.

Arteries The arterial blood supply of the nasal cavity is derived from branches of the maxillary artery, mainly via the sphenopalatine artery in sheep and goat (Dawes and Prichard, 1953; Khamas and Ghoshal, 1982a); in the dog (Christensen and Toussaint, 1957; Lombard, 1966; Hegner, 1962); in buffalo (Nawar et al., 1975); in human (Topozada and Gaafar, 1976; Osborn, 1978); in the pig (Dawes and Prichard, 1953); in rabbit (Bugge, 1968; Dawes and Prichard, 1953; Godynicki, 1975); in ox and horse (Getty, 1975). The sphenopalatine artery is a branch of the maxillary in the above mentioned species, but it is a branch of the infraorbital artery in the rat (Dawes and Prichard, 1953). It enters the nasal cavity via the sphenopalatine foramen and divides into the dorsal, ventral and septal branches. The dorsal branch vascularizes the dorsal concha, as well as the lateral wall of the nasal cavity; the ventral branch supplies the floor of the nasal cavity and the ventral nasal concha, and the septal branch supplies the nasal septum. This pattern was observed in the sheep (Khamas and Ghoshal, 1982a). In the rabbit, however, the sphenopalatine artery divides into septal and lateral branches (Bugge, 1968; Godynicki, 1975). The lateral branch supplies the wall of the nasal cavity, the ventral nasal concha, and partly the dorsal nasal concha. The septal branches ramify in the rostral floor of the nasal cavity, vomeronasal organ, and the inferior part of the nasal septum. In the buffalo, the sphenopalatine artery splits mainly into relatively large dorsal and ventral branches, and smaller caudal and septal branches. In large ruminants, the sphenopalatine artery bifurcates into dorsal and ventral branches (Getty, 1975). In the horse, it divides into the caudal, lateral and septal nasal arteries (Getty, 1975). In man, it ramifies into three branches: the inferior conchal branch, the middle conchal branch and the nasopalatine branch which supply the septum and the dorsal nasal turbinate (Howard, 1935).

The other arteries contributing to the vasculature of the nasal cavity are the external and internal ethmoid arteries; the former originates from the maxillary artery in the rabbit (Bugge, 1968). In the buffalo, the external ethmoid is one of the terminal branches of the external ophthalmic artery (Nawar et al., 1975). In ox, horse, goat, and sheep, the external ethmoid is the continuation of the external ophthalmic artery and supplies the ethmoid bone, the caudal nasal septum, and the dorsal nasal concha. In man the internal ethmoid artery arises from the internal carotid artery (Dawes and Prichard, 1953). In the dog, it is a branch of the anterior cerebral artery (Shahen, 1970).

Other arteries such as the malar and the major palatine arteries play a minor role in the blood supply to the nasal cavity. This was confirmed in the rabbit (Godynicki, 1975); in sheep (Khamas and Ghoshal, 1982a); in the dog (Christensen and Toussaint, 1957), in man (Osborn, 1978); and in pig (Ghoshal and Khamas, 1986). Further, Khamas and Ghoshal (1982a) in the sheep and Nawar et al. (1975) in the buffalo reported that the infraorbital artery contributes to the nasal vestibular area.

Veins The nasal mucosa is drained by the veins especially in the region of the external nares, and the blood is carried away by the dorsal nasal, lateral nasal, angularis oculi, dorsal external ophthalmic, sphenopalatine, external ethmoid, and the major palatine veins.

The dorsal nasal vein begins in the region of the external nares, collects blood from the rostral part of the nasal septum, and joins the facial vein, which carries blood to the external jugular vein in the dog (Christensen and Toussaint, 1957), in rabbit (Godynicki, 1975), and in sheep (Khamas and Ghoshal, 1982a). The right and left dorsal nasal veins in the sheep are connected by a transverse anastomotic branch across the nasal bone (Khamas and Ghoshal, 1982a).

The lateral nasal vein drains the rostral part of the lateral nasal wall and joins the facial vein. In sheep, it arises either directly from the facial or by a common trunk with the dorsal nasal vein (Khamas and Ghoshal, 1982a).

Anatomically the angularis oculi vein is considered as a terminal branch of the facial; it continues the course of that vessel around the medial angle of the eye toward the frontal region where it courses caudally along the orbital margin. This vein is a component of a venous pathway from the nasal and facial areas to the cavernous sinus in the dog (Magilton and Swift, 1968; Baker, 1979), and in sheep (Khamas and Ghoshal, 1982a). The angularis oculi vein has valves in human (Dawes and Prichard, 1953). Many investigators have paid special attention to the angularis oculi vein because it is a component of above venous pathway connecting the dural sinuses. Baker and Hayward (1968b) injected latex into the angularis oculi vein of the sheep. When the injection was made distally, the latex entered the nasal cavity via the lateral and dorsal nasal veins, and filled the superficial venous plexus of the nasal mucosa of the same side over the ventral concha. When the latex was injected proximally into the angularis oculi vein, the latex entered the supraorbital vein and accumulated in the back of the orbit via the ophthalmic vein, and filled the cavernous sinus bilaterally. Baker and Hayward (1968b) concluded that the angularis oculi vein is directly connected to the cavernous sinus via the ophthalmic plexus.

This pathway was confirmed in the dog (Magilton and Swift, 1968), in Thompson's gazelle (Taylor and Lyman, 1972), in man (Cabanac and Caputa, 1979), and in live sheep by venography (Khamas and Ghoshal, 1982a).

The sphenopalatine vein forms another route for the venous drainage of the nasal cavity. In the dog, this vein joins at first the deep facial and infraorbital veins, and then the ventral external ophthalmic vein to drain into the cavernous sinus (Hegner, 1962). In sheep, it is a branch of the deep facial, and joins the pterygoid plexus (Baker and Hayward, 1968b). It drains the ventral and dorsal nasal conchae, part of the middle nasal concha, nasal septum as well as the floor (Khamas and Ghoshal, 1982a). In human, the sphenopalatine veins are continuous with the venous plexus of the soft palate and nasopharynx and join the infraorbital vein.

The external ethmoid vein of the sheep drains a part of the nasal cavity, caudal part of the nasal septum especially the midlle nasal concha, and joins the ophthalmic plexus (Baker and Hayward, 1968; Khamas and Ghoshal, 1982a). Both the sphenopalatine and ethmoid veins are connected to the cavernous sinus via the ophthalmic vein and the pterygoid venous plexus, respectively. In man, the ethmoid vein passes through the cribriform plate of the ethmoid bone to join the dorsal sagittal sinus (Dawes and Prichard, 1953).

The major palatine vein is satellite to the homonymous artery inside the palatine canal only in small ruminants (Nickel et al., 1981). In the other domestic mammals, it is a small branch which passes over the ventral border of the pterygopalatine fossa into the palatine groove. In addition, Godynicki (1975) described in the rabbit an anastomotic branch connecting the septal nasal veins to the cavernous sinus. This anastomotic branch passes through the craniopharyngeal canal, and participates in accelerating the flow of the blood to the cavernous sinus.

From the studies of Baker and Hayward (1968b) and Khamas and Ghoshal (1982a) in sheep, Magilton and Swift (1969) in the dog, and Ghoshal and Zguigal (1986) in the pig, it can be concluded that the nasal blood flows to the cavernous sinus via the ophthalmic plexus of sheep and dog, or ophthalmic sinus in the pig. Robertshaw (1976) and Baker (1979) stated that in ruminants the blood not only from the nose but also from parts of the mouth drains into the cavernous sinus. Also, in the goat the venous blood of the horn had been shown to drain into the cavernous sinus (Taylor, 1966). These connections between the cavernous sinus on one hand, and the nasal venous blood on the other, results in a bathing of the carotid rete which allows for cooling of carotid blood destined to supply the brain.

Specific blood supply to the carotid rete-cavernous sinus complex

The carotid rete The "carotid rete" (rostral epidural rete mirabile) is found in cattle, sheep, goat, pig, and carnivores. In these species, the cerebral arterial circle receives its blood from the carotid rete which, in turn, receives blood from branch of the internal carotid artery, or from branches of the maxillary artery, or both. The carotid rete is a network of small blood vessels, freely anastomosing with each other at the base of the brain. It can be either intracranial as in sheep, goat, ox, pig and dog, or extracranially located at the apex of the orbit as in the cat (Daniel et al., 1953; Godynicki and Frackowiak, 1979; and Uehara et al., 1978). The development of the carotid rete in sheep, goat, pig and calf depends on the form of the basilar venous plexus (Uehara et al., 1978).

In ruminants, the carotid rete is supplied by rostral rete branches arising either from the maxillary or the external ophthalmic artery, and by caudal rete branch coming from the maxillary artery (Baldwin, 1964; Balankura, 1954; Daniel et al., 1953; Godynicki and Frackowiak, 1979). In the ox, there is an anastomosis between the carotid rete and the caudal epidural rete mirabile (Uehara et al., 1978). In the pig, the rostral rete mirabile is supplied mainly by the internal carotid artery and the rostral rete branches that originate from the external ophthalmic artery (Godynicki and Frackowiak, 1979; Daniel et al., 1953; Ghoshal and Khamas, 1985), and from the middle meningeal and maxillary arteries (Ghoshal and Khamas, 1985). In Cervidae, the rostral epidural rete mirabile is supplied mainly by the caudal rete branches of the maxillary, small rostral rete branches from the external ophthalmic, and the small internal carotid artery (Godynicki and Frackowiak, 1979). In the cat, the rete branches stem mainly from the maxillary (Gillilan and Markesbery, 1963), and in the dog from the internal carotid artery (Daniel et al., 1953).

Besides the carotid rete, there is a caudal epidural rete mirabile which is found in ox and pig. In the ox, the caudal rete mirabile is situated on basisphenoid and basioccipital bones. In the pig, however, the caudal rete fails to join the rostral epidural rete mirabile, and is supplied by branches of the condylar, vertebral, and basilar arteries (Godynicki and Frackowiak, 1979). In sheep and goat, the caudal epidural rete mirabile is absent (Baldwin, 1964; Daniel et al., 1953; Getty, 1975; Khamas and Ghoshal, 1982a). In these animals including ox, according to the previous authors, the internal carotid artery was reported to regress in the adult and this regression occurs within a few weeks to several months after birth. The blood supply to the carotid rete through the afferent arteries is greater than that carried by the internal carotid artery which transports blood from the rete to the cerebral arterial circle. The blood flow in the basilar artery in goat is from rostral to caudal, that is flowing away from the cerebral arterial circle toward the spinal cord (Anderson and Jewell, 1956). Edelman et al. (1972) demonstrated that the flow in the basilar artery of the goat is negligible which is supported by the finding of Godynicki and Frackowiak in sheep (1979).

The intracranial portion of the internal carotid artery ramifies to form the rostral epidural rete mirabile (Nomina Anatomica Veterinaria, 1983). It pierces the internal meningeal layer of the dura mater and gives off the caudal communicating artery that joins the basilar artery. It runs rostrally being ventral to the optic tract, releases the middle cerebral artery, and continues further as the rostral cerebral artery. In the cat, Gillilan and Markesbery (1963) described an arteriovenous anastomosis between the rete branches and the venous plexus. The left and right rostral epidural rete mirabilia are connected to each other by many branches. In the goat, it was reported that the vessels connecting both retia, located caudal to hypophysis cerebri, are more numerous and plexiform in comparison to those of sheep (Daniel et al., 1953). These anastomotic branches are very extensive in the pig (McGrath, 1977; Ghoshal and Khamas, 1985), which give them the appearance of one single structure. In the dog, De La Torre et al. (1959) reported an anastomosis between the two internal carotid arteries, and between the internal carotid and ascending pharyngeal arteries.

Other mammals such as the rat, monkey, rabbit and horse do not have a carotid rete. These animals have a direct vascular pathway from the aortic arch through the internal carotid artery to the cranial cavity. This vessel runs through the cavernous sinus on its way to the cerebral arterial circle. In the horse and the camel, the internal carotid traverses the ventral petrosal sinus with its first bend, then enters the cavernous sinus where it forms the second bend.

The cavernous sinus This sinus belongs to the basilar system of the dural sinuses; it lies on both sides of the hypophysis cerebri on the basisphenoid bone. The right and left cavernous sinuses are usually connected by rostral and caudal intercavernous sinuses. The rostral one, however, may be absent in the horse. The cavernous sinus receives its blood from the base of the brain, but most of it comes from the extracranial area (Baker, 1979). Some of its drainage comes from the nasal cavity as has been shown by Baker and Hayward (1968b), and Khamas and Ghoshal (1982a) in sheep; Magilton and Swift (1976) in the dog; Ghoshal and Zguigal (1986) in the pig, from horns in the goat (Taylor, 1966), and parts of the mouth in ruminants (Robertshaw, 1976). The cavernous sinus forms a circular sinus around the hypophysis (Uehara et al., 1978), and is drained into the basilar venous plexus and into four emissary veins in the calf (Uehara et al., 1978; Payan, 1975). The cavernous sinus has connections with the ophthalmic plexus and the pterygoid plexus (Gillilan, 1974). The blood from this sinus flows via the internal jugular vein in man, rhesus monkey, pig and cat. In the dog, horse, rabbit, sheep, and ox, the venous blood from the cavernous sinus, however, leaves the cranial cavity via the dorsal cerebral vein which exits through the temporal foramen.

Light Microscopy

Nasal cavity

Most of the nasal cavity is lined by mucous secreting goblet cells, and subepithelial glands that play an important role in conditioning the air entering the lung. Scott (1954) studied the nasal mucous membrane of different animals and stated that in the seal the surface area of the nasal mucosa may approach, if not exceed, the total surface area of the skin covering the body due to the complexity of the conchae. Swindle (1937) stated that in rabbit, dog, sheep, and deer the nasal blood vessels are arranged in superficial, middle, and deep layers in relation to the epithelium. The superficial layer is arterial and extends through the greater part of the nasal cavity; it is divided into greater and lesser superficial layers, and are connected by simple anastomosis. The middle venous layer supplying its greater and lesser middle layers. The deep layer is non-functional and remains collapsed in rabbit and dog, while in sheep and deer is patent throughout life.

Generally, the arterial walls consist of the following layers called tunics: the intima, media, and adventitia. The tunica intima is composed of endothelium which is simple squamous epithelium, the subendothelial connective tissue, and the internal elastic lamina. The tunica intima differs among vessels of various parts of the body, as well as between species. The tunica media of large elastic arteries consists of varying amounts of smooth muscle cells and elastic laminae fibers. Sometimes this tunic is surrounded by an external elastic lamina separating the tunica media from the tunica adventitia. The peripheral layer is the tunica adventitia consisting mainly of collagen and elastic fibers. In addition, the outer tunic has autonomic nerve fibers and ganglia, and blood vessels. Cauna and Cauna (1975) demonstrated the subendothelial cushion in the vein of the human nasal mucosa. The tunica media consists of four to six layers of smooth muscle. On the other hand, Cauna and Hinderer (1969) and Cauna (1970a) stated the subendothelial and periglandular capillaries of the nasal vascular bed of man are fenestrated, while those of the deeper region were not. Adams and Hotchkiss (1983) described fenestrated endothelial cells and porous basement membrane in the superficial subepithelial microvessel and the subepithelial vessels of the nasal mucosa of the dog. According to them, the endothelium of the subepithelial and periglandular capillaries is fenestrated, whereas the venules are lined with a continuous endothelium. The arterioles have a thin layer of endothelium with numerous pinocytic vesicles; there is no internal elastic lamina. The small arteries have internal elastic laminae interposed between endothelial cells and the muscular layer (Toppozada and Gaafar, 1976; Cauna and Hinderer, 1969; Cauna, 1970a). Naessen (1970) found that the respiratory epithelium of man and the guinea pig had furrows or gutters aligned in rows. Further, Batson (1954) mentioned that the mucous membrane of the nasal cavity of man is pervaded throughout by interlacing venous network. Thick walled veins are present in the nasal cavity in sheep (Khamas and Ghoshal, 1982b), and in pig (Ghoshal and Khamas, 1984). In sheep, the tunica media of arteries is very thin in the vestibular region and relatively thick in the respiratory region; the diameter of the arteries is very small in the respiratory region and relatively larger in the nasal vestibule (Khamas and Ghoshal, 1982b).

Arteriovenous anastomosis (AVA) has been reported first in the tongue of the dog (Prichard and Daniel, 1953), in the tongue of sheep and goat (Prichard and Daniel, 1954), and in human external ear (Prichard and Daniel, 1959). Also, Daniel and Prichard (1956) described the existence of AVA in the external ears of sheep, goat and pig. Gillilan and Markesbery (1963) demonstrated the presence of AVA between the carotid rete and the cavernous sinus in the infraorbital region of the cat. These anastomoses are, however, absent in sheep, ox, and pig (Gillilan, 1974). Anggard (1974) described AVA in the cat nose near the nasal glands in the deeper section of the nasal mucosa. Also, Spence et al. (1972) reported the presence of AVA in the skin and paw of the pelvic limb in the dog. Khamas and Ghoshal (1982b) reported the presence of AVA in the nasal mucosa of sheep. The venous limb in the AVA of the human nose does not have smooth muscles (Cauna, 1970b).

Intraarterial bolsters in different mammals have been described in most cases at the branching sites of arteries, opposite the direction of blood regulating the blood flow (Menshick and Dovi, 1965; Moffat, 1969; Nawar et al., 1975; Taher, 1976). In addition, Moller and Fahrenkrug (1971) reported the presence of swell bodies in the nasal cavity of the rat and rabbit, and related them to the normal cyclic changes associated with air conditioning. The bolsters are composed of smooth muscle controlled by the autonomic nervous system. Ritter (1970) stated that the nervous control of the nasal mucosa of the dog depends only on α-adrenergic receptors, while β-adrenergic receptors are absent. The control of blood flow can be accomplished either by increasing vasomotor tone through α-adrenergic receptors via the cranial cervical ganglia or by decreasing the parasympathetic activity which will result in vasoconstriction resulting in the decrease of blood flow.

Moisture is needed in the nose for evaporative cooling of the circulating blood. The moisture is produced by the nasal glands described in dog, cat, pig, and goat. Blatt et al. (1972) reported that the lateral nasal gland seems to be the main source of moisture in the dog. In man, Moller (1965) mentioned the presence of compound tubuloalveolar glands of mixed type lying in the lamina propria of the nasal mucosa. Katz and Mertzel (1977) studied the various glands of the nasal septal mucosa of the rat, and the glands observed are of mucous type with goblet cells. In the dog, Adams and Hotchkiss (1983) stated that the rostral half of nasal mucosa is richly supplied by tubuloacinar glands. In sheep (Khamas and Ghoshal, 1982b) and in pig, (Ghoshal and Khamas, 1984), the nasal mucosa is supplied by compound tubuloalveolar type mixed glands that are predominantly serous in the vestibular region and mostly mucous in other regions.

In the camel, the nasal vestibule lacks sweat glands but sebaceous glands are present (Badawi et al., 1975). According to El Gohary (1978), rosette-like nasal glands were distributed throughout the nasal mucosa. Abdel-Majid and Abdel-Razac (1975) reported the presence of a lateral nasal gland close to the maxillary sinus which represents two communicating sacs. They consist predominantly of simple tubuloalveolar glands .

Carotid rete-cavernous sinus complex

The wall of the carotid rete arterial branches in ox and sheep has been described by Baldwin (1964), Godynicki et al. (1981), and Khamas and Ghoshal (1984). They stated that the periphery of the arterial wall is composed of a simple squamous epithelium which forms the endothelial lining of the cavernous sinus. These vessels are medium-sized muscular arteries in goat and sheep (Anderson and Jewell, 1956; Baldwin, 1964; McGrath, 1977; Khamas et al., 1984). Khamas et al. (1984) reported the presence of the carotid body cells in sheep migrated in the adventitia of the intracranial portion of the internal carotid artery as its extracranial portion degenerates early in life.

Godynicki et al. (1981) described the structure of the cavernous sinus which consists of connective tissue layer covered by endothelium in sheep, and one or more layers of smooth muscle cells intervening between the endothelium and the internal elastic lamina of the carotid rete branches. Furthermore, Khamas et al. (1984) reported that the cavernous sinus in sheep shares a common tunica adventitia with the surrounding rete branches; at the site of emergence of the intracranial portion of the internal carotid artery, there is occasional presence of a distinct tunica media interposed between the endothelial cells and the tunica adventitia of the cavernous sinus in sheep. The cavernous sinus consists of numerous fibrous trabeculae traversing through its lumen. These trabeculae are, however, not observed in <u>Rhesus macacus</u> (Eyster, 1944), fetal or adult rats (Butler, 1957), dogs (Evans and Christensen, 1979), and human fetuses (Bedford, 1966); but they are noticed in sheep (Khamas et al., 1984) and in the pig (Ghoshal and Zguigal, 1986), which represent collapsed veins. In monkey, the cavernous sinus has been described by Rajendran and Ling (1985) as one main venous channel that, together with the internal carotid artery, occupies a meningo-endocranial compartment lateral to the pituitary gland.

According to Uehara et al. (1978), the basilar venous plexus of sheep, goat and pig may be absent and sometimes does not show a distinct structure as in the calf. Intimal cushions have been described in the cerebral arteries at the branching sites in the dog and pig of different ages (Nanda and Getty, 1972). In sheep and steers, Stehbens (1960) described the presence of fenestrated internal elastic lamina and intimal proliferation forming pads which consisted of abundant smooth muscle, elastic tissue, and collagen fibers. Valves in the cerebral arteries of some mammals have been reported (Nanda and Getty, 1972) and they are arranged in a way to impede the movement of the blood flow but not like the venous valves which prevent backward movements. Moffat (1959, 1969) described three types of cushions in the walls of the blood vessels: 1) Intimal cushion protruding into the lumen of the vessel; 2) Paired leaflets with a valve-like appearance, and 3) Polypoid cushions which have a single flap-like intraluminal projection.

Functional Significance of the Nasal Cavity and the Carotid Rete-Cavernous Sinus Complex in the Regulation of Brain Temperature

The nasal passages are the primary sites of evaporation (Blatt et al., 1972) and the lateral nasal gland provides a large part of water for evaporative cooling in the panting dog. Duct of each gland opens 2 cm caudal to the nostrils. This location is essential to avoid desication of the nasal mucosa during thermal panting. Further, Scott (1954) described many secreting mucous glands in the nasal mucous membrane of man, which by their activity keep its surface moist. In addition, Dixon et al. (1949) showed in tracheostomised patients that the nose temperature is constantly 1.2°C higher than normal because of the absence of inspired air. There is a relation between changes in nasal and finger temperature. General warming and chilling of fingers are accompanied by a drop and rise of the nasal temperature, respectively (Ralston and Kerr, 1945). Magilton and Swift (1968 and 1970) described an "external heat exchange system" between the venous lakes in the alar fold region of the ventral nasal concha and the ambient air in the dog. The cool inspired air passes over the nasal mucosa, especially at the nasal vestibule, where the external heat exchange mechanism operates, resulting in cooling of the venous blood present in the so-called venous lakes in the alar fold (dorsal part of the ventral nasal concha). The cool venous blood leaves the nasal cavity via the dorsal and/or lateral nasal veins to the angularis oculi and facial veins. The nasal mucosa is always moist, when the animal inhales dry air, the moisture evaporates and thus the cooled mucosa cools the blood flowing through it. Both the nose and mouth are used for evaporative cooling of the arterial blood. Baker and Hayward (1968b) demonstrated a connection between the nasal veins and the cavernous sinus of sheep via the lateral nasal, the dorsal nasal, and the angularis oculi veins. Hegedus and Shackelford (1965) demonstrated several anastomoses between the orbital and deep facial veins in the dog, horse, ox, sheep and rabbit. The angularis oculi vein is a component of a venous pathway from the nasal and facial areas to the cavernous sinus (Baker, 1979; Khamas and Ghoshal, 1982a). This means the blood flows caudally through the angularis oculi vein to the cavernous sinus. Cabanac and Caputa (1979) and Khamas and Ghoshal (1982a) reported the absence of valves in the angularis oculi vein, so that the blood in this vessel can flow in either direction, i.e., toward the facial vein or toward the ophthalmic plexus. This direction of blood flow depends also upon the body temperature; the skin temperature near the angularis oculi vein was lowered during facial firing affecting the cavernous sinus and brain temperature in man. Magilton et al. (1984) reported a drop in blood temperature of angularis oculi veins in man during thinking.

Fluctuations in the hypothalamic temperature in the dog have been reported (Hammel et al., 1963), and fluctuations in brain temperature related to sleep have been reported in monkey (Hamilton, 1963), in the rabbit (Kawomura and Sawyer, 1965), in the cat (Kundt et al., 1957), and in the dog (Hemingway et al., 1966). These fluctuations in brain temperature during sleep could be due to a change in stability of the hypothalamic control of body temperature (Hammel et al., 1963). Baker and Hayward (1967) could not find any evidence of an increase in central nervous system metabolism coinciding with the rise in brain temperature during paradoxical sleep in the cat. They showed that a rise in brain temperature could be related to the vasoconstriction of the skin of the ear resulting in a rise in arterial blood temperature. They support the hypothesis that most of the fluctuations at least in the cat, dog, and rabbit, when not under thermal stress, are related to extracerebral events and to the changes in the temperature of the arterial blood leaving the heart. Under steady state conditions, it is to be expected that brain temperature will be higher than that of the blood in the aortic arch, because the oxygen consumption and heat production of the brain are greater than that of the most other tissues of the body, while the aortic blood temperature is influenced by the cooled venous return from the periphery (Bligh, 1973). However, brain temperature may be either higher or below other core temperature, such as that of the rectum. The temperature of the blood in the cerebral arterial circle in the monkey is the same as that in the carotid artery and variations in brain temperature are reflections of changes in the temperature of the arterial blood leaving the heart (Hayward et al., 1966; Hayward and Baker, 1968). The possibility of a large and variable heat flow dissipation from the brain to the external environment was considered possible by Hunter and Adams (1966), who suggested that local alterations in ventral brain temperature of the cat was due to direct transfer of heat from the diencephalon to the cooled surface of the upper respiratory tract. The arterial blood is cooled before it enters the brain and most of the heat generated in the brain is removed by the circulating blood. There is good evidence that in some species the arterial blood is cooled by losing heat to the cooled venous blood returning from the peripheral tissue.

In the cat (Baker and Hayward, 1967) and in sheep (Baker and Hayward, 1968a,c), it was demonstrated that an exchange of heat takes place between the arterial blood in the carotid rete and the venous blood which bathes it in the cavernous sinus. In sheep, the venous blood returning from the nasal mucosa and the skin of the head to the cavernous sinus cools the central arterial blood in the carotid rete. This is an important factor in the maintenance of hypothalamic temperature in the wool covered, long-nosed panting sheep. Baker and Hayward (1968d) also showed that when the sheep was panting at an ambient temperature of 45°C to 50°C, the drop in the temperature of the arterial blood was greatly increased, as it passed through the carotid rete from the external carotid artery to the cerebral arterial circle. Magilton and Swift (1968) described the second physiologic heat exchange system and called it the "internal heat exchanger" between the warm blood in the internal carotid artery and the cooled venous blood in the cavernous sinus. The cooled inspired air passed over the nasal mucosa, especially at the nasal vestibule, where the external heat exchange mechanism operates, and results in cooling of the venous blood that leaves the nasal cavity via the dorsal and lateral nasal veins either to the angularis oculi or to the facial veins.

Cyclic breathing at a certain time interval in man was reported by Stoksted (1952) and Principato and Ozenberger (1970). Moller and Fahrenkrug (1971) showed that the distension of the swell bodies in rats and rabbits exhibits a cyclic alternation between the two halves of the nasal cavity. They stated that total conductivity is independent of the cyclic changes in respiration of the animals. The cyclic alternation in nasal mucosa of sheep was reported by Ritter (1970) and stated that it ceases if the nose is blocked by hypertrophied adenoids after tracheostomy. Moller and Fahrenkrug (1971) in the rat and rabbit and Schnorr and Hegner (1967) in sheep described cyclic alternation of airflow through both nostrils due to the engorgement of the venous plexus in the nasal conchae and the septum.

To substantiate the hypothesis that the nasal mucous membrane plays a role in brain temperature regulation, Cole (1954) showed that the upper respiratory mucosa has a thermoregulatory function in man, which is similar to the skin and is much more effective in animals with complicated conchae. Ingram and Whittow (1962) reported that the increase in respiratory frequency or increase in the skin temperature of the ear of the ox, by using infrared irradiation under certain condition, resulted indetectable cooling of blood in the external jugular vein. Young et al. (1976) stated that mechanical blockage of the nostrils caused an increase in hypothalamic temperature and unblocking the nostrils caused a decrease in hypothalamic temperature of sheep. Moreover, vasodilatation of the nasal mucosa of rabbits paralleled a fall in brain temperature, and conversely its vasoconstriction paralleled an increase in brain temperature (Caputa et al., 1976a,b). Panting, in general, accelerates airflow through the nasal passages, and thereby enhances the rate of heat exchange from the circulating blood to the inspired air on the surface of the nasal mucosa. All ruminants pant on heat exposure with their mouths closed (Robertshaw, 1976).

The air conditioning capability of the nasal mucosa and its effect on brain temperature were described by several investigators. Carithers and Seagrave (1976) irrigated the nasal alar fold of dogs having body core temperature elevated to 42°C, a difference of 0.5-1.5°C between brain temperature and body core temperature was maintained for up to 1.5 hours. By blowing air in the nasal mucosa of the sheep, Baker (1979) demonstrated that there was a reduction of temperature of blood in the cavernous sinus. Magilton et al. (1981b) irrigated the nasal mucosa of the dog with hot and cold water; there was an increase in blood pressure and vasodilatation during hot water irrigation, and a reversal during cold water irrigation. Baker (1972) and Baker and Hayward (1968b) demonstrated that lowering the temperature of the nasal mucosa in cat and sheep was accompanied by an increase in cerebral activity. This shows the importance of the upper respiratory passage in the regulation of cerebral arterial blood and hypothalamic temperature in sheep. The function of the rete as a cranial heat exchanger might shed some light upon its significance as it is present in heavily furred animals which pant in order to lose heat at high ambient temperature. Furthermore, an increase in blood flow to the respiratory mucosa increases expiratory and inspiratory air temperature; inspiratory air warming is increased and expiratory air carries away more heat and water from the body. Normally the inspired air does not pass into the olfactory mucosa of the dog, cat and rat unless high pressure is applied (Dawes, 1952). The evaporation of water from the large nasal mucosal surface (conchae) lowers the temperature of venous blood, and thus plays a significant role in preventing hyperthermia of brain.

Some researchers hypothesized that the oral cavity might be a site for heat exchange in animals which pant with their mouths open, but Kluger and D'Alecy (1975) stated that the nasal passages offer a greater area for cooling venous blood than the oral area due to its complexity, vascularity and available moisture. Blood flow, against gravity, in the angularis oculi vein is facilitated by the absence of valves and the presence of a thick tunica media in its wall as described by Magilton and Swift (1969) in the dog. Khamas and Ghoshal (1982a) found the same in sheep as did Caputa et al. (1986) in the goat. The lung is excluded as a possible site for heat loss from the arterial blood (Bligh, 1957). Bligh (1959) stated that in sheep the onset of panting can occur in the absence of any rise in the temperature of the blood supplying the brain.

In cats subjected to hot environment, panting increased and cooling of cerebral arterial blood increased (Baker, 1972). The nasopharyngeal temperature was reported to rise in man more than that of the ambient temperature (Negus, 1958). This showed that the nasal mucosa is responsible for the changes in air temperature in the nasopharynx. In the cat, Hunter and Adams (1966) determined that the respired air, bypassed the normal upper respiratory pathways underlying the ventral brain, caused the hypothalamic temperature to rise approaching the rectal temperature. Reinstituting normal respiratory flow lowers diencephalic temperature. Jessen and Pongratz (1979) stated that during cold stress (hypothermia) the hypothalamic temperature in the goat was uncoupled from the temperature of the upper respiratory surfaces and presented an undistorted body core temperature due to shunting of blood away from the cavernous sinus to the external jugular vein via the facial vein, reversing the usual flow pattern during normothermia and hyperthermia. The cerebral arterial blood in species with carotid rete (e.g., sheep, ox, dog, cat, chicken, and rhea) has been shown to be, on an average, 1.0-1.5°C cooler than the blood at the aortic arch during heat stress, while in the non-carotid rete species (e.g., rat, rabbit, monkey, and man), the temperature differential between the cerebral arterial blood and the core was not as great during hyperthermia.

New techniques in tracheostomy are recently being used in many experiments on the brain temperature regulation. Kluger and D'Alecy (1975) had rabbits with tracheal bypass canula which enabled the animals to breathe normally with bypass closed. They found that hypothalamic temperature was influenced by the venous blood cooled by the upper respiratory tract, and that the subsequent transfer of heat to the cooler venous blood in the cavernous sinus could effectively cool the brain. Baker (1979) found in the dog with a tracheostomy, breathing through the tracheal opening, induces an immediate rise of temperature in the hypothalamus. Krabill and Ghoshal (1982, 1983) used the upper respiratory bypass canula in the sheep. The brain temperatures measured at the sites near the cerebral arterial circle were significantly higher when the animals were breathing through the canula; when sheep were placed on normal nasal breathing, they were able to maintain a relatively lower brain temperature. In the sheep, where the thermistor (temperature sensor) was nearest to the desired site in the brain, the brain temperature difference between tracheal breathing and normal nasal breathing registered a peak of $1^{o}C$ in these animals. The average difference in brain temperature in all trials between normal nasal breathing and tracheal bypass breathing, was $0.37^{o}C$. A bead thermistor was placed in the right nasal vestibule of sheep, the ambient temperature was kept consistently at $18^{o}C$ in order that any change in nostril temperature could not be attributed to any fluctuations of the environmental temperature. The nostril temperature increased ($6^{o}C$) when the animal was placed in tracheal (bypass) breathing and it decreased when the sheep was changed to normal nasal breathing (Krabill and Ghoshal, 1982). The use of the upper respiratory bypass canula has proved to be an effective way to interrupt normal nasal breathing in the sheep. Krabill and Ghoshal (1983) reported changes in the hypothalamic temperature and in the cerebrospinal fluid pressure during tracheal bypass breathing. An increase in intracranial cerebrospinal fluid pressure is transmitted through the optic canal to the subarachnoid space around the optic nerve in sheep. Ohale and Ghoshal (1982a) described that ophthalmic plexus of sheep receives the same cooled venous blood draining from the nasal mucosa, and the anatomic arrangement of the ophthalmic plexus and ophthalmic rete conforms with those of countercurrent heat exchanger. Ohale and Ghoshal (1982b,d) implanted the canula in the upper respiratory tract and showed a decrease in intraocular pressure recording during bypassed breathing. The outer diameter of the superotemporal retinal vein increased significantly in size during nasal bypass breathing. An electroretinogram recorded an increased amplitude and decreased duration of the b-wave during bypassed breathing. When the ewes were allowed to breathe simultaneously through the tracheal opening and nostrils, the b-wave amplitude was decreased, compared with the amplitude during normal nasal breathing alone. The functional elimination of the upper respiratory cooling of venous blood could definitely disrupt the efficiency of heat exchange between the ophthalmic plexus and ophthalmic rete and between cavernous sinus and carotid rete. Normally, warm blood reaches the eye via the external ophthalmic and the cool blood comes via the internal ophthalmic arteries. Ohale and Ghoshal (1982c) analyzed the arterial blood gas chemistry during both breathing phases in sheep to eliminate the possible effect of blood gases and some other factors causing cerebral vasodilatation and increased blood flow through the brain. There were no significant differences in the partial pressures (PCO_2 and PO_2) during normal nasal breathing and tracheal bypassed breathing periods. Bypassed breathing did not apparently alter the anatomical dead airspace to such an extent as to affect either the depth or rate of respiration. The most signficant findings have been described by Magilton et al. (1981b) when they irrigated the nasal mucosa of the dog with hot and cold water. There were an increase in both blood pressure (BP) and cerebrospinal fluid pressure (CSFP) during hot water irrigation and a decrease in both parameters during cold water irrigation. This suggested that mechanisms exist in the brain, which are sensitive to temperatures and are capable of controlling BP and diameter of the cerebral vessels, thus regulating cerebral blood flow.

The heat loss depends not only upon the rate and pattern of airflow over the nasal passages but also upon the rate of blood flow through its mucosal surface. In warm environment, panting increases the evaporation in the nasal cavity. In a cool environment when the respiratory rate is relatively constant, vasoconstriction of the mucosal vessels decreases the nasal heat loss and vasodilatation increases it. When the nasal mucosa is constricted, the amount of cooled venous blood bathing the rete decreases, and cerebral arterial blood temperature rises toward central arterial temperature. When the nasal mucosa is dilated, the amount of cooled venous blood bathing the rete increases, and blood in the rete is cooled below central arterial temperature (Baker, 1972).

The existence of the countercurrent heat exchange between the arterial and venous blood has been described in the animals cited previously. Countercurrent heat exchange lowers the hypothalamic temperature in animals such as the goat (Taylor, 1966; Caputa et al., 1986); large African ungulates (Taylor and Lyman, 1972); dogs (Magilton and Swift, 1968); sheep (Hayward and Baker, 1968; Krabill and Ghoshal, 1982), and other species such as man (Cabanac and Caputa, 1979); rabbits (Kluger and D'Alecy, 1975), and ponies (Magilton et al., 1981a). The heat loss from superficial vessels of the nasal mucosa and parts of the buccal region to the ambient air allows cooling of venous blood toward the cavernous sinus via the angularis oculi vein. This drop of blood temperature was accompanied by an increase of brain temperature during mental activities in man (Magilton et al., 1984).

MATERIALS AND METHODS

A total of thirty camel (Camelus dromedarius) heads were used in this investigation: age, body weight and sex of camels were not considered. These heads were obtained from a local slaughter-house: eighteen heads were injected with various intravascular plastic materials, five were injected with Hypaque sodium 50% (diatrizoate sodium injection) for arteriography and venography, six heads were used for light microscopy, and one was used for scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

Heads injected with latex were dissected routinely and kept in the freezer below 20°C or in 4% formalin solution to prevent decomposition for later studies.

Heads injected with Batson's # 17 and latex, after their dissection, were macerated with 33% potassium hydroxide (KOH) for two to three weeks or with hydrochloric acid (HCL) for one week. The heads were taken out of both solutions every day and washed under running tap water for two to four hours and then put back into the corrosive solution. At the end of 1.2 or 3 weeks, the casts were washed with warm running water to remove the remaining fat and tissue debris.

The total length and diameter of all afferent latex cast vessels contributing to both carotid and ophthalmic retia were determined by a measuring scale after cutting them into small pieces.

The tissues used for light microscopic study were obtained from different regions of the nasal cavity: 1) alar fold (dorsal part of the ventral nasal concha and septal alar fold); 2) second upper premolar (lateral and septal wall); 3) last upper molar (lateral and septal wall), from the carotid rete-cavernous sinus complex, and from the facial, angularis oculi, and dorsal nasal veins. The tissues were immersed in 10% buffered neutral formalin (BNF) or Bouin's solution for 24 hours prior to employing standard histological procedures.

From a total of six specimens for light microscopic study, samples obtained from two heads were transferred to Calex solution (Fisher, 1986) for decalcification for 3 days. After complete decalcification, the tissues were placed in formalin solution for 24 hours to remove the residues of Bouin's or Calex solution and to prevent precipitation in alcohol. Tissues were processed for paraffin embedding by following standard histological techniques; sections were cut at 5-8 μm thickness, and stained with the following stains:

1) Harris' hematoxylin eosin
2) Masson's trichrome (Luna, 1968)
3) Van Gieson's (Luna, 1968)
4) Weigert's resorcin fuchsin (Luna, 1968)

In addition, one head was flushed with normal saline solution, followed by perfusion of 5% glutaraldehyde in phosphate buffer (ph: 7.2) via both common carotid arteries. The carotid retia were carefully dissected and placed in 5% glutaraldehyde. The samples were taken from the nasal mucosa as well as from the angularis oculi vein and the carotid rete-cavernous sinus complex for both light microscopic and SEM studies. Other samples were taken from the carotid rete-cavernous sinus complex for TEM study.

(Detailed material injected for gross anatomical investigation and staining techniques are given in the appendix).

RESULTS

Gross Anatomy

General blood supply of the head

The nomenclature used conforms to that used in the third edition of the Nomina Anatomica Veterinaria (N.A.V.). Latin terms were translated to accepted English equivalents.

Arteries The arterial blood supply of the head was derived from the common carotid artery (Figs. 1,2,4/1) which trifurcates, ventral to the wing of the atlas in the retromandibular region, into the internal carotid, the occipital and the external carotid arteries.

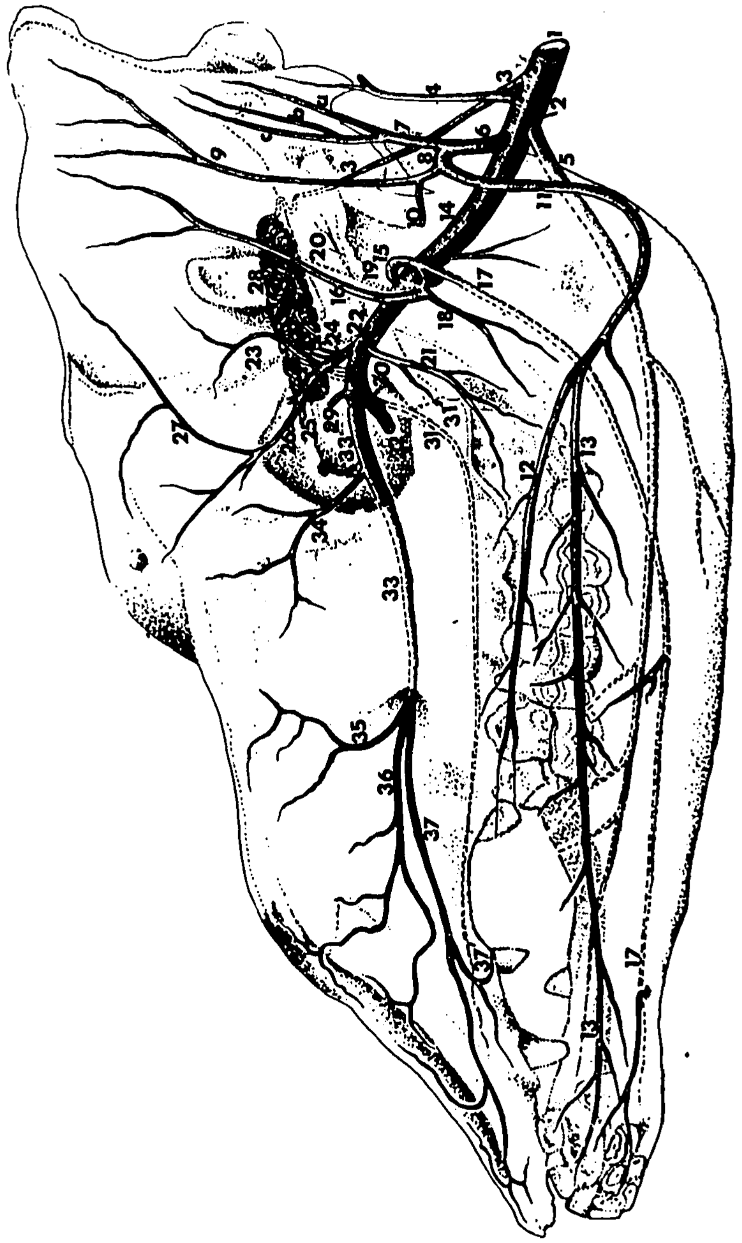
The internal carotid artery (A. carotis interna) (Figs. 1,2,4,28,29/3) This artery had a dilatation (the carotid sinus) at its origin lying deep to the lateral retropharyngeal lymph node and the mandibular gland. It ran craniodorsally toward the skull coursing medial to the occipital artery. This vessel continued its course lateral to the cranial cervical ganglion paralleling the cervical sympathetic trunk. Shortly after its origin, the internal carotid artery was related medially to the hypoglossal nerve and entered the cranial cavity via the carotid canal. It had a double curvature (S-shaped) inside the ventral petrosal and cavernous sinuses, and contributed to the formation of the carotid rete (rostral epidural rete mirabile).

The occipital artery (A. occipitalis) (Fig. 1/4) The occipital artery also presented a dilatation (so-called occipital sinus) at its origin. The occipital artery was situated deep to the mandibular

Plate 1

Figure 1. Arteries of the head of the camel (schematic drawing)

1. Common carotid artery
2. External carotid artery
3. Internal carotid artery
4. Occipital artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
    a: lateral auricular branch
    b: medial auricular branch
    c: stylomastoid artery
8. Superficial temporal artery
9. Rostral auricular artery
10. Transverse facial artery
11. Facial artery
12. Superior branch of the facial artery (glandular artery)
13. Inferior labial artery
14. Maxillary artery
15. Common trunk of the inferior alveolar, caudal deep temporal and pterygoid arteries
16. Caudal deep temporal artery
17. Inferior alveolar artery
18. Pterygoid artery
19. Middle meningeal artery
20. Rostral tympanic artery
21. Buccal artery
22. External ophthalmic artery
23. Rostral deep temporal artery
24. Rostral rete branches
25. Lacrimal artery
26. External ethmoid artery
27. Frontal artery
28. Rostral epidural rete mirabile ("carotid rete")
28'. Ophthalmic rete
29. Second branch of the external ethmoid artery
30. Descending palatine artery
31. Major palatine artery
32. Sphenopalatine artery
33. Infraorbital artery
34. Malar artery
35. Caudal lateral nasal artery
36. Rostral lateral nasal artery
37. Superior labial artery
37'. Angularis oris artery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gland at the level of the wing of the atlas. It ran dorsally toward the occipital region, lateral to the internal carotid artery and the vagus nerve, coursing lateral to the rectus capitis ventralis and rectus capitis lateralis muscles. Finally, this vessel entered the lateral vertebral foramen of the first cervical vertebra to anastomose with the vertebral artery inside the vertebral canal. During its course, this artery gave off the following branches: 1) a branch to the lateral retropharyngeal lymph node; 2) branches to the mandibular gland; 3) muscular branches to the obliquus capitis cranialis and caudalis; and 4) the condylar artery that divided into two branches; one of these entered the cranial cavity via the hypoglossal canal and the other via the jugular foramen. The condylar artery gave rise to an anastomotic branch to the vertebral artery and then ramified within the meninges as the meningeal branch.

The external carotid artery (A. carotis externa) (Figs. 1,2, 3,4,5/2) This vessel was larger than the other two terminal branches and assumed the direct continuation of the common carotid artery. The external carotid coursed cranially along the lateral aspect of the pharyngeal wall and medial to the hypoglossal nerve. It passed between the stylohyoid bone and the stylohyoideus muscle, and terminated as the maxillary artery after giving off the superficial temporal.

The collateral branches of the external carotid were:

1) The lingual artery (Figs. 1,2,3,4,5/5) arose from the ventral aspect of the external carotid, and was situated caudal to the stylohyoid bone cranial to the hypoglossal nerve, and medial to the

stylohyoideus muscle. This artery coursed rostroventrally, lateral to the hyopharyngeus muscle, and gave off several perihyoid branches to the stylohyoid bone, and stylohyoideus and hyopharyngeus muscles. After releasing these branches, the lingual artery became separated from hypoglossal nerve, and pierced the hyoglossus muscle. From its medial aspect arose the dorsal lingual branches, which passed between the hyoglossus and genioglossus muscles, to supply the root of the tongue. Thereafter, the lingual artery left the hyoglossus muscle to run between the geniohyoideus and the styloglossus muscles and continued its course along the ventral aspect of the styloglossus muscle. It supplied the mandibular gland and the mucosa of the tongue, and continued further as the deep lingual artery that formed an arterial circle with its fellow of the opposite side. The submental artery originated from the parent vessel, joined its fellow of the opposite side, and pierced the mylohyoideus muscle to ramify in the intermandibular space. The dorsal lingual branches (5 to 8) were well developed and flexuous at the root of the tongue. From the lingual artery arose the ascending pharyngeal and laryngeal branches.

2) The caudal auricular artery (Figs. 1,2,3,4/7) took its origin from the external carotid deep to the parotid gland and to the stylohyoideus muscle. In 50% of cases, it formed a common trunk with the facial (Fig. 1/6) and/or the superficial temporal artery (Fig. 1/8). This artery continued its course between the mastoid process and the stylohyoid, passed lateral to the jugular process of the occipital bone, and ramified deep to the obliquus capitis cranialis muscle. At this

level, the stylomastoid artery came off of the parent trunk, entered the stylomastoid foramen and reached the middle ear via the facial canal. Thereafter, the caudal auricular artery ran deep to the caudal auricular muscles and anular cartilage. It gave off the following branches: (1) branches to the parotid gland; (2) the lateral auricular branch; (3) the intermediate auricular branch; and (4) the medial auricular branch. The auricular branches anastomosed freely with each other. The deep auricular artery was absent. The caudal auricular terminated by giving off the caudal meningeal artery that coursed lateral to the jugular process toward the occipital region, where it entered a foramen of the occipital bone to supply the meninges.

3) The facial artery (Figs. 1,2,3,4,5/11) arose from the external carotid, formed a common trunk with the caudal auricular and/ or superficial temporal artery in 50% of cases, as mentioned above. The initial course of this artery lay deep to the parotid gland, and passed between the stylohyoideus muscle and the ramus of the mandible; at first it ran caudodorsally, then rostroventrally to appear on the lateral surface of the masseter muscle. It was satellite of the ventral buccal branch of the facial nerve, and was located dorsal to the facial vein and ventral to the parotid duct. This vessel continued further between the masseter muscle and the ventral buccal gland, where it divided into the inferior labial artery and glandular artery. It vascularized the parotid gland and the masseter muscle. (1) The inferior labial artery (Figs. 1,3/3) accompanied the ventral buccal branch of the facial nerve and the inferior labial vein. It coursed along the superior border of

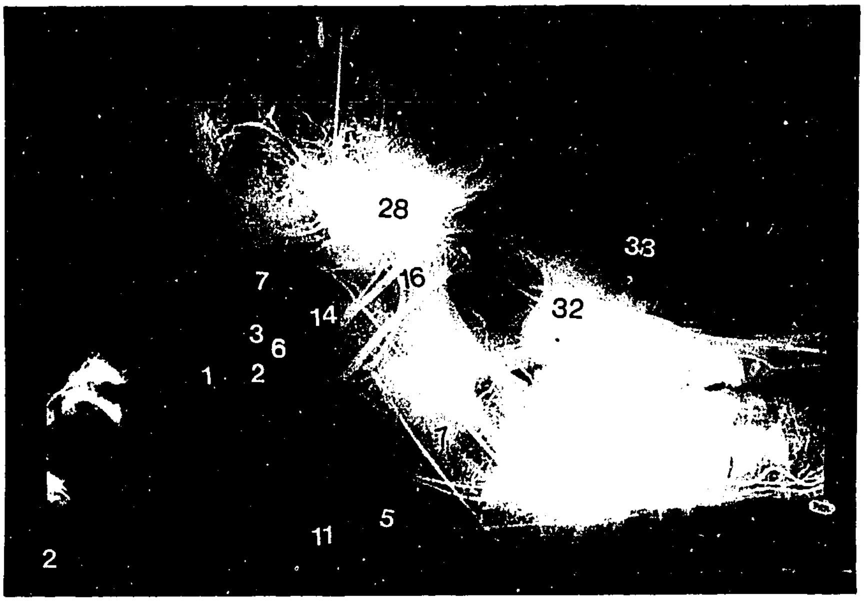
Plate 2

Figure 2. Arteriograph of the head of the camel (lateral view)

1. Common carotid artery
2. External carotid artery
3. Internal carotid artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
11. Facial artery
14. Maxillary artery
16. Caudal deep temporal artery
17. Inferior alveolar artery
28. Rostral epidural rete mirabile ("carotid rete")
32. Sphenopalatine artery
33. Infraorbital artery

Figure 3. Arterial supply to the head of the camel (lateral view) Batson's # 17 cast

1. Common carotid artery
5. Lingual artery
7. Caudal auricular artery
   a: Lateral auricular branch
   b. medial auricular branch
   c. stymastoid artery
10. Transverse facial artery
11. Facial artery
12. Superior branch of the facial artery (Glandular artery)
13. Inferior labial artery
14. Maxillary artery
16. Caudal deep temporal artery
17. Inferior alveolar artery
33. Infraorbital artery
42. Septal nasal branches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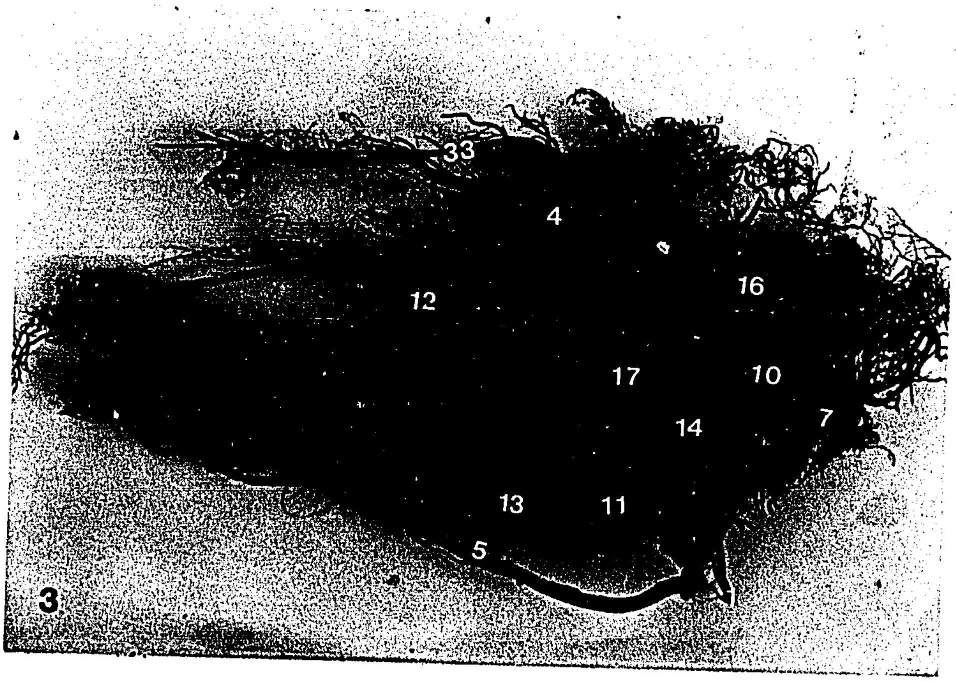
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the ventral buccal gland and after releasing glandular branches terminated within the lower lip; (2) the glandular artery (Figs. 1,3/12) of the facial ran with the buccal vein, coursed within the buccinator deep to the zygomaticus muscle and the dorsal buccal gland. This vessel anastomosed with the buccal artery.

4) The superficial temporal artery (Fig. 1/8) was the last branch of the external carotid. In 50% of cases it formed a common trunk with the caudal auricular and/or facial arteries, or with the inferior alveolar, caudal deep temporal and the pterygoid arteries. It left the pterygoideus medialis muscle through the angular notch of the mandible and coursed deep to the proximal part of the masseter muscle when it arose with the caudal auricular artery. This vessel appeared on the lateral aspect of the masseter where it accompanied the dorsal buccal branch of the facial nerve. In 5 cases the superficial temporal artery, when it arose by a common trunk with the caudal deep temporal, traversed the mandibular notch to appear on the lateral aspect of the skull. It detached articular branches to the temporomandibular joint, and divided into the transverse facial and the rostral auricular arteries. (1) The transverse facial artery, smaller of the two, ran rostrally along the ventral border of the zygomatic arch, and supplied branches to the parotid gland and the masseter muscle; (2) the rostral auricular artery, originated from the superficial temporal artery, caudal to the mandibular condyle, and coursed toward the ear. It gave off branches to the parotid gland and to rostral auricular muscles, and terminated in the temporal region.

The maxillary artery (Figs. 1,2,3,4,5/14) This vessel was the continuation of the external carotid artery following the origin of the superficial temporal. It began at the lateral aspect of the stylohyoid bone and medial to the digastricus muscle, and continued its rostral course between the pterygoideus medialis muscle and the pharyngeal wall. This artery crossed medially the mandibular nerve, and extended further inside the pterygopalatine fossa with the maxillary nerve. At the rostral part of this fossa, it terminated as the infraorbital and descending palatine arteries. The collateral branches of the maxillary artery were: 1) the caudal deep temporal artery; 2) the inferior alveolar artery; 3) the pterygoid artery; 4) the buccal artery; 5) the external ophthalmic artery; 6) rete branches; 7) the descending palatine artery; and 8) the infraorbital artery.

1) The caudal deep temporal artery (Figs. 1,2,3,4/16) usually formed a common trunk with inferior alveolar. It was well developed, ran superficial to the pterygoideus lateralis muscle and medial to the zygomatic arch, to reach the temporalis muscle. It supplied almost the entire temporalis, pterygoideus medialis and lateralis muscles, and the temporomandibular joint. The masseteric artery left the caudal deep temporal and followed the masseteric nerve to supply the homonymous muscle.

2) The inferior alveolar artery (Figs. 1,2,3,5/17) took its origin caudal to the pterygoid artery, usually formed a common trunk with the caudal deep temporal artery, and passed between the pterygoideus muscles and the ramus of the mandible. It gave off

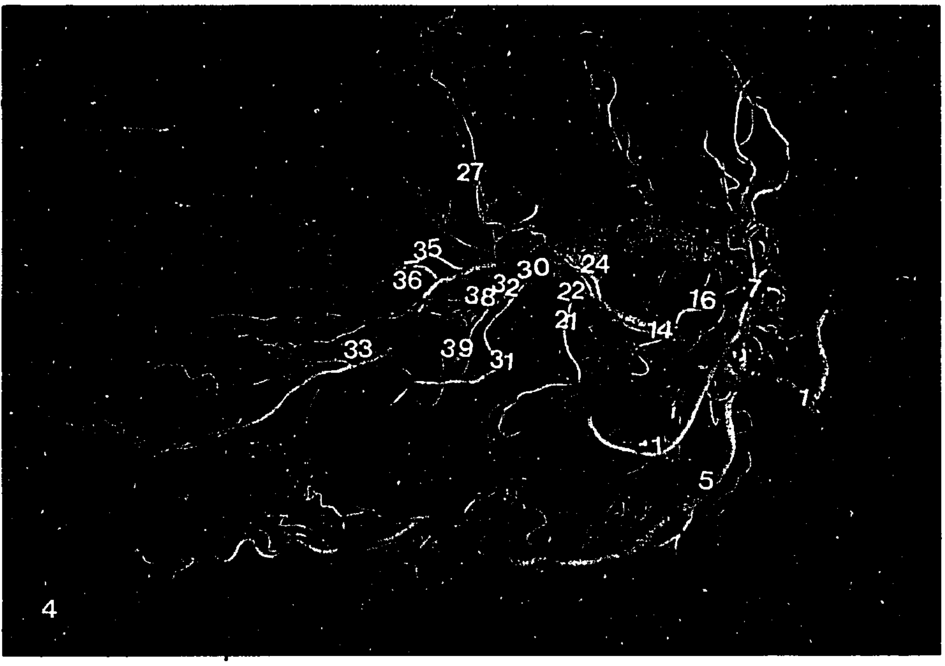
Plate 3

Figure 4. Latex' cast of the carotid rete and the maxillary artery (left lateral view)

1. Common carotid artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
    a: lateral auricular branch
    b: medial auricular branch
    c: stylomastoid artery
11. Facial artery
14. Maxillary artery
16. Caudal deep temporal artery
21. Buccal artery
22. External ophthalmic artery
24. Rostral rete branches
27. Frontal artery
28. Rostral epidural rete mirabile ("carotid rete") A and B terminal branches of the internal carotid artery
28'. Ophthalmic rete
30. Descending palatine artery
31. Major palatine artery
32. Sphenopalatine artery
33. Infraorbital artery
35. Caudal lateral nasal artery
36. Rostral lateral nasal artery
38. Dorsal nasal artery
39. Ventral nasal artery

Figure 5. Arteriograph of the head of the camel (lateral view)

2. External carotid artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
11. Facial artery
14. Maxillary artery
17. Inferior alveolar artery
21. Buccal artery
23. Rostral deep temporal artery
32. Sphenopalatine artery
33. Infraorbital artery
37. Superior labial artery
40. Lateral branches of the ventral nasal artery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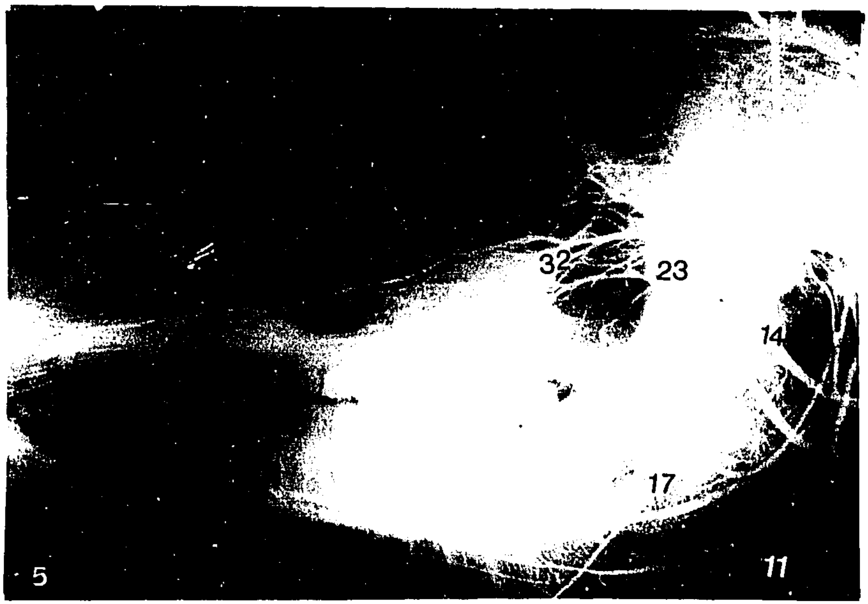
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branches to pterygoideus medialis muscle and entered the mandibular canal after giving off a common trunk to the middle meningeal artery (Fig. 1/19) and the rostral tympanic artery (Fig. 1/20). The middle meningeal, after coursing lateral to the tympanic bulla, entered the cranial cavity via the oval foramen paralleling the mandibular nerve, and supplied the meninges. The rostral tympanic artery lay close to the chorda tympani and entered the middle ear via the petrotympanic fissure. Within the mandibular canal the inferior alveolar artery gave off dental branches, and terminated by two branches; one of them left the mandibular canal via the mental foramen and continued as the mental artery. In one case, there was an arteriovenous anastomosis between the mental artery and the inferior labial vein. The other terminal branch of the inferior alveolar traversed the alveolar (mandibuloincisive) canal to supply the lower incisor and canine teeth.

3) The pterygoid artery (Fig. 1/18) sometimes formed a common trunk with the caudal deep temporal and the inferior alveolar arteries. It supplied the pterygoideus medialis and lateralis muscles.

4) The buccal artery (Figs. 1,3,4/21) departed from the ventral aspect of the maxillary, or arose in common with the external ophthalmic artery. This vessel coursed rostroventrally lateral to the maxillary tuberosity, accompanied the buccal nerve, and supplied the buccinator muscle, as well as the dorsal buccal gland.

5) The external ophthalmic artery (Figs. 1,4,25′/22) arose from the maxillary artery inside the pterygopalatine fossa, and sometimes together with the buccal artery near the orbitorotundum

foramen. This artery coursed dorsorostrally along the medial aspect of the orbit and gave off the rostral rete branches that entered the cranial cavity via the orbitorotundum foramen. Several branches of the external ophthalmic broke into the ophthalmic rete that seemed to be a rostral extention of the carotid rete.

From the ophthalmic rete arose the following: (a) The frontal artery (Fig. 1/27) ran dorsal to the rectus dorsalis muscle of the eye, and pierced the periorbita to enter the frontal sinus. (b) The lacrimal artery (Fig. 1/25) arose from the parent vessel, coursed obliquely rostrodorsally on the lateral side of the orbit, and deep to the periorbita. It released 2 to 3 branches to the lacrimal gland and then pierced the periorbita to leave the orbit. This artery passed caudal to the zygomatic process of the frontal bone where the lateral superior and lateral inferior palpebral arteries took their origin. After releasing these branches, the lacrimal artery continued further in the frontal region and gave off several subcutaneous temporal branches supplying the temporalis muscle and the skin. This vessel anastomosed with other branches of the rostral auricular and transverse facial arteries. (c) An anastomotic branch came from the external ophthalmic to anastomose with the internal ophthalmic artery. This branch traversed the optic canal to enter the cranial cavity. (d) The rostral deep temporal artery (Fig. 1/23) may be absent, but when present it was small and supplied the most rostral part of the temporalis muscle. (e) Branches to the bulbar muscles. (f)The anterior ciliary arteries. (g) The central artery of the retina followed the optic nerve. (h) The posterior ciliary arteries, and (i) one root of the external ethmoid artery.

6) Rete branches (Figs. 1,4,25,26,27,28/24) will be described with the rostral epidural rete mirabile ("carotid rete").

7) The descending palatine artery (Figs. 1,4/30) was one of the terminal branches of the maxillary, and branched into the major palatine, the minor palatine, and the sphenopalatine arteries. (a) The major palatine artery (Figs. 1,4/31) took its origin from the parent vessel and entered the palatine canal through the caudal palatine foramen. It released several small branches to the maxilla while coursing inside the canal. Opposite to the upper second premolar tooth, this vessel emerged at the major palatine foramen, to reach the ventral surface of the palatine process of the maxilla and the palatine bone. The artery continued rostrally within the erectile tissue of the hard palate. The palatolabial artery (Fig. 21/37') appeared to be an anastomotic branch between the major palatine and the superior terminal branch of the superior labial artery. (b) The minor palatine artery (Fig. 1/31') arose together with the major palatine just caudal to the last upper molar tooth. At first it curved rostrally and then, at the transition of the soft palate and hard palate, caudally to terminate along the free edge of the soft palate. In its tortuous course through the soft palate, the minor palatine artery gave off branches to pterygoideus medialis and palatinus muscles, including the palatine glands. The sphenopalatine artery will be described with the nasal cavity.

8) The infraorbital artery (Figs. 1,2,3,4,5/33) was the other

terminal branch of the maxillary, well developed, and entered the maxillary foramen to traverse the infraorbital canal. Within this canal, the infraorbital artery released small dental branches supplying the upper cheek teeth and the maxilla. At the infraorbital foramen, this vessel emerged and continued as superior labial artery (Figs. 1,5,7/37). This artery coursed rostrally in company with the infraorbital nerve and vein, along the deep aspect of the levator nasolabialis and levator labii superioris muscles. It was crossed laterally by the dorsal buccal branch of the facial nerve during its rostral course. The collateral branches of the infraorbital artery were: (a) The malar artery (Fig. 1/34) left the dorsal surface of the parent trunk shortly before it reached the maxillary foramen. It sent a nutrient branch into the lacrimal bone, a branch to the nasolacrimal duct, and a branch to the bony lacrimal canal. The main trunk of the malar artery continued to the lower eyelid where it terminated into the medial superior and medial inferior palpebral arteries. The dorsal nasal artery may arise from the malar artery. (b) The rostral and caudal lateral nasal arteries (Figs. 1,4/35,36) will be described with the nasal cavity. (c) Muscular branches arose from the infraorbital artery at the infraorbital foramen for the malaris, the levator nasolabialis, and the levator labii superioris. (d) The angularis oris artery (Fig. 1/37') arose opposite to the rostral lateral nasal artery, and ran ventrorostrally toward the angle of the mouth. It supplied the lateral part of the orbicularis oris muscle. (e) The superior labial artery (Figs. 1,5/37) coursed deep to levator nasolabialis and levator labii superioris muscles, and was satellite of the superior labial vein. It divided into two branches: the inferior one followed the inferior margin of the orbicularis oris muscle until the philtrum; it ramified within the muscle and anastomosed with its fellow of the opposite side. The superior branch ascended toward the inferior border of the nostril and formed a circle around the external nares. Here, it anastomosed with the major palatine via the palatolabial artery and the rostral lateral nasal artery. The superior labial ramified within the orbicularis oris muscle, as well as along the inferior border of the nostril. At the midline of the nostril, after ascending it divided into branches which coursed along the superior border of the external nares.

Veins

The venous blood of the head was drained by the linguofacial and the maxillary.

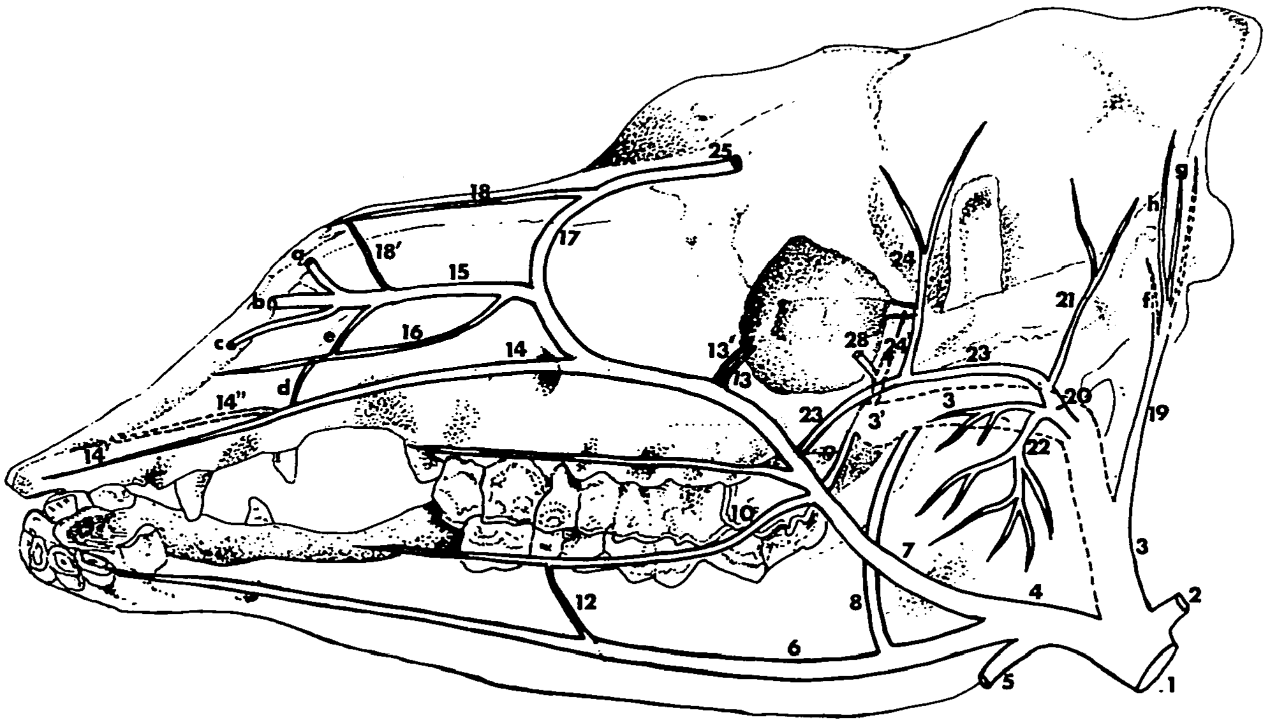
The linguofacial vein (V.linguofacialis) (Figs. 6,7,8,9,12/4) This vein arose from the external jugular at the ventral extremity of the parotid gland. It coursed rostrally toward the mandibular lymph node, released the lingual vein and continued as the facial vein. Sometimes both the lingual and facial veins arose separately from the external jugular, and in that case a linguofacial vein was absent.

The lingual vein (Figs. 6,7,8,9,12/5) took its origin from the linguofacial caudal to the mandibular lymph node and sometimes arose directly from the external jugular vein. This vein coursed rostroventrally along the ventral aspect of the mandibular lymph node

Plate 4

Figure 6. Lateral view of the major superficial veins of the head of the camel (schematic drawing)

1. External jugular vein
2. Occipital vein
3. Maxillary vein
3'. Sinus of the buccal vein
4. Linguofacial vein
5. Lingual vein
6. Inferior labial vein
7. Facial vein
8. Buccal vein
9. Deep facial vein
10. Inferior glandular branch
11. Superior glandular branch
12. Anastomotic branch between 6 and 10
13. Medial inferior palpebral vein
13'. Medial superior palpebral vein
14. Superior labial vein
14'. Superficial branch
14". Deep branch
15. Dorsal nasal vein
    a: dorsal branch
    b: septal branch
    c: ventral branch
16. Lateral nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
18'. Anastomotic branch between 5 and 18
19. Caudal auricular vein
20. Superficial temporal vein
21. Rostral auricular vein
22. Masseteric vein
23. Transverse facial vein
24. Temporal branch
24'. Lateral superior and inferior palpebral veins
28. Ventral external ophthalmic vein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and the inferior border of the hyoglossus muscle. It drained the deep lingual, a venous radicle from the root of the tongue, and ascending pharyngeal and submental veins. The sublingual vein anastomosed with its fellow of the opposite side to form the superficial hyoid arch.

The facial vein (Figs. 6,7,8,9,11,12/7) continued the parent vessel, toward the mandibular lymph node, and crossed obliquely the lateral aspect of the face. The facial vein coursed at first along the ventral border of the masseter muscle, and at the rostral end of the mandibular lymph node, it changed its direction from rostral to dorsal to continue along the lateral aspect of the buccinator and medial to the zygomaticus and malaris muscles. In this region, the facial vein lay between the rostral border of the masseter muscle and the caudal end of the ventral buccal gland, and was satellite of the facial artery. After parting from the facial artery it ran parallel to the inferior margin of the orbit and dorsal to the infraorbital foramen, the facial vein passed dorsocaudally. Along the caudolateral aspect of the nasal cavity, the facial bifurcated into the dorsal nasal and angularis oculi veins. The facial vein received several branches from the parotid gland, and the masseter, buccinator, zygomaticus and malaris muscles. The diameter of the facial vein differed at various sites; for instance, the diameter was 5 mm caudal to the infraorbital foramen and 6 mm rostral to this foramen. This vein was crossed laterally by the dorsal and ventral buccal branches of the facial nerve, and medially by the terminal portion of the parotid duct. The valves of the facial were located close to the external jugular vein on the lateral spect of the masseter and buccinator muscles, but the rest of this vein coursing on the lateral aspect of the maxilla was devoid of valves. There were about seven valves present in the facial vein: one caudal to the buccal vein, and the other six were situated in the stretch between the origin of the deep facial and the external jugular vein. The collateral branches of the facial vein were: 1) the inferior labial vein; 2) the inferior and superior branches to buccal glands and buccinator muscle; 3) the superior labial vein; 4) the buccal vein; 5) the medial inferior palpebral vein; 6) the medial superior palpebral vein; 7) the dorsal nasal vein; 8) the angularis oculi vein; and 9) the deep facial vein.

1) The inferior labial vein (Figs. 6,7,8,9,12/6) was superficial and well developed, arose near the angle of the mandible dorsal to the mandibular lymph node. The inferior labial coursed rostrally with the ventral branch of the facial nerve, along the ventral border of the ventral buccal gland, and continued within the inferior lip. The inferior labial vein received glandular branches from the ventral buccal gland, and muscular branches from depressor labii inferioris, mentalis and orbicularis oris. It also received anastomotic branches from the deep facial, inferior alveolar, and inferior and superior branches from the buccal glands. There were four valves present in the inferior labial vein: one of them was located close to the lower lip, one near the rostral end of the ventral buccal gland, and the other two were found before its confluence with the facial vein.

2) Branches to the buccal glands (Figs. 6,9,12/10,11). The inferior glandular branch originated at the dorsocaudal extremity of

Plate 5

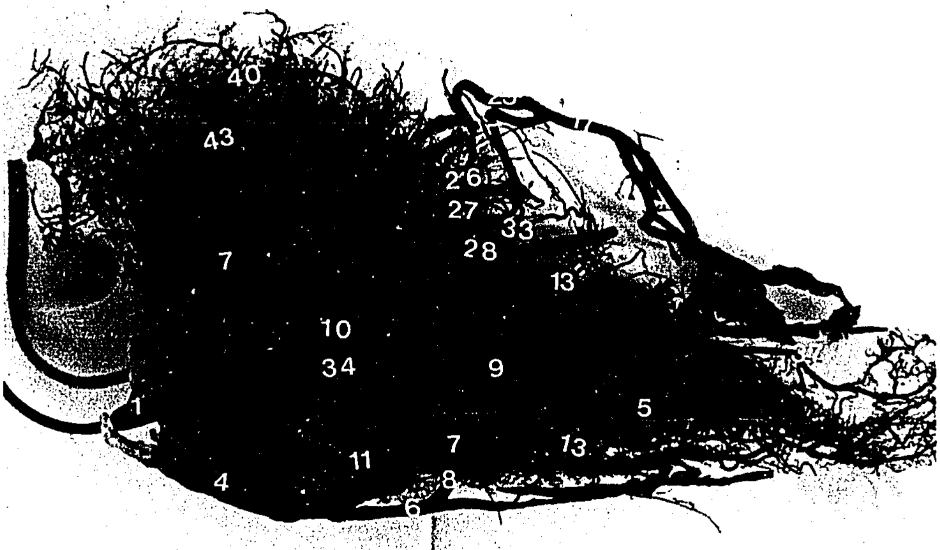
Figure 7. Lateral view of the arteries of the head and major veins draining to the cavernous sinus (Batson's # 17 cast)

Arteries: (red cast)
1. Common carotid artery
5. Lingual artery
7. Caudal auricular artery
10. Transverse facial artery
11. Facial artery
13. Inferior labial artery
33. Infraorbital artery
37. Superior labial artery

Veins: (blue cast)
4. Linguofacial vein
6. Inferior labial vein
7. Facial vein
8. Buccal vein
9. Deep facial vein
13".Infraorbital vein
17. Angularis oculi vein
25. Frontal vein
26. Dorsal external ophthalmic vein
27. Ophthalmic plexus
28. Ventral external ophthalmic vein
34. Pterygoid plexus
40. Dorsal sagittal sinus
43. Sigmoid sinus

Figure 8. Superficial veins of the head in the camel (Latex injection)

3. Maxillary vein
4. Linguofacial vein
6. Inferior labial vein
7. Facial vein
8. Buccal vein
9. Deep facial vein
13. Medial inferior palpebral vein
13'.Medial superior palpebral vein
14. Superior labial vein
15. Dorsal nasal vein
16. Lateral nasal vein
17. Angularis oculi vein
22. Masseteric vein
25. Frontal vein



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the ventral buccal gland, passed rostrally along its dorsal border with the inferior labial artery and the ventral branch of the buccal nerve. It coursed within the buccinator muscle, received small veins from the dorsal buccal glands, and anastomosed with the inferior labial and buccal veins. The inferior glandular branch continued its course within the inferior lip and partly drained the orbicularis oris muscle. There were six valves inside this vein. The inferior glandular branch connected the facial with the inferior labial vein. The superior glandular branch came either from the facial or the deep facial, and had three valves. It ran deep within the superior buccal glands between malaris and buccinator muscles. The superior glandular branch coursed with the glandular artery of the facial and the dorsal branch of the buccal nerve. It collected glandular branches from the ventral and dorsal buccal glands and the terminal portion of the parotid duct. This branch also received small veins from malaris and buccinator muscles, and the angularis oris vein.

3) The superior labial vein (Figs. 6,8,9,10,11,12/14) arose just dorsal to the infraorbital foramen, and coursed rostrally, deep to the malaris muscle, with the infraorbital artery and nerve. The superior labial vein received anastomotic branches from the infraorbital and the dorsal nasal veins, and the superior glandular branch. It had five valves and gave off two superficial and two deep branches ramifying within the orbicularis oris muscle. One of the superficial branches ran toward the superolateral border of the upper lip to reach the lateral angle of the nostril, and the philtrum where it anastomosed with its

fellow of the opposite side. The superior labial drained a part of the alar fold (dorsal part of the ventral nasal concha), and lateralis nasi and levator nasolabialis muscles. A large anastomosis was apparent between the lateral nasal and superior labial veins.

4) The buccal vein (Figs. 6,7,8,9,12/8) originated from the ventral aspect of the maxillary, coursed ventrorostrally along the rostral border of the ramus of the mandible. The buccal vein anastomosed with the deep facial vein and, within the buccinator muscle, divided into two branches. One of these branches joined the facial vein, and the other the inferior labial vein. At its origin there was a large dilatation called the buccal sinus close to the initial part of the pterygoid plexus.

5) The medial inferior palpebral vein (Figs. 6,8,9, 10,12/13) originated from the caudal aspect of the facial vein dorsal to the infraorbital foramen, ran caudodorsally to the medial canthus of the eye, where it anastomosed with the lateral inferior palpebral vein. The medial inferior palpebral connected the facial vein to the ophthalmic plexus.

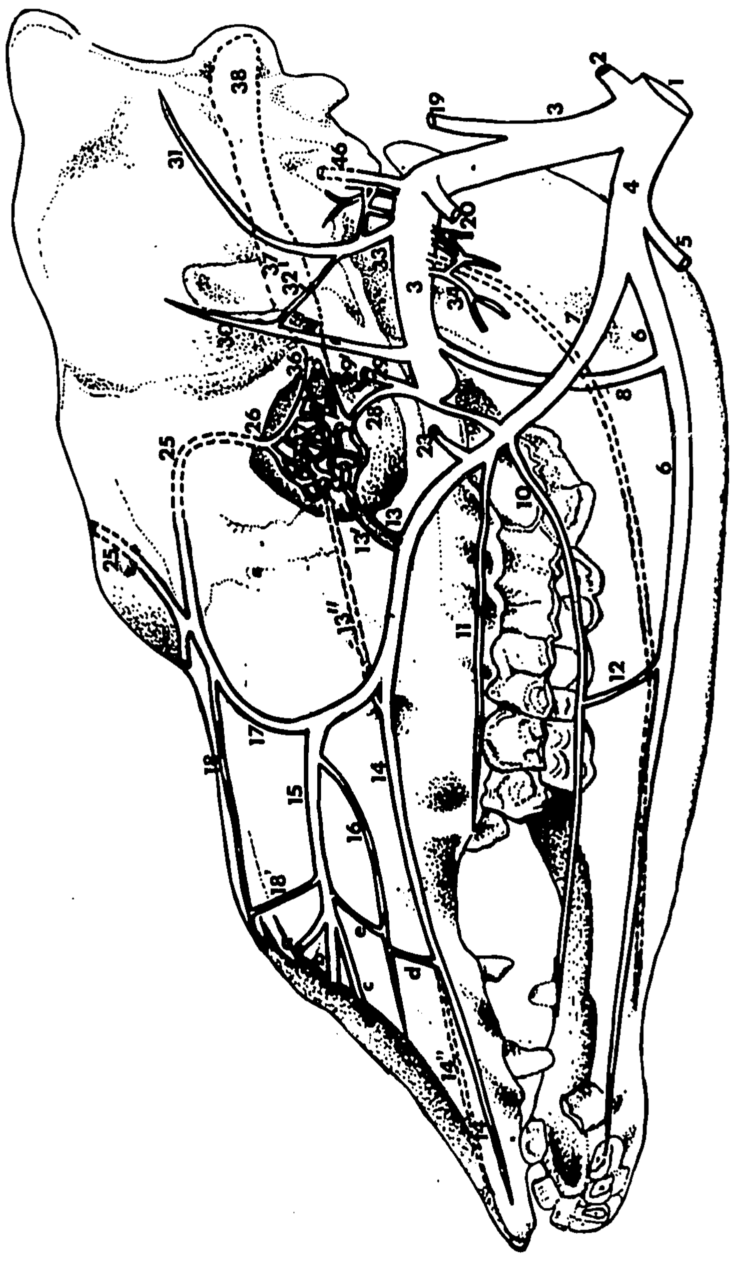
6) The medial superior palpebral vein (Figs. 6,8,9, 10,12/13') came off the caudal aspect of the facial, passed caudodorsally to the medial part of the superior eyelid. It anastomosed with the lateral superior palpebral vein.

7) The dorsal nasal vein (Figs. 6,9,10,12/15) was well developed, often double, and formed one of the terminal branches of the facial vein. Frequently it arose by a common trunk with the lateral

Plate 6

Figure 9. Lateral view of the venous drainage of the head in the camel (schematic drawing)

1. External jugular vein
2. Occipital vein
3. Maxillary vein
4. Linguofacial vein
5. Lingual vein
6. Inferior labial vein
7. Facial vein
8. Buccal vein
9. Deep facial vein
10. Inferior glandular branch
11. Superior glandular branch
12. Anastomotic branch between 6 and 10
13. Medial inferior palpebral vein
13'. Medial superior palpebral vein
13". Infraorbital vein
14. Superior labial vein
14'. Superficial branch
14". Deep branch
15. Dorsal nasal vein
    a: dorsal branch
    b: septal branch
    c: ventral branch
16. Lateral nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
18'. Anastomotic branch between 5 and 18
19. Caudal auricular vein
20. Superficial temporal vein
23. Transverse facial vein
25. Frontal vein
26. Dorsal external ophthalmic vein
27. Ophthalmic plexus
28. Ventral external ophthalmic vein
29. Descending palatine vein
30. Rostral deep temporal vein
31. Caudal deep temporal vein
32. Anastomotic branch between 30 and 31
33. Retroarticular plexus
34. Pterygoid plexus
35. Inferior alveolar vein
36. Emissary vein of the orbitorotundum foramen
37. Cavernous sinus
46. Emissary vein of the retroarticular foramen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nasal. This vein coursed rostrally on the lateral side of the nose without accompaniment of a homonymous artery. Its course and distribution will be described with the blood supply of the nasal cavity.

The lateral nasal vein (Figs. 6,8,9,10,12 /16) will be described with the blood supply of the nasal cavity.

8) The angularis oculi vein (Figs. 6,7,8,9,10,11,12/17) was the other terminal branch of the facial. It coursed dorsocaudally toward the medial canthus of the eye. This vein was 3-4 mm in diameter and devoid of valves. The angularis oculi vein passed underneath the levator nasolabialis and frontalis muscles, and continued as the frontal vein (Figs. 6,7,8,9,10, 11,12/18) that coursed in the frontal region to reach the supraorbital foramen. In the frontal region, the angularis oculi vein anastomosed with its fellow to form the dorsal impar nasal vein (Figs. 6,9,10/18). The frontal became the supraorbital vein while coursing inside the long supraorbital canal. The supraorbital vein received diploic veins of the frontal bone, branches from the frontal sinus, and anastomosed with the rostral meningeal vein. It continued further as the dorsal external ophthalmic vein that joined the ophthalmic plexus.

The ophthalmic plexus (Figs. 7,9,10,12/27) was intermingled with the ophthalmic arterial rete. It was located in the orbit between the bones and the periorbita, and was divided into a dorsal and a ventral part. The dorsal part of this plexus was located between the frontal bone and the periorbita, received dorsally the dorsal external ophthalmic vein, and caudally it was continuous with the cavernous sinus via the emissary vein of the orbitorotundum foramen. The ventral part of the ophthalmic plexus lay on the floor of the orbit dorsal to the last upper molar alveolus. Rostrally, ophthalmic plexus released the infraorbital vein, and caudally it received the ventral external ophthalmic vein arising from the deep facial vein, and connected the cavernous sinus via the emissary vein of the orbitorotundum foramen. Both parts of the ophthalmic plexus anastomosed medially and together formed a venous plexus surrounding the structures of the orbit. The ophthalmic plexus released and/or drained the following veins:

(a) The <u>infraorbital vein</u> (Figs.9,10,12/13") coursed medial to the maxillary nerve within the infraorbital canal, and finally joined the superior labial vein or the facial vein.

(b) The <u>lacrimal vein</u> may be double; it arose on the lateral aspect of the ophthalmic plexus, coursed with the homonymous nerve and artery, along the dorsal border of the rectus lateralis muscle of the eyeball, to reach the lacrimal gland.

(c) The <u>external ethmoid vein</u> left the medial aspect of the ophthalmic plexus, and entered the ethmoid foramen to drain the ethmoturbinates.

(d) The <u>dorsal external ophthalmic vein</u> (Figs. 9, 10,11,12/26) continued the supraorbital vein, received a branch of the superficial temporal vein, and coursed ventrocaudally toward the orbitorotundum foramen. This vein continued to the dorsal part of the ophthalmic plexus and the latter was connected to the cavernous sinus by

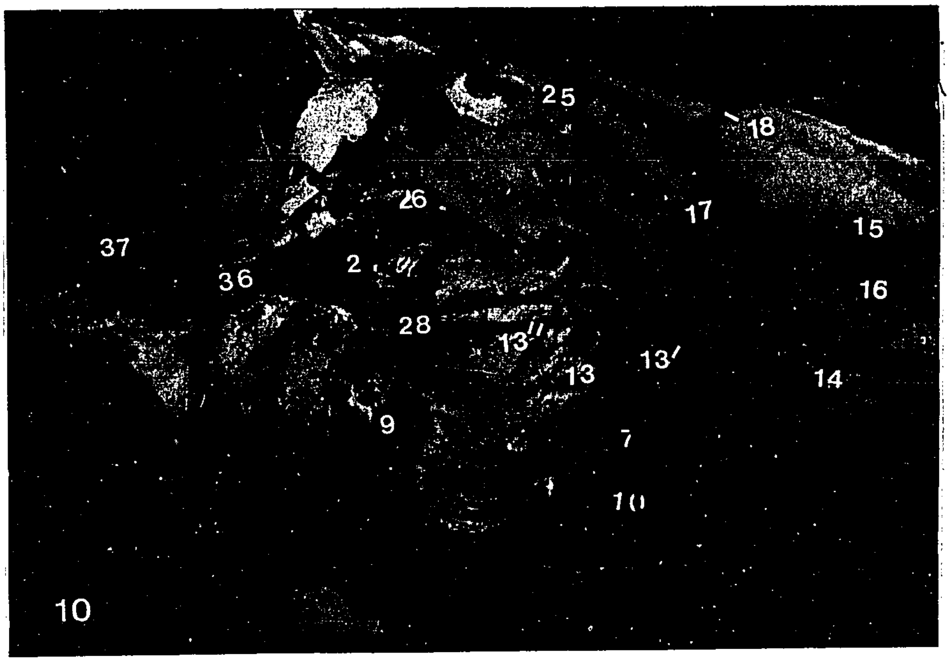
Plate 7

Figure 10. Major veins draining to the ophthalmic plexus (Latex injection) (Right lateral view)

7. Facial vein
9. Deep facial vein
10. Inferior glandular branch
13. Medial inferior palpebral vein
13'. Medial superior palpebral vein
13". Infraorbital vein
14. Superior labial vein
15. Dorsal nasal vein
16. Lateral nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
25. Frontal vein
26. Dorsal external ophthalmic vein
27. Ophthalmic plexus
28. Ventral external ophthalmic vein
36. Emissary vein of the orbitorotundum foramen
37. Cavernous sinus

Figure 11. Radiograph of the veins draining to the ophthalmic plexus and cavernous sinus (Right lateral view)

7. Facial vein
9. Deep facial vein
14. Superior labial vein
15. Dorsal nasal vein
17. Angularis oculi vein
25. Frontal vein
26. Dorsal external ophthalmic vein
27. Ophthalmic plexus
36. Emissary vein of the orbitorotundum foramen



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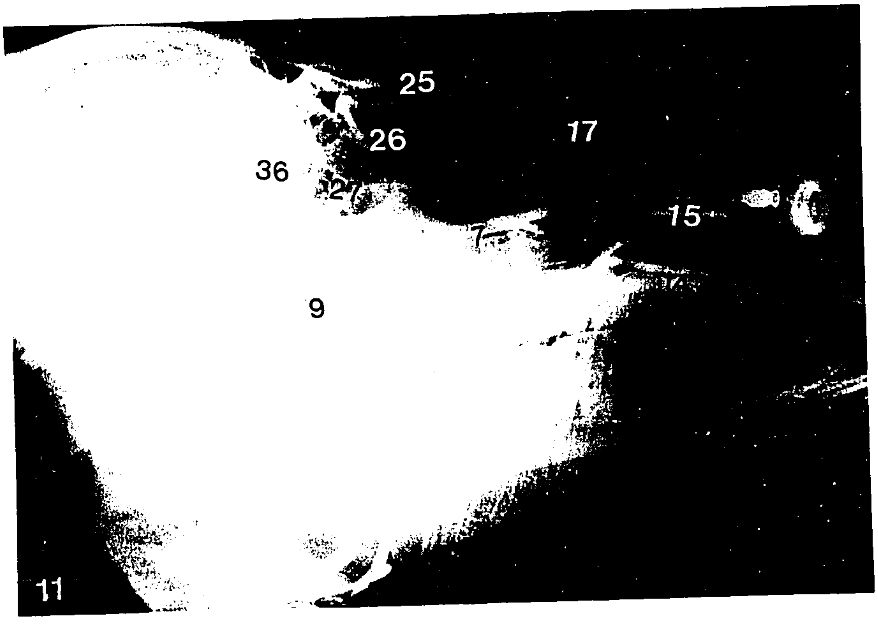

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means of the emissary vein of the orbitorotundum foramen.

(e) The ventral external ophthalmic vein (Figs. 9,10,12/28) originated from the ventral aspect of the ophthalmic plexus, and was located on the caudomedial aspect of the orbit. This vessel contributed several branches to the ophthalmic plexus, connected with a branch of the deep facial vein, and became confluent with the cavernous sinus via the emissary vein of the orbitorotundum foramen.

9) The deep facial vein (Figs. 6,7,8,10/9) arose from the caudal aspect of the facial vein, close to the last upper molar tooth near the caudoventral extremity of the ventral buccal gland. It ran dorsocaudally toward the orbit and passed within the fat between masseter and buccinator muscles. On the lateral aspect of the maxillary tuberosity, it described a dilatation called the sinus of the deep facial vein connecting it with the maxillary. This sinus received, in turn, four veins: the rostral deep temporal dorsally, the deep facial rostrally, the buccal ventrally, and the maxillary caudally. The deep facial continued its course across the floor of the orbit toward the sphenopalatine foramen and gave off the sphenopalatine, major palatine and minor palatine veins. The sphenopalatine vein, in turn, received dorsal caudal, middle caudal, ventral caudal and septal caudal nasal veins. The major palatine vein did not course within the palatine canal; it formed an extensive plexus within the hard palate, and received anastomotic branches from the nasal floor via unnamed foramina. The deep facial received confluence from the buccal, inferior labial, ventral external ophthalmic, and rostral deep temporal veins. The minor

palatine vein drained the soft palate and joined the major palatine vein.

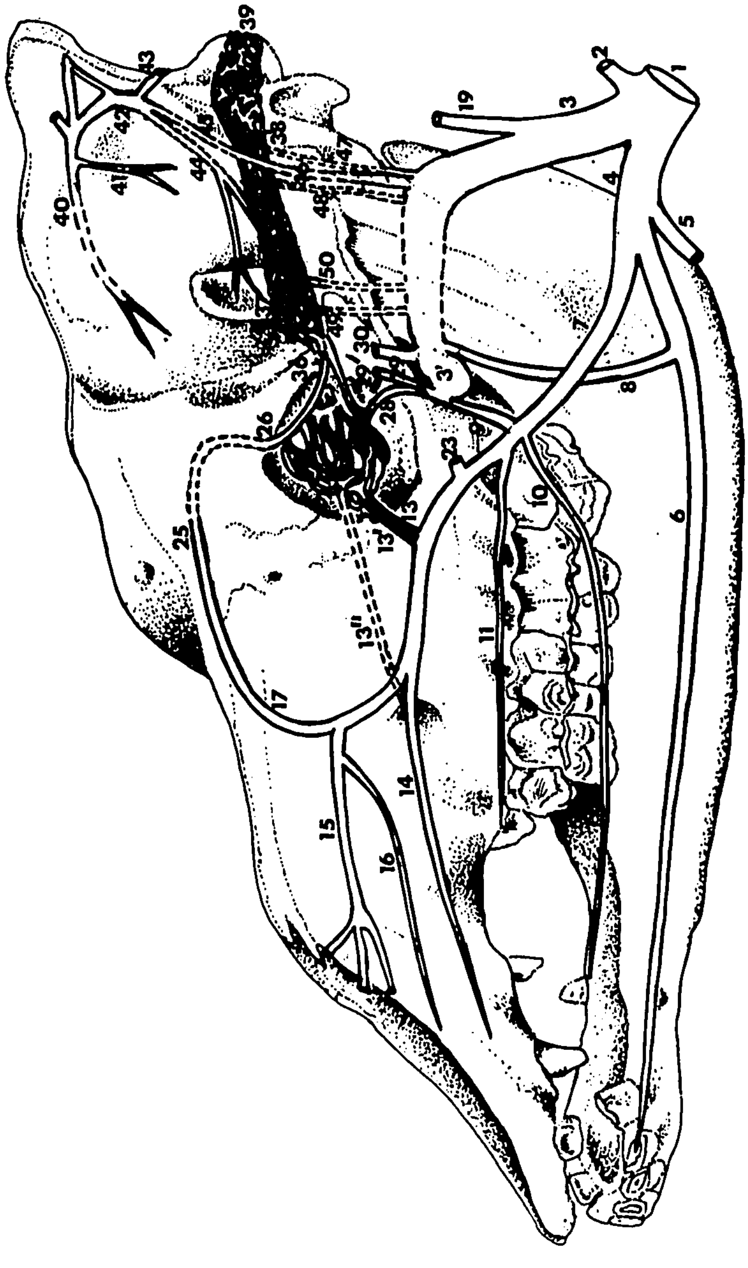
The maxillary vein (V. maxillaris) (Figs. 6,7,9,12,23/3) The maxillary was the other terminal branch of the external jugular vein. Its origin was located caudal to the angle of the mandible, lateral to the mandibular gland and ventral to the mandibular condyle. This vein ascended subcutaneously to pass through the angular notch of the mandibular ramus and continued its course between the mandible and the pterygoideus medialis muscle. Here, it formed a pterygoid plexus (Figs. 6,7/34) by anastomosing with the buccal, inferior alveolar, and pterygoid veins. The maxillary vein terminated caudal to the sinus of the deep facial vein at the site of confluence of the rostral deep temporal and buccal veins. During its course, the maxillary vein received tributaries from the parotid and mandibular glands, and released the following branches:

1) The caudal auricular vein (Figs. 6,9,12/19) arose from the parent vessel and sometimes from the external jugular vein, ascended toward the base of the ear inside the parotid gland. It supplied small branches to both the parotid and mandibular glands, and tendons of the brachiocephalicus and splenius. At the level of the jugular process, it received the stylomastoid vein (Fig. 6/19f) that emerged via the stylomastoid foramen. The medial auricular vein (Fig. 6/19i) drained the medial aspect of the auricle and after passing under the frontoscutularis muscle joined either the caudal auricular, or the lateral auricular branch. The caudal auricular supplied the temporalis

Plate 8

Figure 12. Lateral view of the dural sinuses and their connections with the veins of the head (schematic drawing)

1. External jugular vein
2. Occipital vein
3. Maxillary vein
4. Linguofacial vein
5. Lingual vein
6. Inferior labial vein
7. Facial vein
8. Buccal vein
9. Deep facial vein
10. Inferior glandular branch
11. Superior glandular branch
13. Medial inferior palpebral vein
13'. Medial superior palpebral vein
13". Infraorbital vein
14. Superior labial vein
15. Dorsal nasal vein
16. Lateral nasal vein
17. Angularis oculi vein
19. Caudal auricular vein
23. Transverse facial vein
25. Frontal vein
26. Dorsal external ophthalmic vein
27. Ophthalmic plexus
28. Ventral external ophthalmic vein
29. Descending palatine vein
30. Rostral deep temporal vein
36. Emissary vein of the orbitorotundum foramen
37. Cavernous sinus
38. Basilar plexus
39. Ventral atlantooccipital plexus
40. Dorsal sagittal sinus
41. Straight sinus
42. Transverse sinus
43. Sigmoid sinus
44. Dorsal petrosal sinus
45. Temporal sinus
46. Emissary vein of the retroarticular foramen
47. Emissary vein of the jugular foramen
48. Emissary vein of the carotid foramen
49. Emissary vein of the oval foramen
50. Emissary vein of the foramen lacerum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muscle and anastomosed with the emissary vein of the occipital foramen that appeared along the ventral aspect of the rectus capitis ventralis muscle. The other branches were the lateral auricular (Fig. 6/19h) and the intermediate auricular veins (Fig. 6/19g) that drained the corresponding aspects of the ear. All these veins anastomosed with each other and formed a venous network surrounding the auricle.

2) The superficial temporal vein (Figs. 6,9/20) originated from the dorsal aspect of the maxillary, ventral to the zygomatic process of the temporal bone. It divided into the rostral auricular and transverse facial veins.

(a) The rostral auricular vein (Fig. 6/21) extended lateral to the zygomatic arch and ran rostrally under the scutiform cartilage to supply the rostral auricular muscles. This vessel gave off the deep auricular vein that was located dorsal to the external acoustic meatus; it drained the inner surface of the skin of the concha.

(b) The transverse facial vein (Figs. 6,9,12/23) arose together with the superficial temporal, and sometimes from the maxillary or the masseteric vein. This valveless vein coursed between the zygomaticus and cutaneus faciei muscles. The transverse facial vein accompanied the transverse facial artery on the lateral aspect of the masseter muscle, and continued rostrally to empty in the facial vein. It released branches to the parotid gland, and masseter and zygomatic muscles. This vein received a temporal branch from the temporal region that anastomosed with the caudal deep temporal vein and together formed an extensive temporal plexus. This temporal branch also anastomosed with the supraorbital vein. The transverse facial vein also gave off the lateral superior and lateral inferior palpebral veins anastomosing with the corresponding veins of the facial.

3) The masseteric vein (Figs. 6,8/22) arose either directly from the maxillary, or in common with the transverse facial vein caudal to the temporomandibular joint. It coursed laterally and divided into several small branches forming a masseteric plexus under the masseter muscle. The masseteric plexus was reinforced by the transverse facial vein, and received articular branches from the temporomandibular joint.

4) The pterygoid plexus (Figs. 6,9/34) consisted of several anastomotic veins located between the pterygoid muscles along the caudal aspect of the pterygoid bone. This plexus was better developed than the masseteric plexus, and received anastomotic branches from the medial aspect of the temporomandibular joint, as well as the emissary vein of the retroarticular foramen. It also received the emissary veins of the jugular, carotid, and oval foramina, respectively.

5) The inferior alveolar vein (Fig. 9/35) was better developed than the preceding vessel. The inferior alveolar vein took its origin from the deep aspect of the pterygoid plexus, or the maxillary vein, and entered the mandibular canal via the mandibular foramen. It drained the teeth of the inferior arcade and after exiting through the mental foramen anastomosed with the inferior labial via the mental vein.

6) The retroarticular plexus (Fig. 6/33) was formed by anastomoses of several veins surrounding the temporomandibular joint, including small branches from the transverse facial and caudal deep

temporal veins, and the emissary vein of the retroarticular foramen.

7) The emissary vein of the retroarticular foramen (Figs. 9,12, 23/46) arose from the temporal sinus, coursed within the temporal canal, and emerged via the retroarticular foramen. This emissary vein joined the maxillary after receiving tributaries from the parotid gland, as well as from the retroarticular plexus.

Dural sinuses

Most of the venous sinuses of the cranial dura mater were located between the periosteal and meningeal layers, but in the temporal and occipital regions they were housed within bony canals. By means of these vascular channels the venous blood from the brain and head was returned to the paired maxillary veins, occipital veins, and the vertebral venous plexus. On the basis of their topography, these dural sinuses are intercalated in the venous pathway between the veins of the head and the neck. Absence of a tunica media in their walls and valves in their lumina were characteristics of these sinuses. Dural sinuses consisted of a dorsal and ventral system. In the camel, the dorsal system comprised single dorsal sagittal and straight, and paired transverse including temporal and sigmoid sinuses, whereas the ventral system included cavernous sinus, intercavernous, basilar, and dorsal and ventral petrosal sinuses.

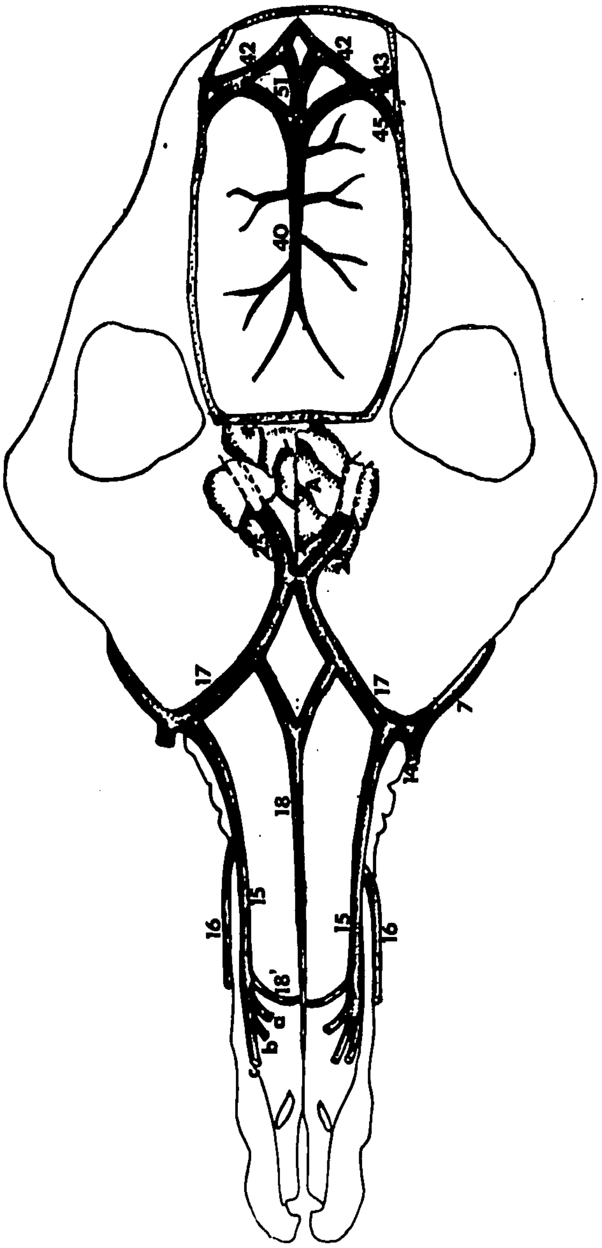
Dorsal system of dural sinuses

The dorsal sagittal sinus (Figs. 12,13,14,15,16/40) was the longest dural sinus measuring 10-12 cm in length and 3-5 mm in width.

Plate 9

Figure 13. Dorsal view of the venous drainage of the nasal cavities and the dorsal system of the dural sinuses (schematic drawing)

A. Frontal sinus
7. Facial vein
14. Superior labial vein
15. Dorsal nasal vein
    a: dorsal branch
    b: septal branch
    c: ventral branch
16. Lateral nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
25. Frontal vein
40. Dorsal sagittal sinus
42. Transverse sinus
43. Sigmoid sinus
45. Temporal sinus
51. Confluence of the transverse sinuses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The dorsal sagittal sinus began, caudal to the cribriform plate, at the rostrodorsal surface of the brain by receiving the rhinal veins draining the olfactory bulb. From there, it ran caudodorsally along the median plane and was attached to the edge of the falx cerebri along the sagittal suture of the parietal bones. This sinus was single in the rostral half, but its caudal half was bifurcated. It received four to six dorsal cerebral veins that drained into the parent vessel at acute angles. It also received the diploic veins of the parietal bones. The dorsal sagittal sinus ran caudolaterally and near its termination, it divided into three to four veins forming a rich plexus near the transition of the cerebellum and cerebrum. The right and left branches of this trifurcation or quadrifurcation were the transverse sinuses that were satellite of the branches of the middle meningeal artery. In cross section, the dorsal sagittal sinus was seemingly triangular with the base oriented dorsally.

The straight sinus (Figs.12,23/41) The origin of this sinus was located at the free caudal margin of the falx cerebri by union of the great cerebral vein ventrally, and the vein of the corpus callosum dorsally. This sinus drained 3-4 branches arising from region of the corpus callosum, habenula, caudate nucleus, septum pellucidum, and the occipital bone. In the thalamic region, it was interspersed between branches of the choroid plexus and received veins from the corpus callosum and dorsal thalamus. After the confluence of these veins, the straight sinus ascended along the median plane between the two cerebral hemispheres, and joined the dorsal sagittal sinus usually

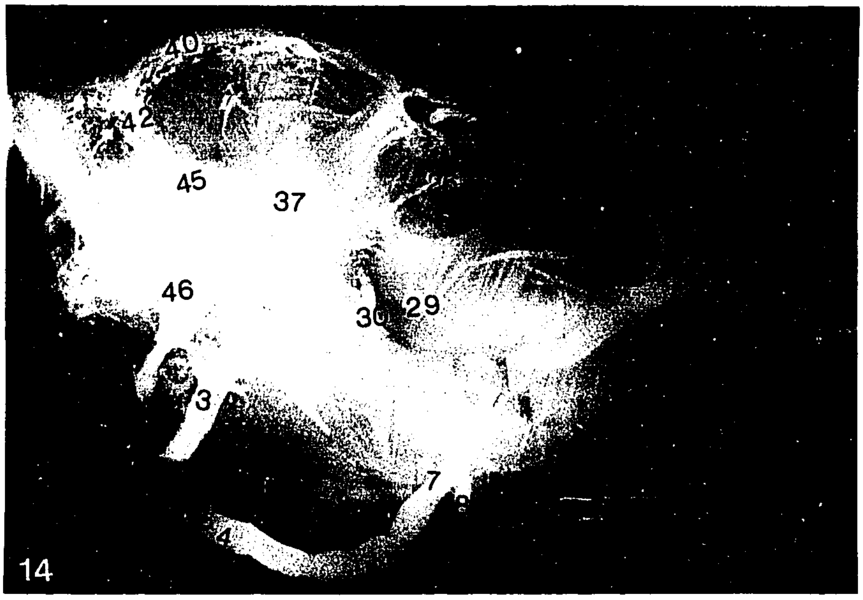
Plate 10

Figure 14. Venograph of the dural sinuses and their connections to the superficial veins (Right lateral view)

3. Maxillary vein
4. Linguofacial vein
7. Facial vein
8. Buccal vein
15. Dorsal nasal vein
17. Angularis oculi vein
25. Frontal vein
26. Dorsal external ophthalmic vein
29. Descending palatine vein
30. Rostral deep temporal vein
37. Cavernous sinus
40. Dorsal sagittal sinus
42. Transverse sinus
45. Temporal sinus
46. Emissary vein of the retroarticular foramen

Figure15. Dorsal view of the major veins draining the nasal cavity (Batson's # 17)

7. Facial vein
13". Infraorbital vein
15. Dorsal nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
25. Frontal vein
31. Caudal deep temporal vein
40. Dorsal sagittal sinus
42. Transverse sinus
43. Sigmoid sinus
45. Temporal sinus



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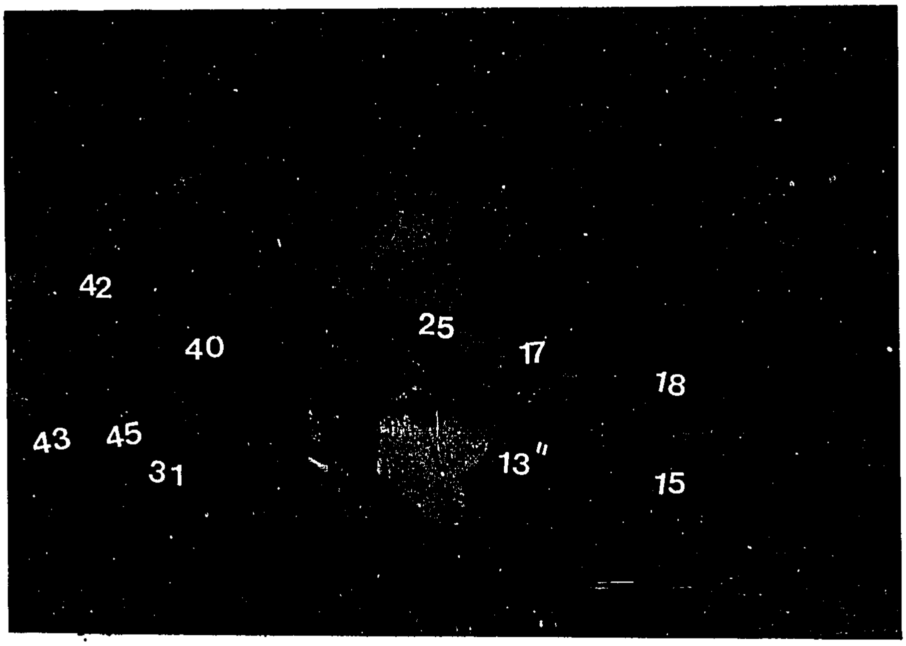


before its termination. It may, however, course independently and join the confluence of the sinuses within the occipital bone.

The transverse sinus (Figs. 12,13,14,15,23/42) was located within the membraneous cerebellar tentorium lying along the cerebrocerebellar crest. It was paired, each of them began dorsally from the dorsal sagittal sinus by receiving sometimes the straight sinus. The transverse sinus merged with its fellow to form the confluence of the sinuses within the occipital bone. From this confluence, the transverse sinus passed laterally in the transverse groove between the occipital bone dorsally, cerebral hemispheres rostrally, and the rostral aspect of the cerebellum caudally. During its course it received two dorsal cerebellar veins, and released the emissary vein of the occipital foramen. At the distal part of the transverse groove, the transverse sinus divided into a rostral branch, the temporal sinus, and a caudal branch, the sigmoid sinus.

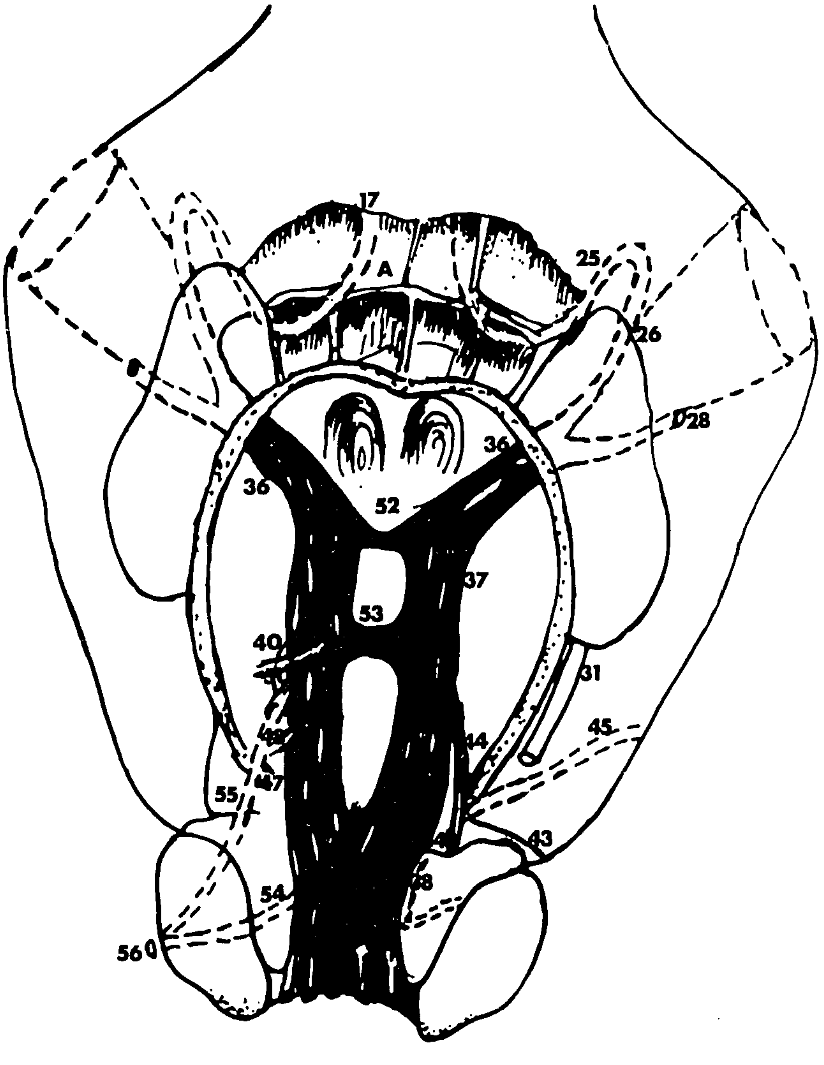
(1) The temporal sinus (Figs. 12,13,14,15/45) was well developed, measuring 6 cm in length and 5 mm in diameter. Each sinus continued rostroventrally as the rostral branch of the transverse sinus to course within the temporal canal. The temporal sinus before traversing the canal released a branch that anastomosed with the caudal deep temporal vein inside the temporal fossa. Subsequently, it emerged as the emissary vein of the retroarticular foramen, caudal to the retroarticular process, to join the maxillary vein.

(2) The sigmoid sinus (Figs.12,13,15,23/43) was the caudoventral continuation of the transverse sinus. The sigmoid sinus

Plate 11

Figure 16. Basilar system of the dural sinuses on the cranial floor
(Schematic drawing)

A. Frontal sinus
17. Angularis oculi vein
25. Frontal vein
26. Dorsal external ophthalmic vein
28. Ventral external ophthalmic vein
31. Caudal deep temporal vein
36. Emissary vein of the orbitorotundum foramen
37. Cavernous sinus
38. Basilar plexus
40. Dorsal sagittal sinus
43. Sigmoid sinus
44. Dorsal petrosal sinus
45. Temporal sinus
47. Emissary vein of the jugular foramen
48. Emissary vein of the carotid foramen
52. Rostral intercavernous sinus
53. caudal intercavernous sinus
54. Emissary vein of the hypoglossal canal
55. Ventral petrosal sinus
56. Occipital vein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released a branch that, after traversing an unnamed foramen of the occipital bone, descended along the temporal crest, and joined the emissary vein of the condylar foramen to finally open into the occipital vein. Another vein after arising from this sinus coursed within the condylar canal as the condylar vein to drain into the basilar plexus. An osseous canal was evident between the condylar canal and the hypoglossal canal containing a vein that connected the emissary vein of the hypoglossal canal with the condylar vein.

Ventral system of dural sinuses

The cavernous sinus and the intercavernous sinuses (Figs. 12,14,16, 17,18,23/37) The cavernous sinus was paired and flanked both sides of the hypophysis cerebri. The right and left cavernous sinuses had a plexiform appearance intermingled with the rostral epidural rete mirabile. Each sinus communicated rostrally with the ophthalmic plexus via the emissary vein of the orbitorotundum foramen; ventrolaterally each gave off emissary veins that ran through the round, oval, carotid, and jugular foramina to join the pterygoid plexus, or the maxillary vein; caudally, the cavernous sinus was continuous with the basilar plexus. Dorsocaudally, it received the dorsal petrosal sinus, and dorsolaterally the middle meningeal entered this sinus. Both cavernous sinuses were connected medially by means of a slender rostral and a well developed caudal intercavernous sinuses along the rostral and caudal aspects of the pituitary stalk.

The basilar sinus (Figs. 12,16,17/38) This plexiform structure represented the venous link between the cavernous sinus and

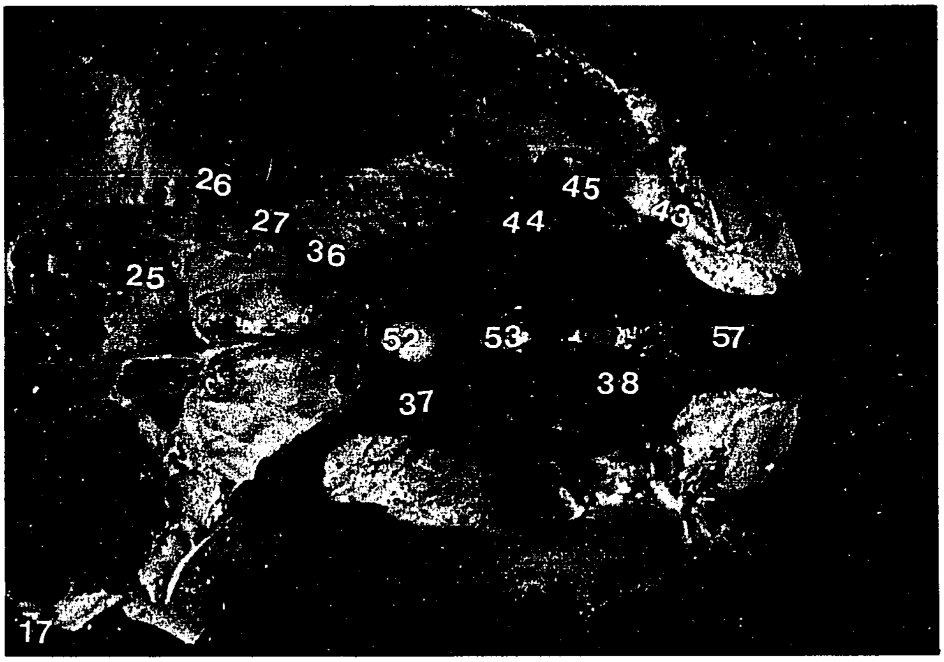
Plate 12

Figure 17. Dorsal view of the basilar system of the dural sinuses on the cranial floor (Latex injection)

25. Right frontal vein
26. Right dorsal external ophthalmic vein
27. Ophthalmic plexus
36. Right emissary vein of the orbitorotundum foramen
37. Left cavernous sinus
38. Basilar plexus
43. Sigmoid sinus
44. Dorsal petrosal sinus
45. Temporal sinus
52. Rostral intercavernous sinus
53. Caudal intercavernous sinus
57. Ventral atlantooccipital venous plexus

Figure 18. Venograph of the head of the camel (Dorsoventral view)

7. Facial vein
9. Deep facial vein
15. Dorsal nasal vein
29. Descending palatine vein
37. Cavernous sinus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the transverse sinus on one hand, and the ventral internal vertebral plexus on the other. This sinus was located on the basilar part of the occipital bone, occupying the floor and its lateral aspect. Caudally, it converged toward the opposite sinus and continued as the ventral internal vertebral plexus beyond the foramen magnum. The latter plexus was situated on the medial aspect of the wing of the atlas inside the vertebral canal. The basilar sinus was transversely connected to its fellow by the ventral interbasilar sinus that was well developed. It was surrounded by adipose connective tissue inside the atlantooccipital joint. The dorsal interbasilar sinus was, however, not developed. The basilar plexus was continuous rostrally with the cavernous sinus, caudally with the ventral internal vertebral plexus, and laterally it received the condylar and diploic veins. The basilar sinus released the emissary vein of the hypoglossal canal, connecting it to the occipital vein.

The dorsal petrosal sinus (Figs. 12,16,17/44) was the rostral extension of the transverse sinus beginning at the free border of the cerebellar membraneous tentorium, opposite the distal end of the petrosal crest. Lateral to the temporal meatus the dorsal petrosal and transverse sinuses joined at an acute angle. The dorsal petrosal sinus was 6 cm long and 3 mm wide, and was related to the lateral aspect of the pyramid. It received the ventral cerebral vein, three to four meningeal veins, and veins from the vermis and pons. This sinus was connected to the dorsocaudal aspect of the cavernous sinus and the caudal intercavernous sinus.

The ventral petrosal sinus (Figs. 12,16/38) was the ventrocaudal extension of the cavernous sinus connecting the cavernous sinus to the emissary vein of the hypoglossal canal. Its wall was thin, and was attached to the basilar part of the occipital bone. In the vicinity of the foramen lacerum, the ventral petrosal sinus was enclosed in thick dura mater. On corrosion cast, the ventral petrosal sinus appeared as the caudal extracranial continuation of both the basilar and cavernous sinuses.

Blood Supply to the Nasal Cavity

The following description emphasized only specific vessels that contribute to the nasal region of the camel.

Arterial supply

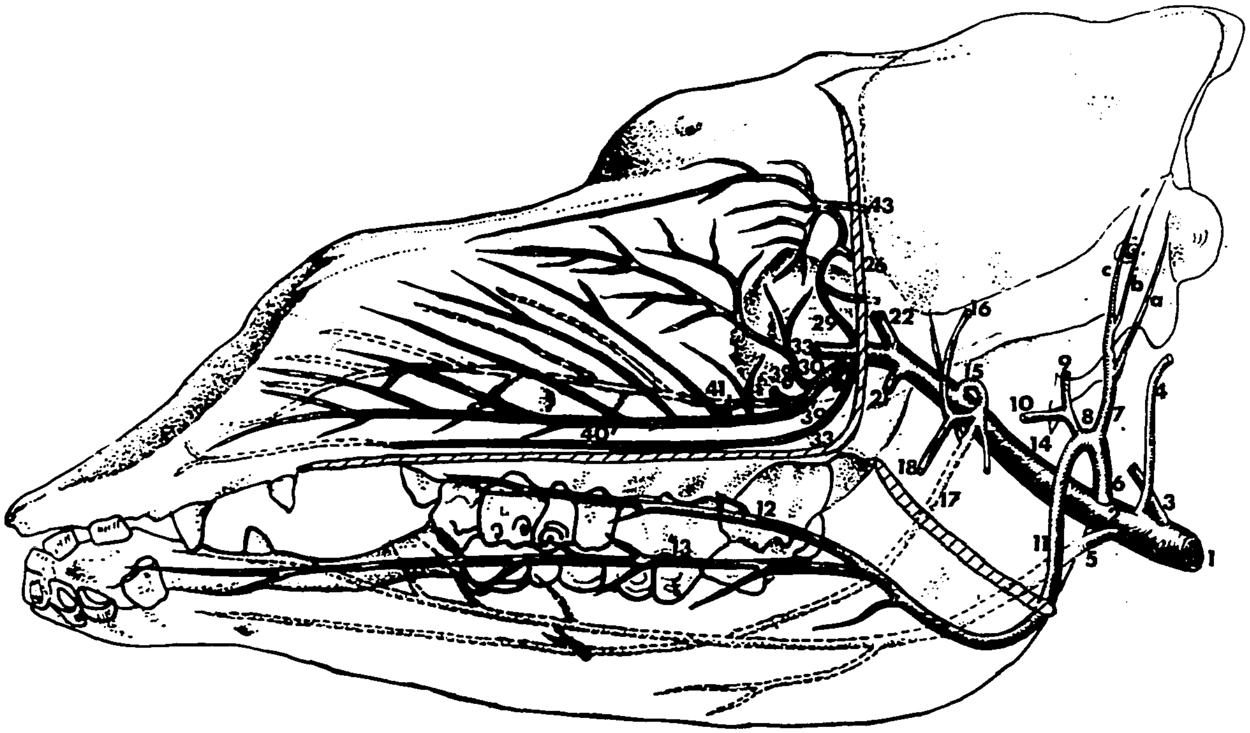
The blood supply to the nasal cavity of the camel was mainly derived from the sphenopalatine and ethmoid arteries, and to a lesser extent from the major palatine. The nostrils and the external surface of the nasal cavity were supplied by the infraorbital artery.

The sphenopalatine artery (Figs. 1,19,20,21/32) branched off the descending palatine at the rostral end of the pterygopalatine fossa and coursed inside the sphenopalatine foramen. It proceeded toward the caudal end of the ventral nasal concha following a short and flexuous course. At the floor of the nasopharynx, it divided into dorsal and ventral nasal arteries. Before reaching the ventral nasal concha, it released: (1) several branches to supply the ethmoturbinates; and (2)

Plate 13

Figure 19. Arterial supply to the nasal cavity of the camel (schematic drawing)

1. Common carotid artery
2. External carotid artery
3. Internal carotid artery
4. Occipital artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
   a: lateral auricular branch
   b: medial auricular branch
   c: stylomastoid artery
8. Superficial temporal artery
9. Rostral auricula artery
10. Transverse facial artery
11. Facial artery
12. Superior branch of the facial artery (glandular artery)
13. Inferior labial artery
14. Maxillary artery
15. Common trunk of the inferior alveolar, caudal deep temporal and pterygoid arteries
16. Caudal deep temporal artery
17. Inferior alveolar artery
18. Pterygoid artery
21. Buccal artery
22. External ophthalmic artery
26. External ethmoid artery
29. Second branch of the external ethmoid artery
30. Descending palatine artery
32. Sphenopalatine artery
33. Infraorbital artery
38. Dorsal nasal artery
39. Ventral nasal artery
40. Lateral branch of 39
41. Medial branch of 39
43. Internal ethmoid artery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the septal nasal artery, which sometimes arose in common with the major palatine. In one instance, the sphenopalatine took its origin before the major palatine artery, and the ventral nasal artery originated in another specimen from a common trunk with the major palatine.

(a) The ventral nasal artery (Figs. 19,21/39) coursed rostroventrally and divided soon into lateral (Figs. 19,22/40) and medial (Fig. 19/41) branches. (i) The lateral branch extended rostrally within the mucosa of the lateral wall covering the ventral nasal concha. During its straight course, this branch gave off both ventral and dorsal branches. The ventral branches ramified within the mucosa of the ventral meatus and the vomeronasal organ, and anastomosed with ventral branches of the septal nasal artery. Its dorsal branches passed rostrodorsally within the mucosa of the lateral wall covering the ventral nasal concha. Their courses were somewhat straight. The most rostral dorsal branches formed an acute angle with the parent vessel, whereas the most caudal branches left at right angles. At the nasal vestibule, the terminal ramifications of these dorsal branches anastomosed with a branch of the palatonasal branch arising from the major palatine artery. (ii) The medial branch of the ventral nasal artery divided into lateral and medial branches. The lateral branch ramified within the lateral side of the ventral nasal concha and terminated in its ventral scroll. The medial branch supplied the medial side of the ventral nasal concha and expended in its dorsal scroll. There were anastomoses between the ultimate ramifications of the ventral and dorsal nasal arteries of the sphenopalatine, and those of the ethmoid arteries.

(b) The dorsal nasal artery (Fig. 19/38) coursed toward the caudal extremity of the ventral nasal concha, and ramified into several branches. These branches supplied the nasal mucosa covering the middle and dorsal nasal conchae and the ethmoturbinates.

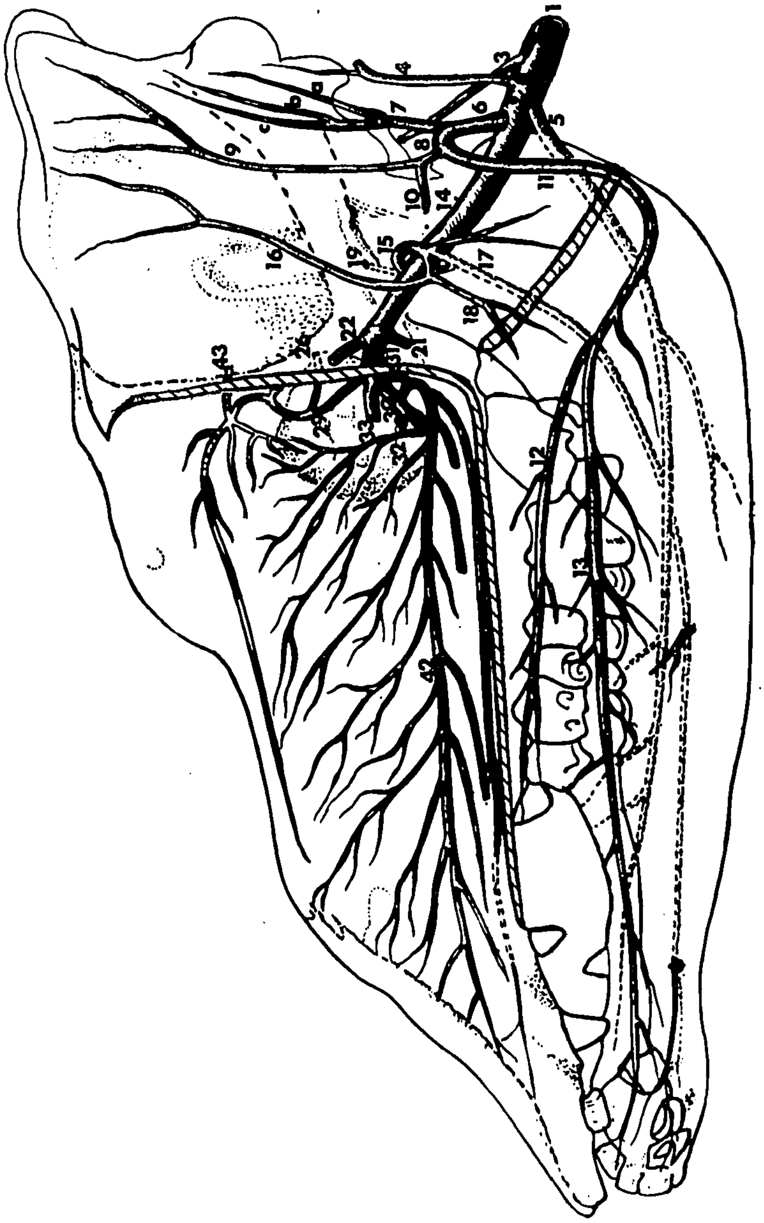
(c) The septal nasal artery (Figs. 20,21,25'/42) took its origin from the sphenopalatine before its bifurcation into dorsal and ventral nasal arteries. In one specimen, it came from the ophthalmic rete or the maxillary artery. It ran rostrally within the septal nasal mucosa parallel to the median plane and released ventral and dorsal branches. Its ventral branches coursed rostrally parallel to the median plane anastomosing with ventral branches of the ventral nasal artery. The dorsal branches of the septal nasal artery passed obliquely dorsally and the most superior branch anastomosed with the septal nasal branch of the external ethmoid artery.

The external ethmoid artery (Figs. 19,20,25'/26) had two sources of origin; one of them originated from the ophthalmic rete and the other one (Figs. 19,20/29) came from the maxillary artery. The first branch, after a short course over the bulbar muscles joined the second branch near the ethmoid foramen. The external ethmoid artery entered the cranial cavity via the ethmoid foramen, and divided into medial and lateral branches. The lateral branch pierced the lamina cribrosa to supply the ethmoturbinates. The medial branch received the internal ethmoid artery that stemmed from the rostral cerebral artery. The internal ethmoid did not, however, course with the optic nerve as the

Plate 14

Figure 20. Arterial supply to the nasal septum of the camel (schematic drawing)

1. Common carotid artery
2. External carotid artery
3. Internal carotid artery
4. Occipital artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
    - a: lateral auricular branch
    - b: medial auricular branch
    - c: stylomastoid artery
8. Superficial temporal artery
9. Rostral auricular artery
10. Transverse facial artery
11. Facial artery
12. Superior branch of the facial artery (glandular artery)
13. Inferior labial artery
14. Maxillary artery
15. Common trunk of the inferior alveolar, caudal deep temporal and pterygoid arteries
16. Caudal deep temporal artery
17. Inferior alveolar artery
18. Pterygoid artery
21. Buccal artery
22. External ophthalmic artery
26. External ethmoid artery
29. Second branch of the external ethmoid artery
30. Descending palatine artery
32. Sphenopalatine artery
33. Infraorbital artery
42. Septal nasal artery
43. Internal ethmoid artery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internal ophthalmic artery (Figs. 19,20,26/43). The resulting vessel from this union between the internal and external ethmoid arteries continued rostrally along the floor of the olfactory fossa to the dorsal edge of the cribriform plate. It entered the nasal cavity to divide into three branches: the most dorsal septal nasal branch ramified within the mucosa along the junction of the nasal septum and the nasal bone, and supplied the dorsal nasal concha. It anastomosed with the dorsal branches of the septal nasal artery of the sphenopalatine. The other two branches were distributed to the mucosa of the ethmoturbinates.

The caudal lateral nasal artery (Fig. 1/35) arose from the infraorbital near the infraorbital foramen, coursed dorsally superficial to the nasal venous plexus and to the levator nasolabialis muscle. This artery supplied the caudodorsal nasal surface, as well as the lateral surface of the nose.

The rostral lateral nasal artery (Fig. 1/36) was more developed than the preceding vessel. It originated from the infraorbital artery few centimeters rostral to the caudal nasal artery. This vessel ran toward the nostril within the levator nasolabialis, supplied the rostrodorsal and adjacent lateral surfaces of the nose, and anastomosed with the superior labial artery. At the nostril, it split into several branches supplying most of the dorsal and lateral wall of the vestibular region.

The superior labial artery (Figs. 1,5,7/31) sent a superior terminal branch to the inferior border of the nostril where it formed a

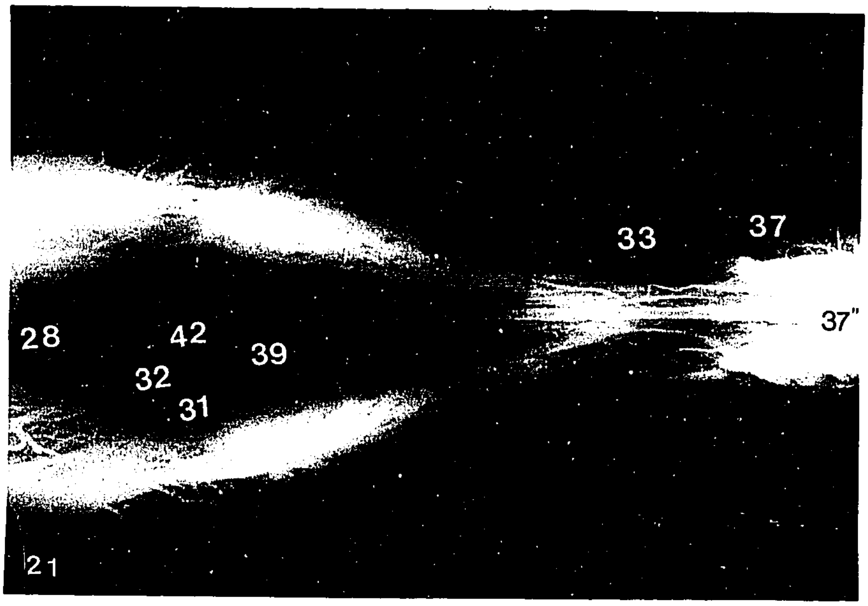
Plate 15

Figure 21. Radiograph of the nasal arteries (Dorsoventral view)

28. Carotid rete
31. Major palatine artery
32. Sphenopalatine artery
33. Infraorbital artery
37. Superior labial artery
37". Palatolabial artery
39. Ventral nasal artery
42. Septal nasal artery

Figure 22. Arterial supply to the left ventral nasal concha (Latex injection)

40. Distribution of the lateral branch of the ventral nasal artery (lateral view)
C. Caudal end
R. Rostral end



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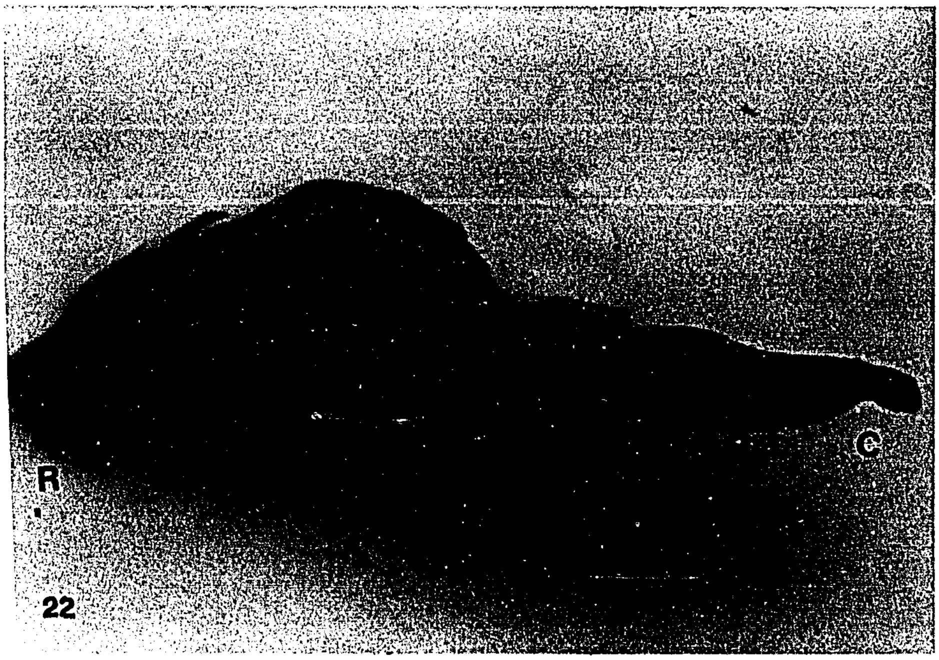

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circle around the external nares. It vascularized the floor and the lateral wall of the vestibular region of the nose.

The external dorsal nasal artery was not consistently present. When present, it arose from the infraorbital, or from the malar. It passed dorsocaudally superficial to the facial vein to supply the caudal external dorsal nasal surface.

The major palatine artery (Fig. 1/31) supplied the bony floor of the nasal cavity and via its palatonasal branch anastomosed with dorsal branches of the ventral nasal artery.

Venous drainage

The nasal cavity of the camel was mainly drained by the dorsal nasal and sphenopalatine veins with minor contributions from the external ethmoid and superior labial. The external surfaces of the nasal cavity were drained by the dorsal nasal, lateral nasal and possibly by the major palatine veins.

The dorsal nasal vein (Figs. 6,8,9,10,11,12,13,14,15/15) was well developed, often double, and formed one of the terminal branches of the facial vein having one valve. It stretched rostrally on the lateral side of the nose without accompaniment of a homonymous artery. This vein coursed obliquely, crossing the rostral border of the maxilla, under the levator nasolabialis muscle, and reached the caudal angle of the nasoincisive notch. Here, it received the deep and superficial veins draining the rostral part of the nasal cavity. The dorsal nasal vein received the confluence of 2 to 3 subcutaneous veins draining the skin of the lateral nasal wall, anastomotic branches from the dorsal impar nasal vein, and a ventral branch coursing ventrorostrally to anastomose with the superior labial vein. The terminal branches of the dorsal nasal consisted of three groups of veins: the first group was dorsal draining the nasal mucosa covering the dorsal nasal concha; the second group drained the rostral part of the nasal septum,and anastomosed with its fellow; and the third group ramified on the floor and the lateral nasal mucosa covering the ventral nasal concha. All these veins formed a very extensive venous plexus (Fig. 24); almost the rostral two-thirds of the nasal cavity were drained by the dorsal nasal vein.

The sphenopalatine vein (Figs. 9,12,18/29′) drained dorsal caudal, middle caudal, ventral caudal, and septal caudal nasal veins, and was satellite of branches of the homonymous artery. The dorsal caudal nasal vein received small tributaries from the ethmoturbinates and the caudal part of dorsal nasal concha. The middle caudal nasal vein came from the caudodorsal aspect of the ventral nasal concha, and the ventral caudal nasal vein drained the caudoventral aspect of the ventral nasal concha. The septal caudal nasal vein collected blood from the caudal septal venous plexus and the caudal part of the nasal floor. It anastomosed with the major palatine and the dorsal branch of the dorsal nasal vein. The sphenopalatine vein emptied into the deep facial that was seemingly valveless. From there, the venous blood reached either the maxillary, or the facial vein, or the cavernous sinus via the ventral external ophthalmic vein.

The deep facial vein (Figs. 7,8,9,10,11,12/9) This valveless

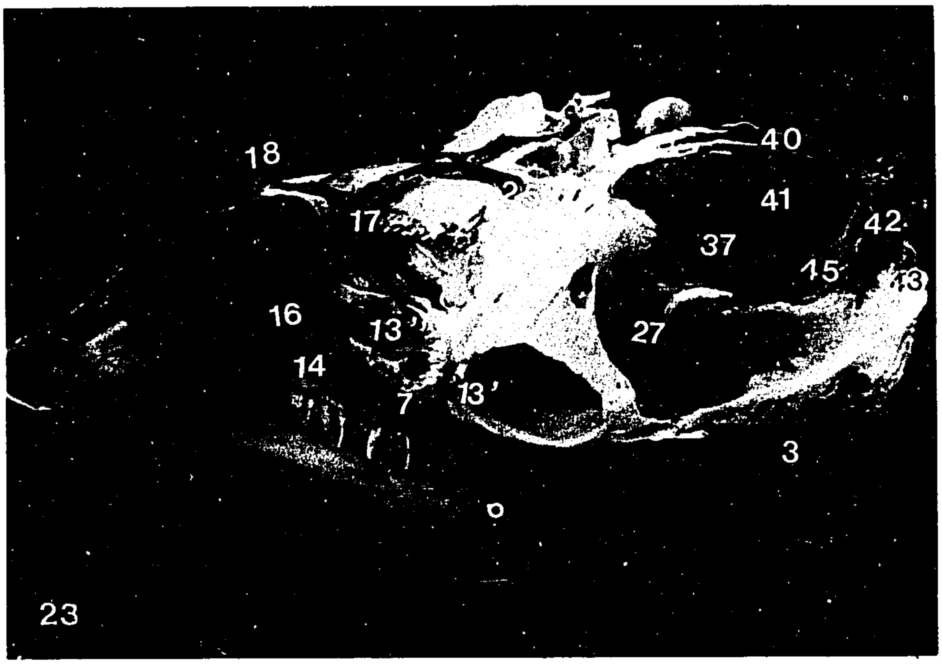
Plate 16

Figure 23. Venous drainage of the nasal cavity (Batson's # 17 injection)

3. Maxillary vein
6. Inferior alveolar vein
7. Facial vein
13'. Medial inferior palpebral vein
13". Infraorbital vein
14. Superior labial vein
16. Lateral nasal vein
17. Angularis oculi vein
18. Dorsal impar nasal vein
25. Frontal vein
27. Ophthalmic vein
37. Cavernous sinus
40. Dorsal sagittal sinus
41. Straight sinus
42. Transverse sinus
43. Sigmoid sinus
45. Temporal sinus
46. Emissary vein of the retroarticular foramen

Figure 24. Distribution of the dorsal nasal vein (15) (Batson's # 17 cast) in the vestibular region

C. Caudal end
R. Rostral end



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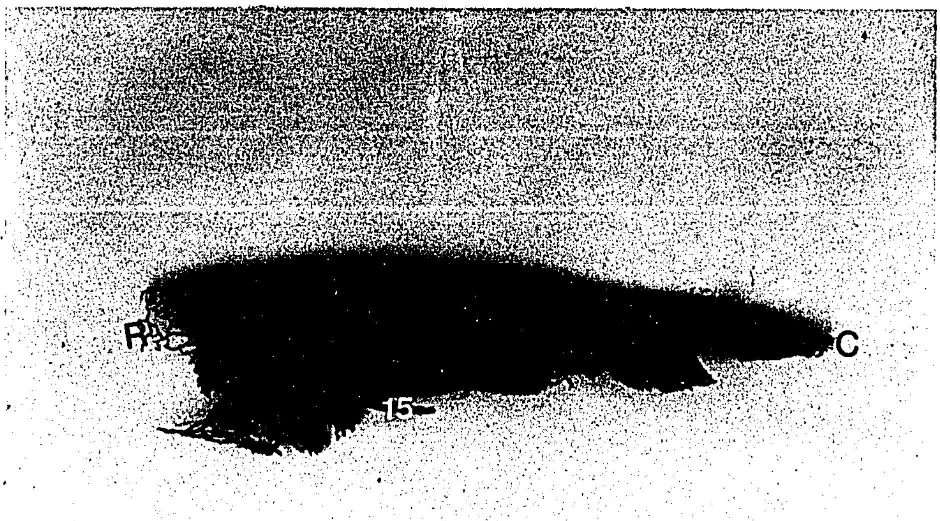

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vein of the facial received the sphenopalatine, major palatine, and minor palatine veins. During its course this vein was connected with the maxillary, ventral external ophthalmic, buccal and rostral deep temporal veins.

The external ethmoid vein drained the ethmoturbinates. It entered the orbit via the ethmoid foramen contributing to the ophthalmic plexus. There was an anastomosis between the right and left external ethmoid veins.

The superior labial vein (Figs. 6,6',8,10,11,12/14) drained the area of the philtrum and part of the floor of the nasal vestibule in addition to the superior lip. At the midline of the philtrum, there was an anastomosis between the right and left superior labial veins. From this confluence arose one vein draining the floor of the nasal vestibule. In this region, the lateral nasal, superior labial, and palatolabial veins anastomosed with each other.

The lateral nasal vein (Figs. 6',8,9,12/16) originated from the facial, or together with the dorsal nasal, coursed rostrally on the lateral aspect of the caninus muscle and then inside the levator nasolabialis muscle, and supplied them, as well as the lateral aspect of the nostrils. There were anastomoses between the lateral nasal, dorsal nasal, and superior labial veins.

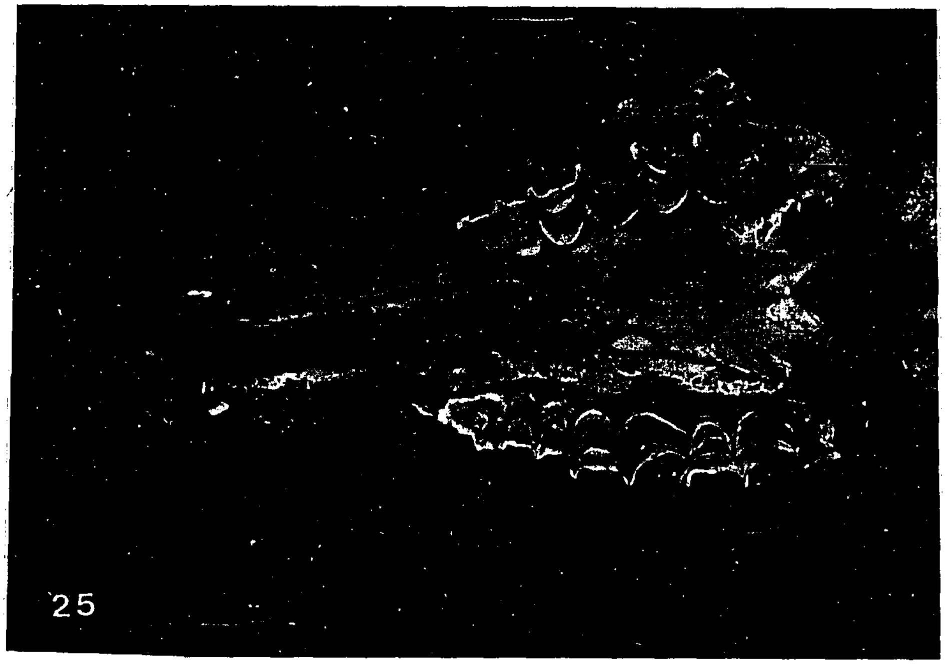
The angularis oculi vein (Figs. 6,7,8,9,10,11,12/17) was the other terminal branch of the facial vein, passed caudodorsally toward the medial canthus of the eye as the frontal vein. This vein received the dorsal impar nasal vein, before traversing the supraorbital canal, and

Plate 17

Figure 25. Venous plexus of the major palatine vein

Figure 25′. Major arteries of the head of the camel (Batson's # 17 cast), this showing the carotid rete, and the distribution of the septal nasal and external ethmoid arteries

1. Common carotid artery
3. Internal carotid artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
7. Caudal auricular artery
11. Facial artery
14. Maxillary artery
17. Inferior alveolar artery
24. Rostral rete branches
26. External ethmoid artery
28. Rostral epidural rete mirabile ("carotid rete")
28′. Ophthalmic rete
33. Infraorbital artery
42. Septal nasal branches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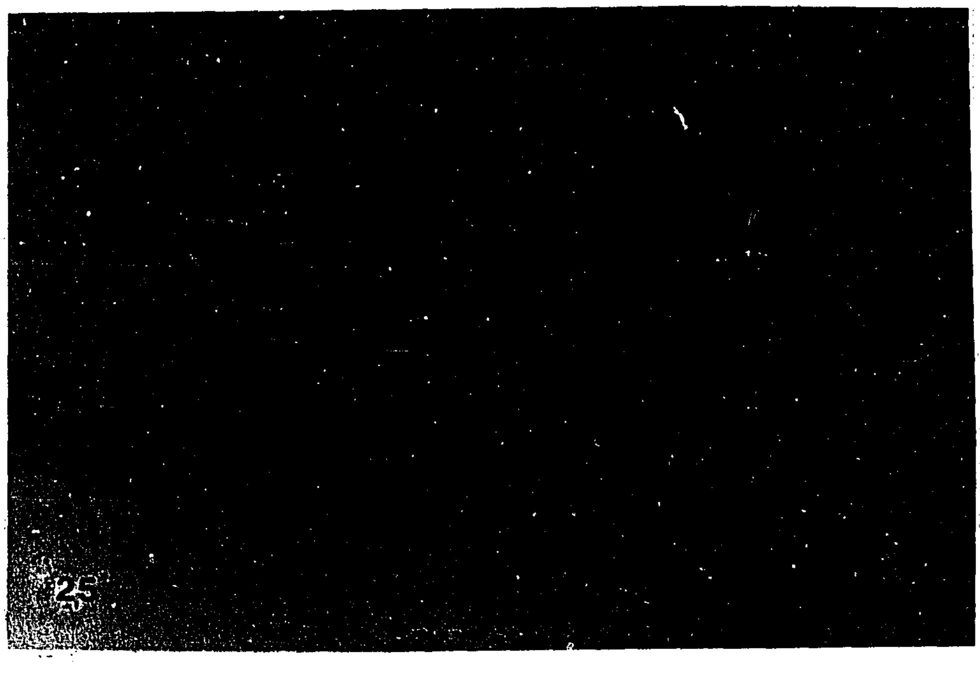
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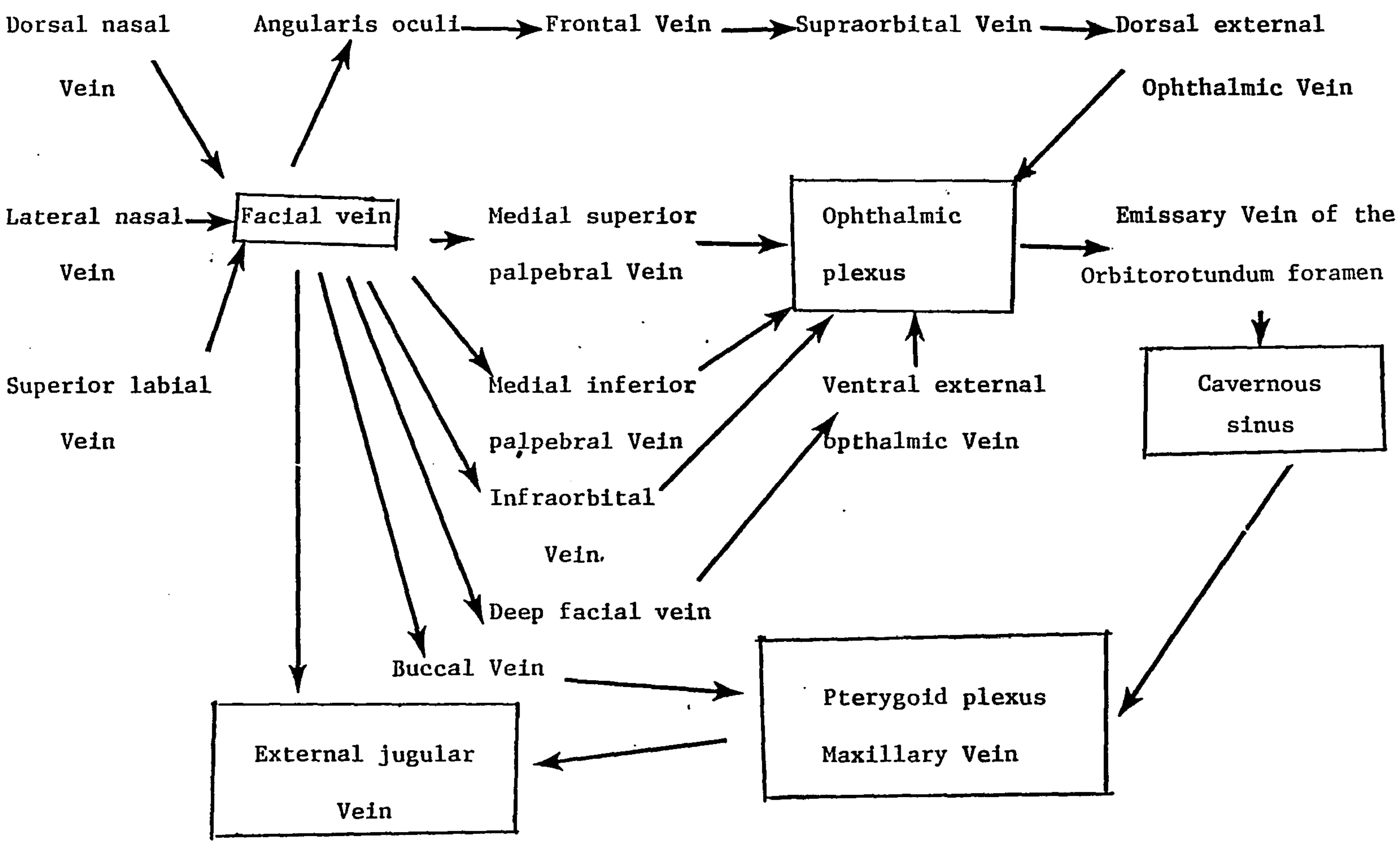
AN OVERVIEW OF THE VENOUS DRAINAGE OF THE NASAL CAVITY AND CONNECTIONS WITH THE CAVERNOUS SINUS



tributaries from the frontal region and adjoining region of the superior eyelid. Beyond the supraorbital canal, the supraorbital vein (extension of the frontal vein inside the canal) continued as the dorsal external ophthalmic vein contributing to the ophthalmic plexus.

The dorsal impar nasal vein (Figs. 6,9,10,13,15/18) took its origin from the anastomosis of both angularis oculi veins in the frontal region, extended rostrally along the internasal suture under the skin, and drained the skin of the dorsal nasal wall. This vein anastomosed on each side with the dorsal nasal veins, and contributed to the formation of the superficial nasal venous plexus.

The major palatine vein (Fig. 25) drained the venous network present throughout the hard palate. This plexus received anastomotic branches from the nasal floor via unnamed foramina, and joined the deep facial vein.

Specific Afferent and Efferent Vessels of the Carotid Rete and the Cavernous Sinus Complex

Rostral epidural rete mirabile (Figs. 1,2,4,25',26,27,28,29/28) The rostral epidural rete mirabile ("carotid rete") was located intracranially inside the cavernous sinus at the base of the brain. It was composed of small-to medium-sized muscular arteries that anastomosed freely with each other forming a meshwork of vessels. This vascular rete received afferents from the rostral rete branches of the maxillary and external ophthalmic, and internal carotid and middle meningeal arteries.

Plate 18.

Figure 26. Dorsal view of the rostral epidural rete mirabilia on the cranial floor (Latex injection)

28.	Right rostral epidural rete mirabile ("carotid rete")
28'.	Right ophthalmic rete
43.	Internal ethmoid artery
44.	Rostral intercarotid artery
45.	Caudal intercarotid artery

Figure 27. Arteriograph of the rostral epidural rete mirabile ("carotid rete") (Dorsoventral view)

6.	Common trunk of the caudal auricular, superficial temporal and facial arteries
14.	Maxillary artery
24.	Rostral rete branches
28.	Rostral epidural rete mirabile ("carotid rete")

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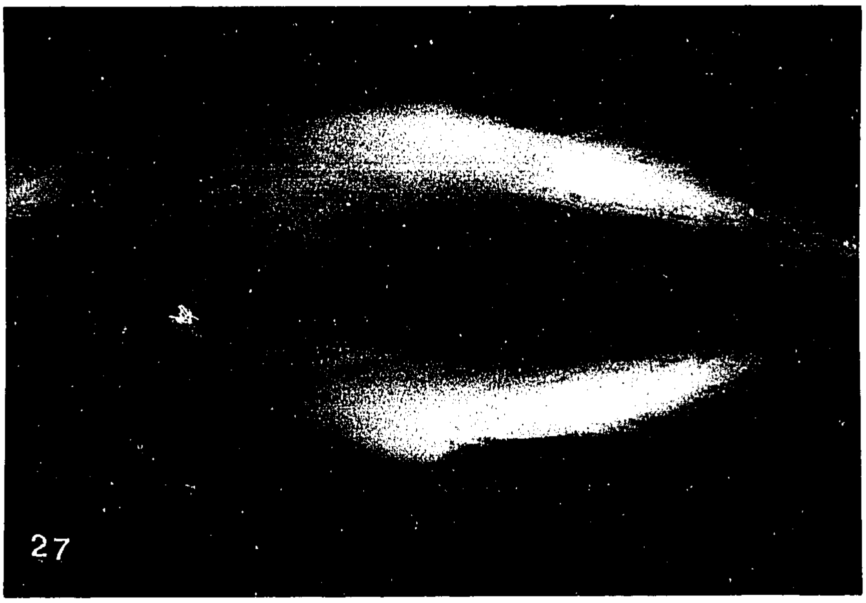

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1) The rostral rete branches (Figs. 1,4,25,26,29/24) of the maxillary artery entered the cranial cavity via the orbitorotundum foramen and after repeated branching they ramified in the carotid rete. These rete branches arose from the lateral (up to 4), dorsal (1 to 4), and medial (2 to 6) aspects of the maxillary.

2) The external ophthalmic artery (Figs. 1,4/22) close to its origin from the maxillary, usually gave rise to 2-3 rostral rete branches. They coursed dorsorostrally and contributed to the formation of the carotid rete after traversing the orbitorotundum foramen. They continued further rostrally participating in the ophthalmic rete.

3) The internal carotid artery (Figs. 1,4,25',29,38/3) had the carotid sinus at its origin, and entered the cranial cavity via the carotid canal. Inside the ventral petrosal and cavernous sinuses, it described a double curvature (s-shaped), and after emerging from these dural sinuses, it contributed to the formation of the carotid rete.

4) The middle meningeal artery (Fig. 1/19), after coursing lateral to the tympanic bulla, entered the cranial cavity via the oval foramen paralleling the mandibular nerve, and in a minor way supplied the carotid rete.

The ophthalmic rete (Figs. 1,4,25',26,28,29/28') appeared to be the direct rostral extension of the carotid rete as the transition between them was grossly indistinguishable. This rete was essentially formed by the external ophthalmic and internal ophthalmic arteries, and terminal ramifications of the external ophthalmic together with its rostral rete branches to the carotid rete.

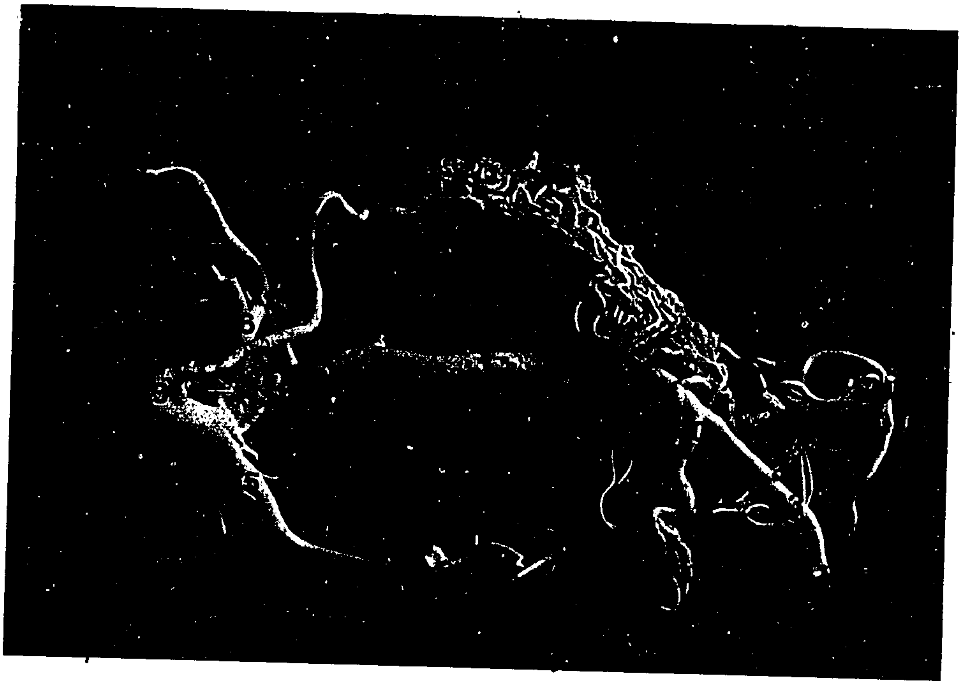
Plate 19

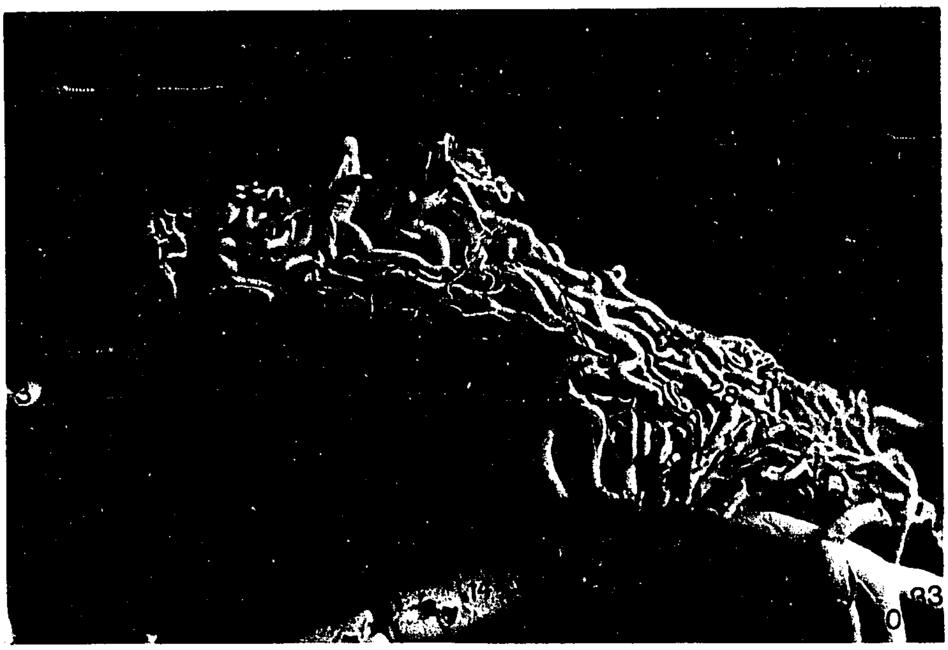
Figure 28. Latex' cast of the carotid rete (Medial view)

3. Internal carotid artery
5. Lingual artery
6. Common trunk of the caudal auricular, superficial temporal and facial arteries
14. Maxillary artery
24. Rostral rete branches
28. Rostral epidural rete mirabile ("carotid rete")
28'. Ophthalmic rete
30. Descending palatine artery
33. Infraorbital artery

Figure 29. Carotid rete (Latex' cast; medial view)

3. Internal carotid artery
14. Maxillary artery
24. Rostral rete branches
28. Rostral epidural rete mirabile ("carotid rete")
28'. Ophthalmic rete
30. Descending palatine artery
33. Infraorbital artery

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The carotid and ophthalmic retia together measured about 10 cm in length and 2-2.5 cm in width, consisting of small-to medium-sized muscular arteries. In unpreserved, latex- injected vascular cast the total length of all afferent vessels contributing to both carotid and ophthalmic retia was measured approximately 2.6 m, and the total surface area as 110 cm^2 in the camel. These vessels comprised a very complex arterial network along the ventral surface of the brain which was surrounded intimately by veins of the cavernous sinus and the ophthalmic plexus, respectively.

The right and left rostral epidural rete mirabilia were connected by the rostral (Fig. 26/44) and caudal (Fig. 26/45) intercarotid arteries, coursing along the corresponding aspects of the hypophysis cerebri. The rostral intercarotid artery was usually slender and ran transversaly ventral to the optic chiasma, whereas the caudal intercarotid artery was well developed representing several small transverse connections along the caudal limit of the hypohpysial fossa. The maxillary nerve proceeded rostrally between the carotid rete and the ophthalmic rete.

The intracranial part of the internal carotid artery consisted of two branches as they left the carotid rete and were destined to contribute to the cerebral arterial circle.

Cavernous sinus (Figs. 12,14,16,17,18,23/37)

The right and left cavernous sinuses lay on the respective sides of the floor of the middle cranial fossa, and occupied the medial groove containing the ophthalmic and the maxillary nerves. Both right and left cavernous sinuses were plexiform structures intermingling with the rostral epidural rete mirabilia. The cavernous sinus was smooth dorsally, convex ventrally, became enlarged caudally, and was related to the maxillary nerve laterally. The cavernous sinuses flanked both sides of the hypophysis cerebri. Rostrally, each sinus was connected with the ophthalmic plexus via the emissary vein of the orbitorotundum foramen; dorsolaterally, it received the middle meningeal vein, and each sinus gave off emissary veins that ran through the round, oval, carotid and jugular foramina to join the pterygoid plexus or the maxillary vein; caudally, the cavernous sinus was continuous with the basilar plexus and dorsocaudally, it received the dorsal petrosal sinus. They received a small meningeal vein, hypoglossal vein, and other veins mentioned previously. Both sinuses were connected medially by means of a slender rostral (Figs. 16,17/52) and a well developed caudal (Figs. 16,17/53) intercavernous sinuses, coursing transversely across the rostral and caudal aspects of the pituitary stalk of the dorsum sellae. The hypophysis cerebri was drained mainly by the caudal intercavernous sinus. The small rostral intercavernous sinus was located ventral to the optic chiasma, and received small veins draining the cribriform plate of the ethmoid.

Light, Scanning and Transmission Electron Microscopy

The nomenclature used here conforms to the Nomina Histologica Veterinaria (N.H.V), second edition (1983) and most official Latin terms

Plate 20

Figure 30. Section in the vestibular region of the nasal cavity (Azure II stain)
Line scale = 44 μm (76 x)

- a. Small artery
- b. Compound tubuloalveolar nasal gland, predominantly serous
- d. capillary
- g. Small arteriole
- i. Propria submucosa containing loose connective tissue
- v. small venule
- Ep. Stratified squamous epithelium

Figure 31. Magnified area of Fig.30 showing the nasal glands (b) and the close relation between the small arteriole (g) and small venule (v)
Line scale = 52.23 m (12 x)

Figure 32. Enlarged area of Fig. 30
Line scale = 39.2 μm (1.63 x)

- a. Small artery with its media (m), internal elastic lamina (i), and adventitia (n)
- b. Compound tubuloalveolar nasal glands, mostly serous
- e. Glandular duct

Figure 33. Photomicrograph of the nala mucosa (vestibular region) showing thin-walled vein (v) surrounding thin walled artery (f) and nasal glands (b). Large sinuses (d) were found close to the glandular duct (e) deep to the stratified squamous epithelium (Ep)
(Azure II stain)
Line scale = 102 μm (78 x)

Figure 34. Magnified area of Fig. 33 showing the glandular duct) opening onto the surface epithelium and surrounded by capillaries (c), large sinuses (d) and small venules (v)
Line scale = 105 μm (76 x)


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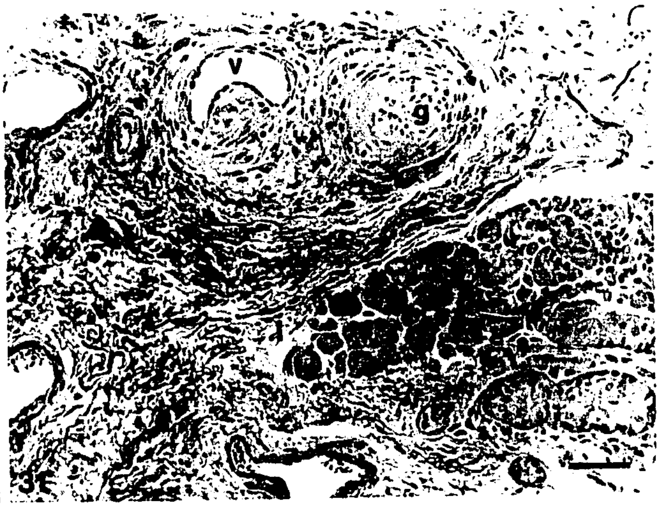
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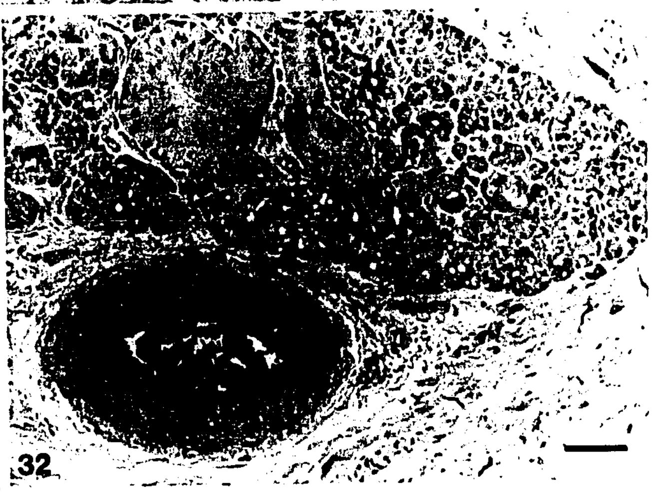
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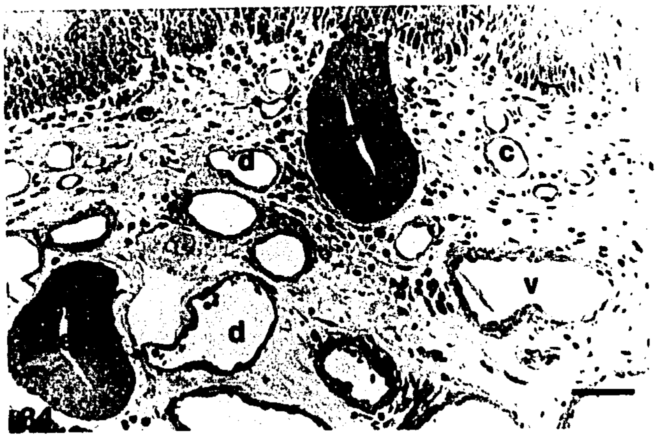
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have been translated to accepted English equivalents. The description below includes the microscopic anatomy of different regions of the nasal cavity, the angularis oculi, dorsal nasal, and facial veins, and the carotid rete-cavernous sinus complex.

Nasal cavity

Vestibular region The nostrils were covered by a thin hairy skin consisting of keratinized, stratified squamous epithelium with a few hair follicles. Each hair follicle was surrounded by two or three lobules of sebaceous glands and associated with erector pili muscles. The connective tissue of the propria submucosa was dense and few vessels and glands were noticed in this region.

At the vestibular region, the epithelium was thick stratified squamous without any hair follicles. The propria submucosa contained rostrally a dense layer of connective tissue which was loose in the rest of the vestibule. Large free bundles of striated muscles were seen in the vicinity of the predominantly serous glands, and occasionally a few free smooth muscle fibers were present. Predominantly serous, compound tubuloalveolar mixed glands (Figs. 30,31,32,36a,36b/b) forming a prominent discoid mass were found within the mobile rostral part of the nasal septum. They were composed of rounded or oval macroscopic lobes held together by connective tissue. Each lobe was divided, in turn, into lobules supported by dense connective tissue septa; each lobule consisted of 1 or 2 intercalated ducts surrounded by coiled tubules. The lobes were disposed on either side of the septum, but on the lateral wall they occupied the entire propria submucosa. There was a large duct

Plate 21

Figure 35. Scanning electron micrograph of the cut surface of the septal nasal mucosa (vestibular region)

Line scale = 102 μm (78 x)

A. Arteriole

Ep. Stratified squamous epithelium

V. Vein

v. Small vein

Figure 36a. Scanning electron micrograph of the surface cut of the lateral wall of the nasal mucosa (Vestibular region)

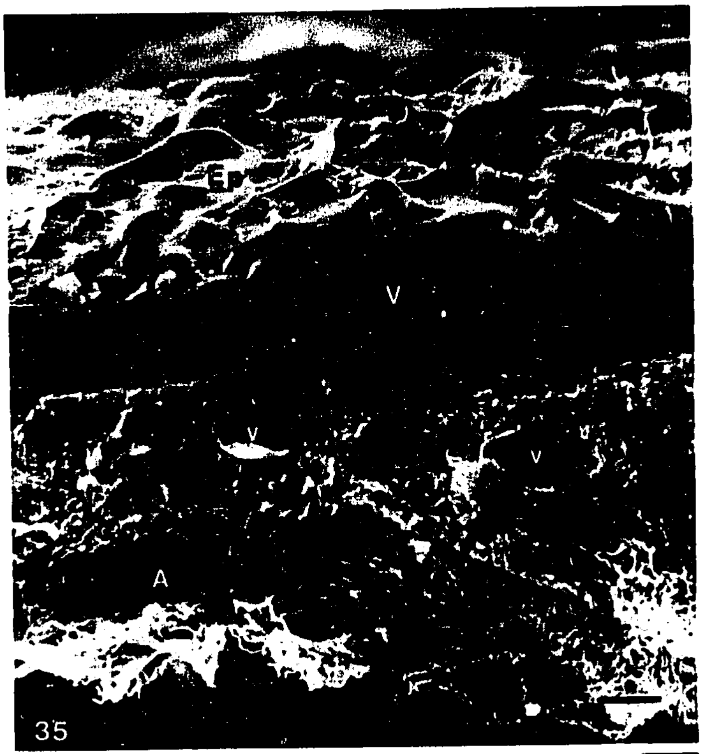
Line scale = 102 μm (78 x)

A. Artery

b. Compound tubuloalveolar glands, predominantly serous

e. Glandular duct

Ep. Stratified squamous epithelium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with low cuboidal epithelium (Figs. 32,33,34,36a,36b/e), draining one or more lobes, which ascended obliquely to open onto the surface epithelium. In the caudal part of the vestibule, the glands were located close to the perichondrium. These predominantly serous glands were also found at the rostral part of the dorsal and ventral nasal conchae, and on the nasal floor.

The propria submucosa of the rostral part of the vestibular region of the septal wall was poorly vascularized by a few arteries and veins, especially at the mobile rostral part of the nasal septum. In the remaining vestibular region, blood vessels were disposed within the propria submucosa subepithelially as well as in the periglandular area. The first group of subepithelial vessels included large sinuses (Figs. 33,34/d), capillaries, arterioles of 1 to 4 smooth muscle layers (Fig. 30/g), and venules of 1 to 2 smooth muscle layers. Within the propria submucosa, compound tubuloalveolar glands were more abundant than arteries. The arteries were invested with a thick wall consisting of 8 to 10 smooth muscle layers, others with 5 to 8 layers. They were located either deeper to the glands (Figs. 30,32/a), deeper to the vein (Fig. 35/A), or at the same level as the glands (Fig. 36/A). They had a well developed internal elastic lamina (Fig. 32/i), but a distinct external elastic lamina was not discernible. The adventitia of these arteries was thinner than the tunica media. Most of the arterioles, with 1-3 smooth muscle layers (Fig. 33/f), were surrounded by thin-walled veins (Fig. 33/v) in the caudal vestibular region. In the propria submucosa between the subepithelium and the glands, thick walled

Plate 22

Figure 36b. Paraffin section of the nasal mucosa of the vestibular region showing the tubuloalveolar glands, predominantly serous (b) (H & E stain)

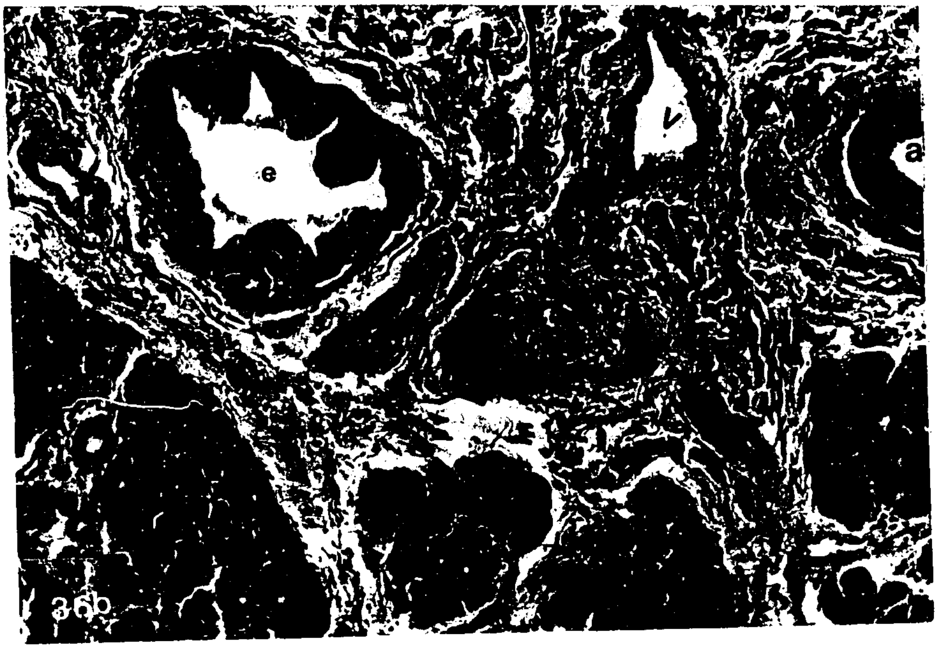
Line scale = 44 μm (88 x)

a. Small artery
b. Nasal glands
e. Glandular duct
v. Small venule

Figure 36c. Photomicrograph of the respiratory nasal mucosa (internal lamina of the ventral scroll of the ventral concha) (Trichrome stain)

Line scale = 105 μm (78 x)

A. Pseudostratified ciliated columnar epithelium
B. Nasal glands
N. Nerve fibers
v. Small venules
a. Small artery


e
v
a
36b


A
36c

veins with 3-5 smooth muscle layers were located superficial to the glands and to the arteries (Fig. 35/V). Small arteries of 3-5 smooth muscle layers with and without an internal elastic lamina, were present (Fig. 36b/a). Also, the terminal portions of the glandular ducts with large lumina surrounded by thin-walled veins and large sinuses were present (Figs. 33,34,36b/e). In addition, both thin- and thick-walled veins, and a third type of vein with 3-5 incomplete circular, smooth muscle layers were found at the alar fold.

In the transitional zone at the level of first upper premolar, the epithelium became thin stratified squamous. The glands were simple, tubuloalveolar mixed type, predominantly serous lying in the upper part of the propria submucosa. The arteries were located deeper to satellite veins and to the glands. The number of smooth muscle layers of the tunica media varied from 5 to 8. Large bundles of nerve fibers were visible at the same level, or deep to the arteries. The elastic fibers and the free smooth muscles became less abundant. The glands were surrounded by thin-walled veins and sometimes by arteries in the dorsal concha.

<u>Respiratory region</u> The appearance of the respiratory epithelium (Figs. 36c,37,38,39) began at the first upper premolar at 4 places, viz., the nasal floor, nasal septum, lateral wall, and the ventral nasal concha, but that of the dorsal concha started at the second upper premolar. In the ventral nasal concha, the respiratory epithelium was sometimes visible at the level of second upper premolar. The epithelial lining was pseudostratified with ciliated and non-ciliated columnar

Plate 23

Figure 37. Paraffin section of the nasal mucosa (second upper premolar region) (H & E stain)
Line scale - 87.5 μm (80 x)

A. Pseudostratified ciliated columnar epithelium
B. Nasal mixed glands predominantly mucous
C. Glandular duct
V. Veins

Figure 38. Scanning electron micrograph of the surface of pseudostratified ciliated columnar epithelium (nasal septum)
Line scale - 2.45 μm (2880 x)

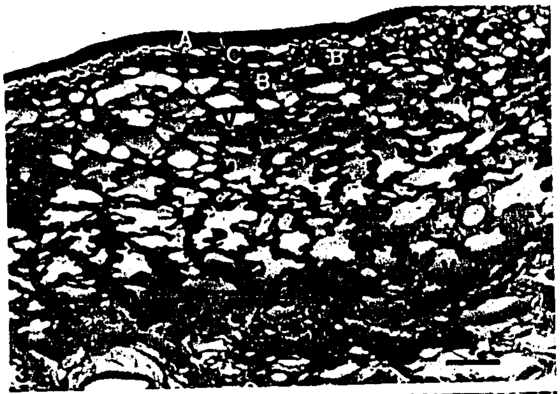
A. Pseudostratified ciliated columnar epithelium
Ci. Cilia
CC. Nonciliated cells
Sd. Secretion
Mv. Microvilli
GC. Goblet cells

Figure 39. Enlarged area of Fig. 37 showing mixed glands (B), predominantly mucous, and their duct (C) opening onto the surface epithelium (A)
Line scale - 27.3 μm (204 x)

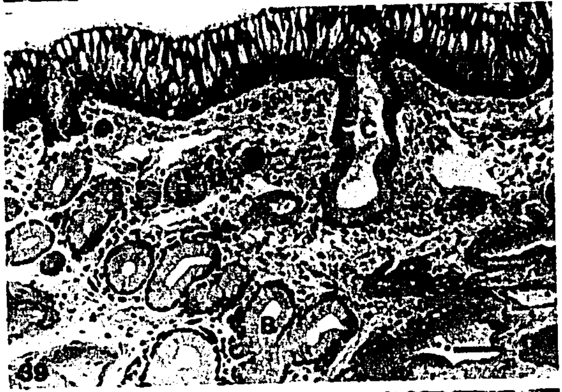
Figure 40. Medium-sized artery with large lumen (E) (Weigert's stain
Line scale - 46 μm (253 x)

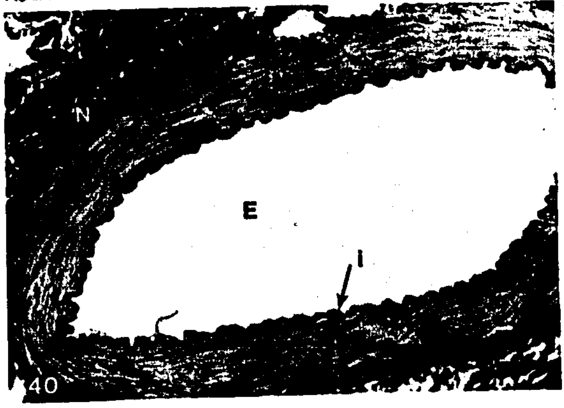
E. Lumen of the artery
i. Internal elastic lamina
M. Tunica media
N. Tunica adventitia

Figure 41. Scanning electron micrograph of the surface cut of the nasal mucosa from the second upper premolar region, showing small artery (a) surrounded by small veins
Line scale - 25 μm (283 x)


A
C
B
B
V


GC
Mv
A
GC
38


C
B
B
39


N
E
I
40


V
V
V
a
41

cells (Fig. 38). The goblet cells (Fig. 38/GC) were abundant in some places, such as the nasal floor, ventral scroll of the ventral nasal concha, and the lateral wall. But in other places, such as the dorsal scroll and dorsal nasal concha had a few goblet cells. Few elastic fibers were discernible subepithelially. The propria submucosa had a loose connective tissue layer lying subepithelially which appeared to be dense in the perichondrial region. The glands (Figs. 37,39/B) were simple tubuloalveolar, mostly mucous type, some of them located subepithelially close to the surface where their ducts opened (Figs. 37,39/C), and others were distributed throughout the propria submucosa between veins. The arteries of the respiratory region (Fig. 41/a) were deeply embedded in the propria submucosa close to the perichondrium. Their lumina (Fig. 40/E) were large and their walls possessed 5 to 8 smooth muscle layers, with well developed internal elastic lamina (Fig. 40/i). Most of these arteries with distinct internal elastic laminae were surrounded by large thin-walled veins that had 1 to 3 smooth muscle layers (Fig. 41/a). The veins of the respiratory region anastomosed with each other forming a rich venous plexus (Figs. 37,41/V). The veins of the dorsal nasal concha did not form a cavernous structure similar to those of the lateral wall, the nasal septum, the nasal floor and the ventral nasal concha. In the ventral nasal concha, the venous plexus was well developed in the external lamina of the ventral scroll that was in contact with air-stream, but its internal lamina did not possess a rich venous plexus (Fig. 36c); the vein did not anastomose with each other and relatively few simple tubuloalveolar glands were observed.

Plate 24

Figure 42. Section of the olfactory area at level of the last upper molar tooth (Azure II Stain)
Line scale = 100 µm (80 x)

- A. Artery
- B. Nasal glands, predominantly mucous
- e. Capillary
- E. Olfactory epithelium
- V. Veins

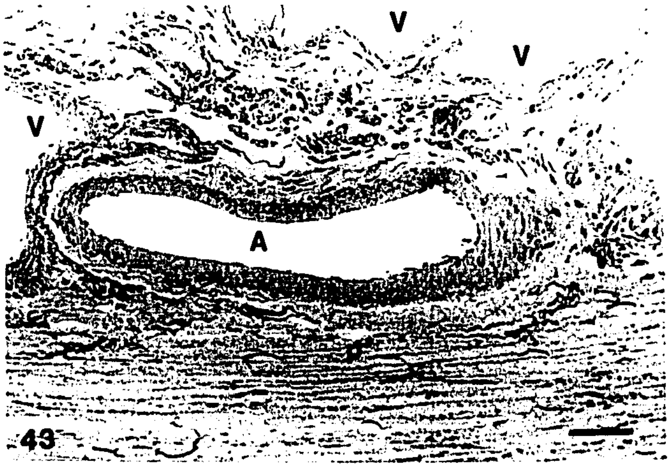
Figure 43. Enlarged area of Fig. 42, showing the artery (A), surrounded by veins (V), and located close to the perichondrium (P)
Line scale = 88.8 µm (90 x)

Figure 44. Scanning electron micrograph of the surface cut of the nasal mucosa (last upper molar region) showing few blood vessels
Line scale = 53.3 µm (150 x)

Figure 45. Scanning electron micrograph of the surface of the nasal mucosa (Last upper molar region) showing the opening of the nasal glands (b)
Line scale = 5.3 µm (1650 x)

Figure 46. Magnified area of Fig. 45 showing the opening of the nasal glands (b)
Line scale = 0.54 µm (14950 x)

42



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46

The goblet cells were evident in those areas directly in contact with the air-stream. The arteries were thin-walled with large lumina and were deeply embedded. Thin- and thick-walled veins and nerve fibers were also found within the propria submucosa of the external lamina of the ventral scroll.

Olfactory region The third kind of epithelium found in the nasal cavity was olfactory in nature (Fig. 42/E). This kind of epithelium was visible at the level of the last upper molar on the lateral wall, ethmoturbinates, caudal part of the nasal septum, and the caudal parts of the dorsal and ventral nasal conchae and the ethmoturbinates. A large number of olfactory glands (Fig. 42/B), mostly mucous type, was scattered subepithelially close to the surface where their ducts opened (Figs. 45,46/b). A few capillaries were seen in this region. The arteries (Figs. 42,43/A) were medium-sized (5-8 smooth muscle layers) with a prominent internal elastic lamina and most of them were surrounded by veins (Figs. 42,43/V) with 2-4 smooth muscle layers in their tunica media. Also, thick-walled arterioles with upto 4 smooth muscles layers were found. The veins were located within the propria submucosa without forming a venous plexus (Fig. 42/V). Large bundles of the nerve fibers were observed in deep propria submucosa with the arteries. In one case, one artery showed a bolster.

Facial, angularis oculi, and dorsal nasal veins The wall of the facial vein differed from that of the angularis oculi and dorsal nasal veins. The facial vein (Figs. 47,48,50) was composed of 8 to 10 incomplete smooth muscle layers; the circular layer (Figs.47,48, 50/E)

Plate 25

Figure 47. Paraffin section of the wall of the facial vein
(H & E Stain)
Line scale - 119 μm (80 x)

A. Lumen
B. Tunica intima
C. Tunica media
D. Tunica adventitia
E. Circular smooth muscle layer
F. Longitudinal smooth muscle layer

Figure 48. Enlarged area of Fig.47
Line scale - 52.6 μm (190 x)

A. Lumen
B. Tunica intima
C. Tunica media
E. Circular smooth muscle layer
F. Longitudinal smooth muscle layer

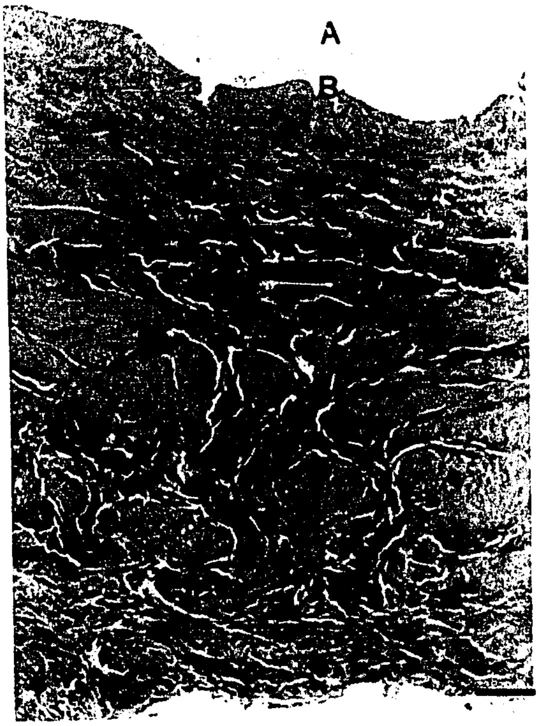
Figure 49. Cross section of the angularis oculi vein
(Azure II Stain)
Line scale - 166 μm (60 x)

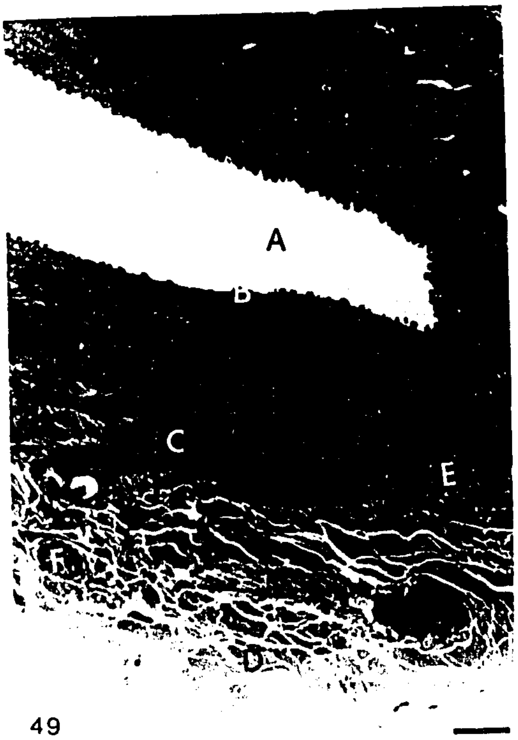
A. Lumen
B. Tunica intima
C. Tunica media
D. Tunica adventitia
E. Circular smooth muscle layers
F. Longitudinal smooth muscle layers

Figure 50. Cross section of the wall of the facial vein
(Azure II Stain)
Line scale - 73.5 μm (136 x)

A. Lumen
B. Tunica intima
C. Tunica media
E. Circular smooth muscle layers
F. Longitudinal smooth muscle layer

47





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50

Plate 26

Figure 51. Scanning electron micrograph of the bifurcation of the facial vein (freeze fracture)

Line scale = 154 μm (48 x)

O. Angularis oculi vein

D. Dorsal nasal vein

L. Lateral nasal vein

Figure 52. Freeze fracture section of the carotid rete-cavernous sinus complex

Line scale = 81 μm (79 x)

A. Artery of the carotid rete

a. Tunica adventitia common to both artery and vein

e. Endothelial lining of the vein

i. Tunica intima of the artery

m. Tunica media of the artery

V. Vein of the cavernous sinus

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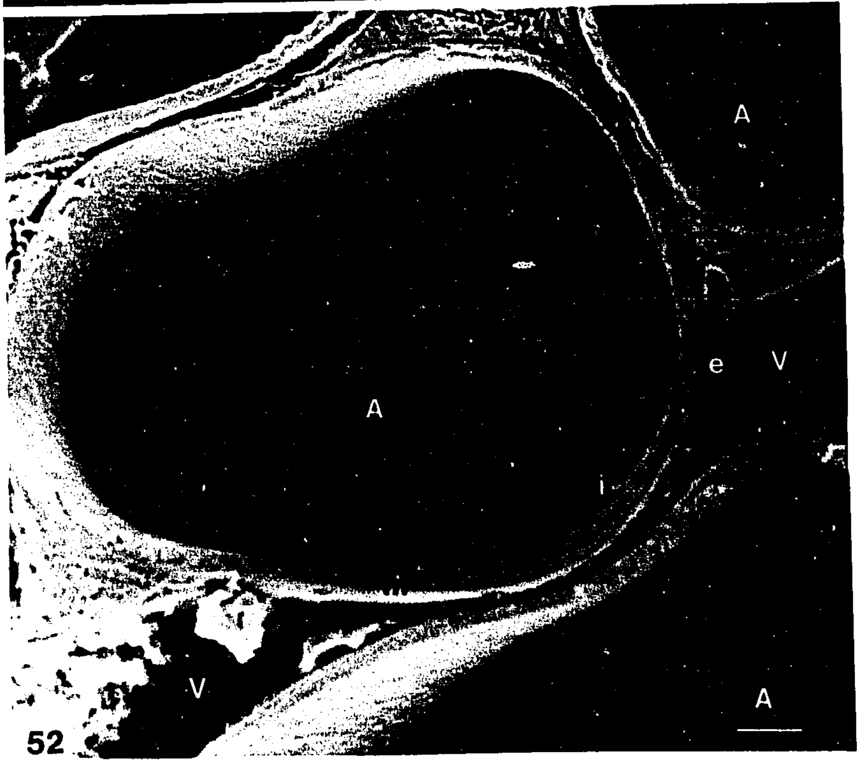

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was thicker than the longitudinal layer (Figs. 47,48,50/F) with abundance of nerve fibers. The internal elastic lamina was distinct. The collagen fibers formed bundles between the smooth muscles and the tunica adventitia. The elastic fibers were scattered in the adventitia and in-between the smooth muscles of the tunica media. The tunica media (Figs. 47,48,50/C) was thicker than the adventitia (Figs. 47,48,50/E). In angularis oculi and dorsal nasal veins, the tunica media (Fig. 49/E) was relatively thinner than in the facial vein. In those veins, there were 3 to 6 incomplete circular layers of smooth muscle and relatively thick longitudinal fibers, and the tunica adventitia was relatively thicker than the tunica media. A valve-like structure was discernible in the dorsal nasal vein close to its origin from the facial. Collagen bundles and elastic fibers were seen in the tunica media as well as in the adventitia; nerve fibers were present in the adventitia.

The carotid rete-cavernous sinus complex

Carotid rete This vascular complex was located within the meningoendocranial compartment of the dura mater. The carotid rete was mainly composed of medium- to small-sized muscular arteries (Figs. 52,53,54,55,56/A), and consequently the thickness of their walls varied in different segments of the rete. The tunica adventitia (Figs. 58,60/L) was thinner than the tunica media, consisted of connective tissue with bundles of collagen fibers (Figs. 58,60/C), fibroblasts (Fig. 58/F) and few elastic fibers. The external elastic lamina was indistinguishable. The tunica media was well developed having 6 to 12 smooth muscle cell layers (Figs. 54,55,56,57,58/M). The longitudinal

Plate 27

Figure 53. Scanning electron micrograph of the carotid rete-cavernous sinus complex

Line scale - 111 μm (81 x)

A. Artery
V. Vein

Figure 54. Enlarged area of Fig. 53 showing the relationship between the arteries (A) surrounded by veins (V) of the cavernous sinus and sharing the same tunica adventitia

Line scale - 67 μm (135 x)

a. Tunica adventitia common to both artery and vein
e. Endothelium of the vein
m. Tunica media of the artery
i. Tunica intima of the artery with the endothelial cells bulging into the lumen

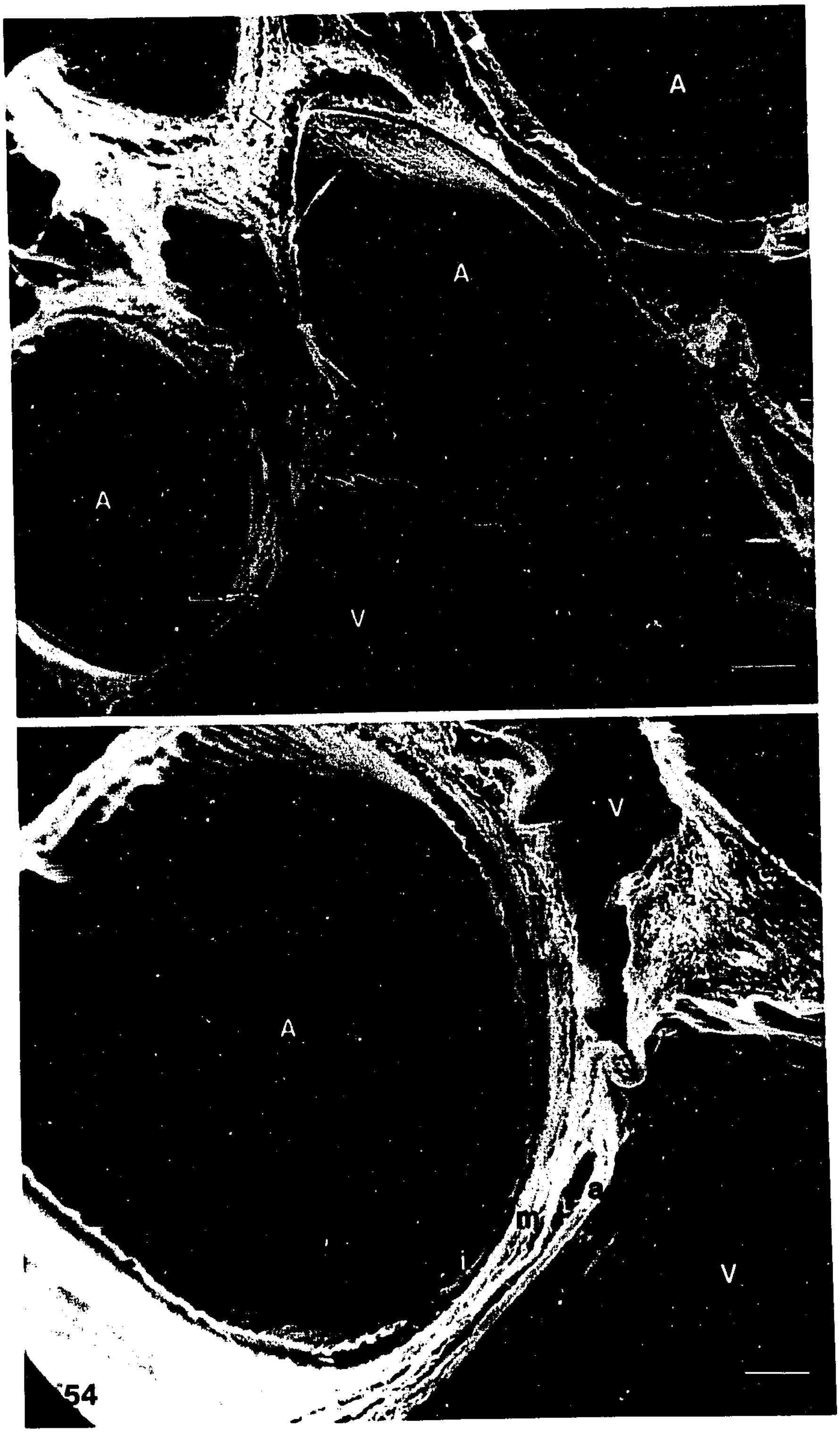

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Plate 28

Figure 55. Paraffin section of the carotid rete-cavernous sinus complex. (Weigert's Stain)

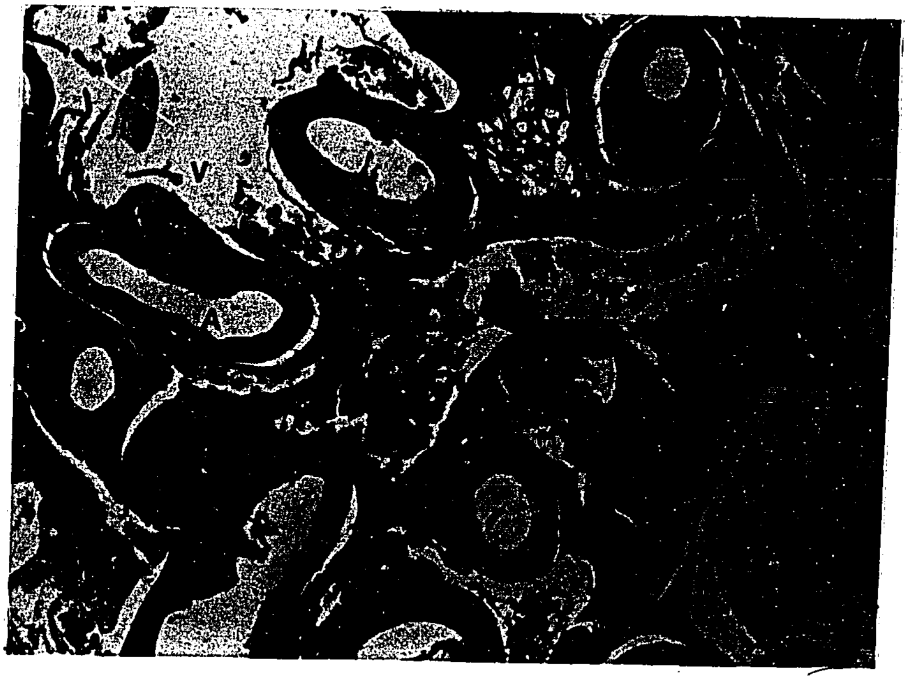
Line scale = 119 μm (84 x)

A. Artery of the carotid rete
I. Internal elastic lamina of the artery
M. Tunica media of the artery
V. Vein of the cavernous sinus

Figure 56. Paraffin section of the cavernous sinus (Trichrome Stain)

Line scale = 119 μm (84 x)

A. Artery of the carotid rete
E. Endothelium of the vein
V. Vein of the cavernous sinus



56

and circular muscle fibers seemingly coursed in all directions and were surrounded by basal laminae and collagen fibers. The tunica intima (Figs. 58,59/E) consisted of the internal elastic lamina (Figs. 56,58,59/I) with quite distinct endothelial lining (Figs. 58,59/E). The endothelial cells had a prominent nucleus and were linked by gap junctions (Figs. 59,63 arrows). Sometimes the endothelial cells bulged into the lumen (Fig. 61/E). The internal elastic lamina was prominent and fenestrated (Figs. 63,64/I). Through this opening, the ground substance of the tunica intima was in continuity with that of the tunica media. In some places, the tunica adventitia was common to both arteries and veins of the cavernous sinus (Fig. 58/L). Therefore, one arterial branch of the carotid rete shared its adventitia with one or more veins. In other places, the adventitia of the arteries was separated, being independent from that of the veins (Fig. 62/C). There were no arteriovenous anastomoses noticed in this vascular complex. Myelinated and non-myelinated nerve fibers were present in the tunica adventitia.

Cavernous sinus The cavernous sinus had a structure different from region to region. It consisted of several thin-walled venous channels, or large caverns surrounding the arteries of the carotid rete (Figs. 52,53,54,55,56/V). Examination of serial sections revealed that in some places one vein consisted of endothelial lining (Figs. 56,60/E) surrounded by a thin adventitia being shared with adjacent arteries (Fig. 60/L). The endothelial cells were flattened (Fig. 60/E) and linked by gap junctions (Fig. 60 arrow). No smooth muscle cells were

Plate 29

Figure 58. Transmission electron micrograph of the carotid rete-cavernous sinus complex showing a common tunica adventitia for both artery and vein
Line scale = 1.6 μm (5143 x)

A. Lumen of the artery
E. Endothelial lining of the tunica intima of the artery
I. Internal elastic lamina of the artery
L. Common tunica adventitia of both artery and vein
M. Tunica media of the artery
N. Endothelial lining of the vein
V. Lumen of the vein

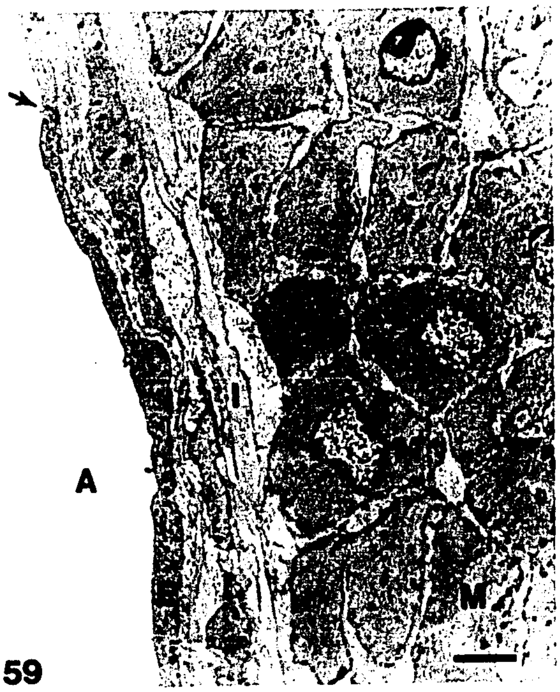
Figure 59. Enlarged area of Fig.58 showing the tunica intima of the artery and a part of the tunica media
Line scale = 0.17 μm (46886 x)

A. Lumen of the artery
E. Endothelial cell (the arrow shows the gap junction between two endothelial cells)
I. Internal elastic lamina
M. Smooth muscle cells

Figure 60. Magnified area of Fig. 58 showing the tunica intima of the vein
Line scale = 0.17 μm (46886 x)

C. Collagen fibers
E. Endothelial cell of the vein
L. Common tunica adventitia of both artery and vein
M. Smooth muscle cells
N. Endothelial lining of the vein
V. Lumen of the vein
Arrow. Gap junction

58



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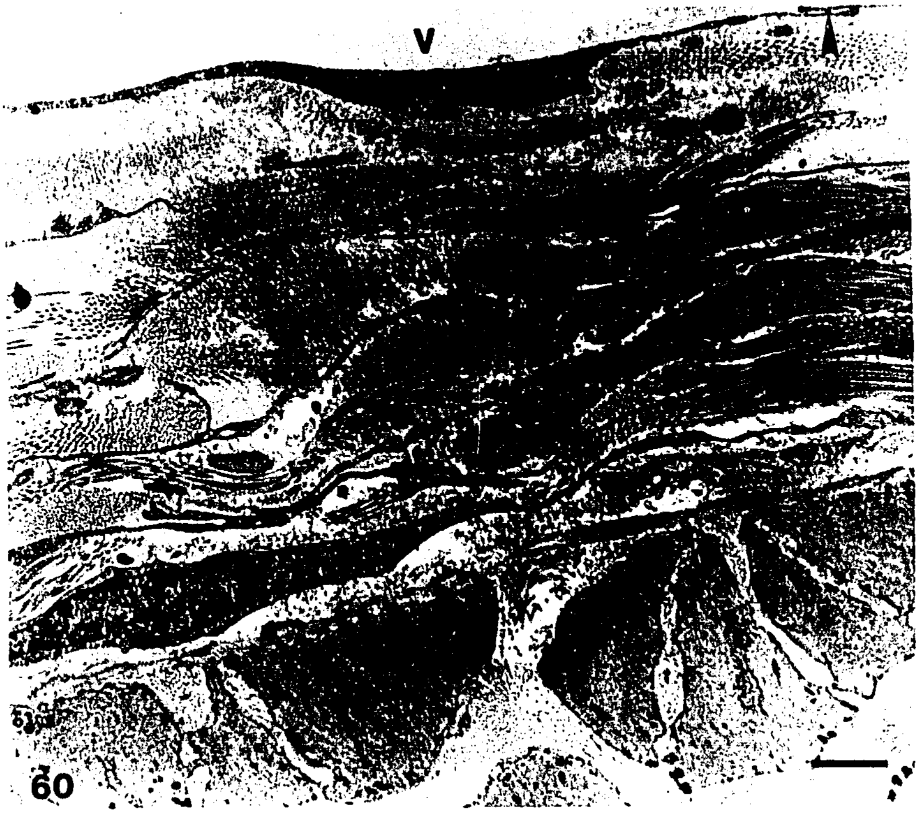

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noticed on the wall of the cavernous sinus, but some elastic fibers were present throughout its extent. In some places, one artery was completely surrounded by the veins and in others one vein was in contact with two or more arteries (Fig. 55). The nerve fibers were abundant within the dura mater.

The carotid rete-cavernous sinus complex was related to the cranial nerves III, IV, V and VI. The maxillary nerve of the trigeminal was seen in relation to the floor of the middle cranial fossa. The oculomotor nerve was located most dorsally. Immediately below was the trochlear that was followed by the ophthalmic nerve of the trigeminal. The abducens nerve, lying inferioromedially, was in contact with carotid rete branches.

Plate 30

Figure 61. Transmission electron micrograph of the tunica intima of one carotid rete branch
Line scale = 0.12 μm (54720 x)

A. Lumen of the artery
C. Collagen fibers
E. Endothelial cells bulging into the lumen
I. Internal elastic lamina

Figure 62. Transmission electron micrograph of the carotid rete-cavernous sinus complex: The tunica adventitia is not common to both the artery and vein.
Line scale = 0.64 μm (9936 x)

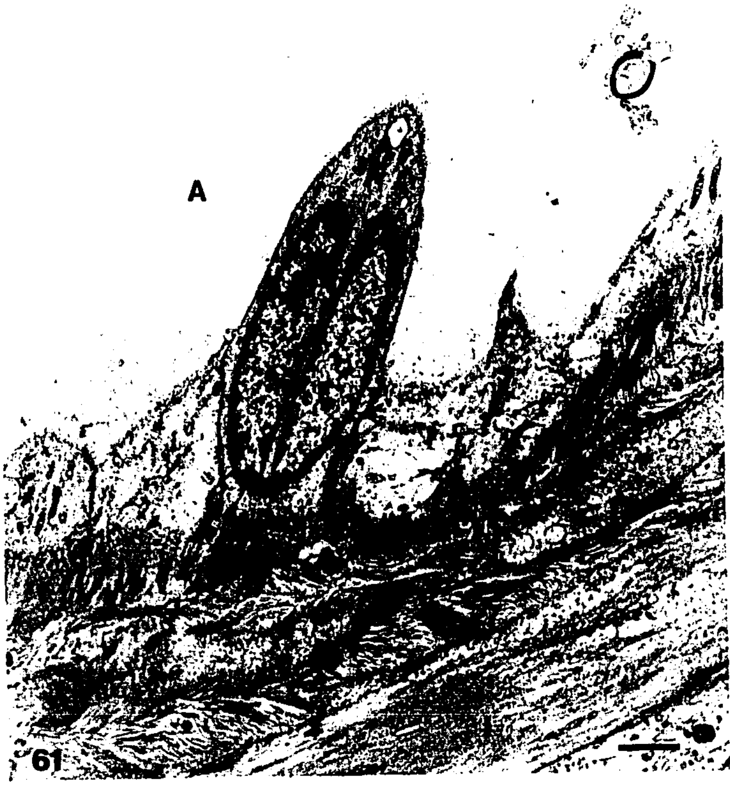
C. Collagen fibers of the arterial wall
E. Endothelial lining of the vein
N. Tunica adventitia of the vein
M. Smooth muscle cells of the tunica media of the artery
V. Lumen of rhe vein

Figure 63. Transmission electron micrograph of one area of the arterial wall of rete branch ,showing gap junction (arrow) between two endothelial cells
Line scale = 0.10 230 μm (54000 x)

A. Lumen of the artery
C. Collagen fibers
E. Endothelial lining of the artery
I. Fenestrated internal elastic lamina
M. Smooth muscle cells

Figure 64. Transmission electron micrograph of the carotid rete showing a fenestrated internal elastic lamina (I): Arrow is showing the continuation of the ground substance of the tunica intima with that of the tunica media
Line scale = 0.16 μm (39940 x)

A. Lumen of the artery
E. Endothelial lining of the artery
M. Smooth muscle cells



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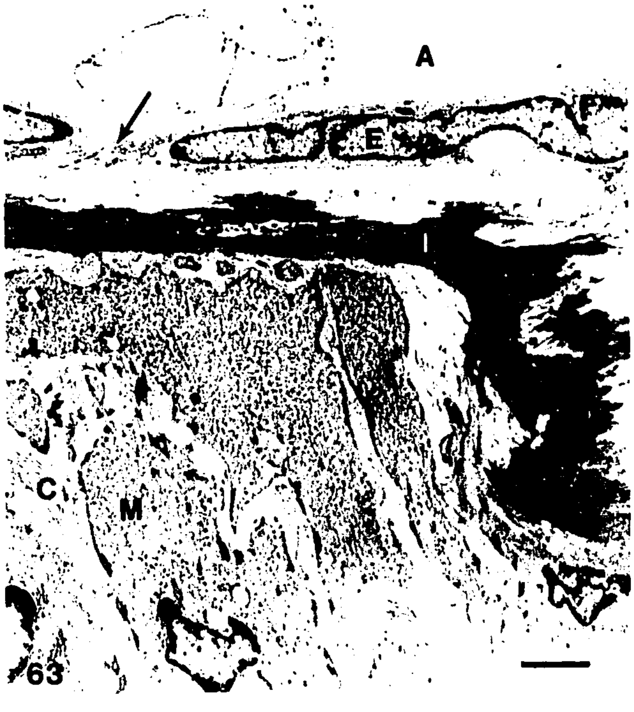

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DISCUSSION

Gross Anatomy

General blood supply of the head

Arteries Similar to the horse, pig, and dog, the internal carotid artery of the camel remained patent and functional throughout life. This vessel contributed to the formation of the rostral epidural rete mirabile ("carotid rete") that is found in pig, ruminants and dog (Bourdelle and Bressou, 1964, 1972; Getty, 1975; Nickel et al., 1981). The internal carotid artery in the camel had a double curvature (S-shaped) at first inside the ventral petrosal and then in the cavernous sinus similar to the horse. The course and branching pattern of the occipital artery of the camel resembled those of the horse. It gave off the condylar artery as in the horse, ruminants and carnivores, and had a more extensive anastomosis with the vertebral artery in the camel than in ruminants. The distribution of the external carotid artery was similar to that of the dog. In the camel, carnivores, small ruminants, and pig, the lingual artery arose from the external carotid artery, but a distinct sublingual artery of the camel was lacking and was replaced by several branches from the lingual instead. In 50% of cases the facial artery formed a common trunk with the caudal auricular and superficial temporal, but in carnivores and pig it stems from the external carotid artery, and in ox and horse from the linguofacial trunk. The facial artery supplied the lower lip and buccal glands, but the upper lip received its arterial blood from the infraorbital via the superior labial artery, and this observation is not in agreement with the finding of Tayeb (1951) and Benkoukous (1983). The superior labial artery comes from the facial artery in ox, horse and carnivores, from the buccal artery in the pig, and from the transverse facial artery in small ruminants. The caudal auricular artery in the camel, in 50% cases, formed a common trunk with the facial and superficial temporal as mentioned above. It detached the lateral, intermediate and medial auricular branches, and the caudal meningeal and the stylomastoid arteries. The deep auricular artery was, however, absent in the camel, concordant with the finding of Benkoukous (1983). The terminal branches of the external carotid artery were not the facial and the superficial temporal arteries as described by Tayeb (1951), but were, in 50% cases, the maxillary, and the auriculotemporofacial trunk. Further, the superficial temporal occasionally arose together with the caudal deep temporal and the inferior alveolar arteries and this fact was not mentioned by Tayeb (1951) and Benkoukous (1983). The maxillary artery had an extraosseous course similar to ruminants (absence of the alar canal), and this was in accord with the observations of Badawi et al. (1977) and Benkoukous (1983). In pig, horse, ruminants and carnivores, the inferior alveolar artery usually arises from the maxillary, but in the camel it formed a common trunk with the caudal deep temporal artery and sometimes with the superficial temporal that stemmed from the external carotid in other species. The rostral deep temporal artery, when present, branched from the ophthalmic rete similar to the cat, but it separates from the buccal artery in pig and ox, and from the maxillary in dog and horse. The middle meningeal artery, not described by Lesbre (1903), formed a common trunk with the rostral tympanic and arose from the inferior alveolar artery. The external ophthalmic artery contributed to both the ophthalmic rete and the rostral epidural rete mirabile. The ophthalmic rete and external ophthalmic artery supplied the eye, its adnexa, and released the external ethmoid artery, which was similar to the observations of Kanan (1972). The rete also released an anastomotic branch with the internal ophthalmic artery which Kanan (1972) reported to be absent in the camel. The rostral epidural rete branches arose both from the maxillary and external ophthalmic arteries. The infraorbital artery was well developed, and gave off the malar as in horse and carnivores, and the lateral nasal arteries similar to pig and carnivores. The superior labial stemmed from the infraorbital artery.

Veins Like small ruminants, and usually in the horse, the internal jugular vein was absent in the camel, but it is present in ox, carnivores and pig. The bifurcation of the external jugular into the maxillary and linguofacial veins was similar to that of the other species (Ghoshal et al., 1981, Nickel et al., 1981a). In the camel, the lingual vein sometimes arose from the external jugular. The facial vein coursed along the lateral aspect of the face and continued as the angularis oculi toward the medial canthus of the eye. It continued further as the frontal vein toward the supraorbital foramen. This course resembled that of ruminants and pig. In agreement with the findings of Hefney et al. (1981a,b) and Arifi (1986), the facial vein drained both lower and upper lips, superior, and inferior buccal glands, palpebral and common trunk for dorsal nasal and lateral nasal veins in the camel. The facial vein had a large connection with the ophthalmic plexus via the angularis oculi, frontal, supraorbital and dorsal external ophthalmic veins; other connections of the facial with the ophthalmic plexus was via the medial superior and medial inferior palpebral veins, the deep facial vein, and the infraorbital vein (Figs. 7,8,9,10). Valves were observed inside inferior and superior labial veins, branches to the buccal glands, as well as in the lateral and dorsal nasal veins; but the valves were absent in the angularis oculi and deep facial veins. The facial vein had valves only in the segment between the external jugular and the superior labial veins. The proximal injection of latex into the angularis oculi filled the ophthalmic plexus, dural sinuses, and deep facial and maxillary veins; the distal injection of the angularis oculi filled the facial, external jugular, and maxillary veins via the deep facial and buccal veins and the pterygoid plexus. This demonstrated that the angularis oculi vein, ophthalmic plexus and dural sinuses are devoid of valves. The injection of the dorsal nasal vein filled almost the rostral two-thirds of the nasal cavity but the injection of the deep facial vein filled only a small part of this cavity, the ophthalmic plexus, the cavernous sinus, and the angularis oculi vein. The frontal vein continued the angularis oculi as in ruminants, pig and carnivores and coursed inside the supraorbital canal traversing the frontal sinus as the supraorbital vein to join, via the dorsal external ophthalmic vein, the ophthalmic plexus. The infraorbital vein connected the ophthalmic plexus to the facial or superior labial vein in the camel; but it originated from the pterygoid plexus in the cat and from the deep facial in other species. The blood of the nasolabial region could flow toward: (1) the external jugular vein via the facial vein; and (2) to the ophthalmic plexus via the infraorbital, the angularis oculi, medial inferior and medial superior palpebral, and deep facial veins. The lower lip is drained by the inferior labial vein that joined the facial near external jugular vein. In the literature, branches to buccal glands in the camel are not described for other domestic species. Superficial and deep labial veins described by Hefney et al. (1981a,b) and Arifi (1986) in the camel were branches of the superior and inferior labial veins, respectively. The sphenopalatine vein of the camel came from the deep facial vein similar to horse, ruminants, pig and carnivores.

Dural sinuses The veins of the brain are generally divided into 4 groups: 1) Dural sinuses; 2) Diploic veins; 3) Emissary veins; and 4) Cerebral veins. The veins of the brain differ from most systemic veins in that they do not follow a satellite arterial vessel and are devoid of valves. In the horse, there is no direct intracranial anastomoses between the dorsal and ventral systems (Ghoshal et al., 1981). In camel, ruminants, carnivores, and pig, however, there were intracranial connections between these two systems. The dorsal petrosal connected the transverse sinus to the cavernous sinus in the camel, but it is absent in the pig (Ghoshal and Zguigal, 1986); the sigmoid sinus connected the transverse sinus to the basilar plexus. The cavernous sinus and basilar plexus were continuous and plexiform in appearance. 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. The dorsal sagittal sinus originated from the rhinal veins in camel, pig, and carnivores, and from the rostral cerebral veins in ruminants. The transverse sinus of the camel was similarly disposed as in other species, and released the emissary vein of the occipital bone. This vein originates in the ox from the condylar sinus (Payan, 1975), and in carnivores from the sigmoid sinus (Ghoshal et al., 1981). The dorsal petrosal sinus was lodged within the cerebellar tentorium in the camel as in ruminants, carnivores and pig (Payan, 1975; Ghoshal et al., 1981; Nickel et al., 1981); in the horse, however, it is located between the dura mater and the temporal bone. The sigmoid sinus was similar to that of the dog, but it is called the condylar sinus in the ox, and has not been described in other species. The rostral intercavernous sinus was smaller as in the ox (Payan, 1975), but the caudal intercavernous sinus was well developed. The ventral petrosal sinus lay ventral to the cavernous sinus assuming its ventrocaudal extension. The basilar plexus resembled that of the horse in its rostral part, and to that of pig and ruminants in its caudal part. The emissary vein of the occipital foramen came off the transverse sinus and joined the occipital vein. The emissary vein of the retroarticular foramen connected the temporal sinus to the maxillary vein as in carnivores; in the horse, however, it joins the superficial temporal vein (Ghoshal et al., 1981). Uehara et al. (1978) indicated that the basilar venous plexus of sheep, goat and pig was either absent or did not show a distinct structure as did in the calf. They concluded that development of the carotid rete (rostral epidural rete mirabile) in these species, including the calf, was dependent on the form of the basilar venous plexus. In sheep and goat (Heeschen, 1958), the dorsal system of dural sinuses is connected to the ophthalmic plexus via the external ethmoid vein. In the pig, an anastomosis was noted between the dorsal sagittal sinus and olfactory veins traversing the cribriform plate of the ethmoid (Ghoshal and Zguigal, 1986). In the camel, however, there was no anastomosis between dorsal sagittal sinus and the veins of the nasal cavity; the only anastomosis observed was between the dorsal rostral cerebral veins and frontal veins via the diploic veins of the frontal bone.

Nasal cavity

The nasal cavity of the camel was supplied by two major arterial sources: 1) the sphenopalatine and 2) the external and internal ethmoids. In addition, the terminal branches of the infraorbital artery, and dorsal nasal, rostral and caudal lateral nasal arteries contributed to the external surface of the nasal cavity, including the alar fold region. The arteries coursed obliquely in the septum, and somewhat horizontally in the dorsal and ventral nasal conchae.

The ventral nasal artery of the sphenopalatine vascularized the lateral wall, nasal floor, ventral concha, and sent branches to the middle and dorsal nasal conchae. In the sheep, this artery supplied only the ventral nasal concha (Khamas and Ghoshal, 1982a), and in the pig the ventral concha received an additional middle branch of the sphenopalatine artery. In the buffalo, however, the ventral nasal artery supplied the ventral nasal concha and a part of the nasal septum (Nawar et al., 1975). This artery was named medial branch by Getty (1975) and Koch (1976) in horse and ox. It is distributed only to the nasal septum (Getty 1975), while Koch (1976) reported that the ventral nasal artery is expended to the caudoventral part of the choanae in the horse and to ventral part of the nasal septum in the ox. The dorsal nasal artery of the sphenopalatine supplied the nasal mucosa covering the ethmoturbinates and the dorsal nasal concha in the camel. This was in accordance with the observation on small ruminants by Schnorr and Hegner (1967) and Khamas and Ghoshal (1982a). The vestibular region received its arterial blood from the sphenopalatine, superior labial, major palatine and rostral lateral nasal arteries. The septum was supplied by the septal nasal artery of the sphenopalatine and the septal branch of the internal ethmoid artery in the camel. The ethmoturbinates concha were vascularized by the internal and the external ethmoid arteries. The external ethmoid artery originated from the maxillary, as well as from the ophthalmic rete. There was no ethmoid rete in the camel as has been reported by Schnorr and Hegner (1967) and Koch (1976) in small ruminants and ox, respectively. The dorsal nasal wall (roof) was vascularized by the internal ethmoid artery similar to the pig. The ventral nasal wall (floor) received its supply from the septal nasal arteries of the sphenopalatine. The observed anastomoses between the arteries of the nasal region were, perhaps, to facilitate shunting of the blood from one area to another, or to regulate the rate of flow in certain areas of the nasal cavity to meet physiological needs. There were anastomoses between terminal branches of different arteries and between branches of the same artery in this region. The most extensive anastomoses between the superior labial and rostral and caudal lateral nasal arteries were noted grossly around the nose and superior lip. In the caudal part of the nasal cavity, there was an anastomosis between the sphenopalatine and the external ethmoid arteries. Inside the nasal cavity, anastomoses were observed between branches of the sphenopalatine artery.

The venous drainage of the nasal mucosa was mainly via the dorsal nasal and the sphenopalatine. The sphenopalatine vein was a branch of the deep facial that was connected to the ophthalmic plexus via the ventral external ophthalmic vein. The dorsal nasal vein was connected to the facial and angularis oculi. The external ethmoid vein drained the ethmoturbinates and the olfactory region and joined the ophthalmic plexus. Khamas and Ghoshal (1982a) stated that the veins on the lateral face in the sheep were guarded by valves at the sites of their confluence, with the exception of both the deep facial and the angularis oculi that did not have valves. Almost the rostral two-thirds of the nasal cavity were drained by the dorsal nasal vein. The major palatine vein formed a minor drainage route of the nasal cavity. The angularis oculi vein was connected to the cavernous sinus via the ophthalmic plexus. This was confirmed by injection of latex into the angularis oculi and by venography in the camel (Figs. 7,8,10,11,23). The injection of latex into this vein filled both cavernous sinuses and ophthalmic plexuses. This is similar to the finding of Magilton and Swift (1968) in the dog, Baker and Hayward (1968a,b), and Khamas and Ghoshal (1982a) in the sheep, Taylor and Lyman (1972) in Thompson's gazelle, and Caputa and Cabanac (1978) in man. This was confirmed by venography in live sheep by Khamas and Ghoshal (1982a). Similar observations have been made in the pig by Ghoshal and Zguigal (1986). The lateral nasal vein formed a common trunk with the dorsal nasal vein. The dorsal impar nasal vein was specific to the camel. In other domestic mammals, this vein is replaced by a transverse anastomotic branch connecting the right and left dorsal nasal veins. Baker and Hayward (1968a) reported that in sheep the injection of latex into the angularis oculi vein filled the nasal cavity via the lateral and dorsal nasal veins. This was, however, not true in the camel; latex was injected directly into the dorsal nasal vein because of valves present at its origin close to the facial. The valves were absent, however, in the infraorbital vein and the medial superior and medial inferior palpebral veins. The venous blood leaves the nasal cavity via the dorsal nasal vein to the angularis oculi or to the facial vein, and via the sphenopalatine to the deep facial vein. This blood can flow to the ophthalmic plexus via the angularis oculi vein, the infraorbital vein and the medial superior and medial inferior palpebral veins, deep facial and then from the ophthalmic plexus to the cavernous sinus via emissary vein of the orbitorotundum foramen. The direction of flow in the angularis oculi vein of man depends upon the core temperature as stated by Caputa and Cabanac (1978). For example, in a hyperthermic condition in man, blood flows from the nose to the cavernous sinus via the angularis oculi vein, while in hypothermia and normothermia the blood flows rapidly in the opposite direction from the angularis oculi vein toward the facial.

The nasal cavity of the camel was drained by superficial and deep veins. The superficial veins consisted of the lateral nasal, dorsal nasal and dorsal impar nasal, whereas deep veins comprised the sphenopalatine and ethmoids.

Carotid rete-cavernous sinus complex

The carotid rete (rostral epidural rete mirabile) of the camel was supplied by the rostral rete branches arising from the external ophthalmic artery, as well as from the lateral, medial and dorsal aspects of the maxillary artery, and the internal carotid and the middle meningeal arteries. In some specimens, the rete branches divided shortly before they entered the rete and in other cases the rete branches divided at their origin from the maxillary and continued to arborize with the growth of the carotid rete. The complexity of the carotid rete, its anatomical close relationship with the cavernous sinus, and the fact that blood of this complex flows in opposite directions, suggest that these structures could be a possible site for conditioning blood temperature before reaching the brain. This has been demonstrated experimentally by several authors (Baker and Hayward, 1968 a, b, c, d; Magilton and Swift, 1968; Krabill and Ghoshal, 1982; Ohale and Ghoshal, 1982a,b,c,d, 1983). In the camel, the carotid rete was enmeshed by the venous plexus of the cavernous sinus as in sheep (Baldwin, 1964; Khamas et al., 1984), and the pig (Ghoshal and Khamas, 1984). Gillilan (1976) in the cat and Khamas et al. (1984) in the sheep described the cavernous sinus as a venous plexus.

The cavernous sinus was an extensive tightly compact venous plexus containing the carotid rete. The veins of the sinus were thin-walled and resembled thin strands of connective tissue (i.e., collapsed veins) in injected specimens. Therefore, the cavernous venous plexus would be an appropriate designation for the cavernous sinus in camel as proposed by Khamas et al. (1984) for sheep. It was connected to the ophthalmic plexus rostrally, basilar plexus caudally, including surrounding dural sinuses and other venous channels.

Light, Scanning, and Transmission
Electron Microscopy

Nasal cavity

The nasal cavity of the camel had an extensive venous plexus, more so in the caudal vestibular and respiratory areas than in the rostral vestibular and olfactory regions. The thick veins were disposed superficial to the glands in the vestibular region, but they lay deep in the respiratory region. In both instances, the veins were located superficial to the arteries. In sheep, Schnorr and Hegner (1967) reported a similar nasal plexus with deep thick-walled veins, but Khamas and Ghoshal (1982b) described these veins only in the alar fold region. In the pig, the cushion veins were present throughout the nasal cavity (Ghoshal and Khamas, 1984). Thin- walled veins (1-3 smooth muscle layers) were more conspicuous in the respiratory mucosa as well as in the caudal vestibular region. They represented the anastomotic terminal branches of the thick-walled veins (Fig. 35/V,v). This was confirmed by gross dissection of latex injected specimen; injection of the dorsal nasal vein filled almost the rostral two-thirds of the nasal cavity. This has provided indirect evidence that the venous blood of the respiratory region may flow toward the vestibular region where it is drained by the dorsal nasal vein. The cushion veins of the respiratory and nasal vestibular areas may accommodate large quantities of blood in response to physiological needs, or by constriction they may allow the veins lying rostral to them to be engorged with blood. Thus, they may decrease the rate of the venous return augmenting the efficiency of the external heat exchanger as described by Magilton and Swift (1968) in the dog. Cauna and Cauna (1975) hypothesized that these veins keep the epithelial surface moist in man by absorbing and releasing water. In the camel, the vestibular region was rich in serous glands; and large sinuses facilitating permeability of water moisten the surface epithelium. The function of the vein explained by Cauna and Cauna (1975) may be true for the respiratory area where the mucous glands predominate. The structure as well as disposition of arteries of the nasal cavity varied considerably between different regions. The arterial wall appeared somewhat thicker in the rostral part of the nasal vestibule and the olfactory region, but relatively thinner in the respiratory region and in the adjoining caudal part of the vestibule. The arteries were located either superficial or at the same level with glands in the vestibule, but in the respiratory and olfactory areas they lay deep to the glands adjoining the perichondrium. As previously mentioned, the veins were superficial to arteries occupying the entire propria submucosa, especially in the respiratory region. The arteries of the internal lamina of the ventral nasal concha were smaller, and the veins did not appear cavernous as they did not anastomose with each other. The external lamina of the ventral nasal concha had a well developed venous plexus facing toward the air-stream.

Similar to sheep (Khamas and Ghoshal, 1982b), both longitudinal and circular smooth muscle layers were seen microscopically on the walls of the facial, dorsal nasal, and angularis oculi veins. The tunica media of the segment of the facial vein between the confluences of the superior labial and common trunk for both dorsal and lateral nasal veins was thicker than that of the angularis oculi vein. In the sheep, however, Khamas and Ghoshal (1982b) reported that the walls of the facial, angularis oculi, and dorsal nasal veins were similar in structure.

The glands were compound tubuloalveolar, mixed type, predominantly serous in the vestibular region; they were relatively more on the septal wall. On the other hand, they were simple tubuloalveolar predominantly mucous type in the respiratory and olfactory regions. These glands lay deep in the propria submucosa close to the perichondrium in the vestibular region, but somewhat superficial in other regions. Their ducts emptied on the surface epithelium to keep it moist for evaporative heat loss in the caudal part of the nasal vestibule. Large bundles of striated muscle fibers were observed surrounding the predominantly serous glands of the vestibule. By contraction they might facilitate squeezing out their secrection toward the surface epithelium.

The intraarterial bolsters described by Nawar et al. (1975) in the nasal cavity of the Egyptian buffalo and in sheep by Khamas and Ghoshal (1982b) were rarely seen in the camel. In one instance, they were noticed in the vestibular region and in another specimen they were found in the olfactory region. According to the above authors, these bolsters function in controlling the rate of the blood flow and they may skim blood cells off the collateral branches because of their projections into the blood stream. In the camel, however, several thick-walled arterioles were evident within the propria submucosa of the caudal vestibular and respiratory regions; their walls were made up of 4 smooth muscle layers. They may exert some control in the regulation of blood flow from arterioles to capillaries and finally to the veins. Nerve fibers in the tunica adventitia of the arteries were apparent possibly controling the blood flow of the nasal mucosa. Arteriovenous anastomoses were rarely noticed in the nasal cavity of the camel and this fact has been verified also on latex injected corrosion casts.

The free smooth muscle bundles found in the respiratory and caudal vestibular regions could assist contraction of the thin- walled veins to drain the nasal cavity. They were also described by Taher (1976) in the propria submucosa of the nasal septum of the albino rat and in sheep by Khamas and Ghoshal (1982b).

The heat exchange mechanism can function effectively in the presence of moisture in the nasal cavity which is mainly derived from the lateral nasal gland (Nickel et al., 1979). Blatt et al. (1972) reported that this function largely depends on the ambient air temperature in the nasal cavity. In this investigation, compound tubuloalveolar glands, mostly serous, predominated the alar fold and the nasal vestibule, and it is possible that their secretion kept the surface of the epithelium moist for evaporative heat loss because the vestibule is directly exposed to inspired air. This is, however, not in agreement with the observations of Badawi and Fath El-Baby (1975) and El-Gohary (1978); Badawi and Fath El-Baby described the presence of only sebaceous glands in the nasal vestibule, whereas El-Gohary reported rosette-like nasal glands throughout the nasal mucosa. In the rest of the nasal mucosa presence of abundant mucous glands protected the surface epithelium from the inspired air temperature especially in the desert environment. This may explain the reason for large number of goblet cells and glands on the medial surface of the ventral concha facing toward the air-stream.

Carotid rete-cavernous sinus complex

In cross section, the carotid rete of the camel was enmeshed by the venous plexus of the cavernous sinus, and was composed of medium-to small-sized muscular arteries. The tunica adventitia was thinner than the tunica media. Some of the rete branches were invested by endothelial lining of the cavernous sinus concordant with the finding of McGrath (1977) in the pig and sheep, Baldwin (1964) in sheep and ox, and Khamas et al. (1984) in sheep. Also, rete branches and the cavernous sinus in the camel shared a common tunica adventitia. The presence of a common tunica adventitia only in some places, gap junctions between endothelial cells of the rete branches and those of the veins, and a fenestrated internal elastic lamina could facilitate the countercurrent heat exchange between the rete branches and venous plexus of the cavernous sinus to regulate brain temperature in the camel.

No smooth muscle cells were observed in the wall of the cavernous sinus of the camel. In sheep, Khamas et al. (1984) reported that at the site of emergence of the intracranial portion of the internal carotid artery, there was an occasional presence of a distinct tunica media consisting of one to several smooth muscle layers interposed between the endothelial cells and the tunica adventitia of the cavernous sinus. In most cavernous venous plexuses, there was an endothelial lining with gap junctions, no tunica media, and a common tunica adventitia between adjacent rete branches and the venous plexus only in some places. Structural modifications such as absence of smooth muscle cells and sharing a common tunica adventitia with the rete branches are possible devices to augment the efficiency of the internal countercurrent heat exchange system, which several investigators described in other species. In addition, other factors such as the temperature gradient, and blood flow velocity in both the rete and the sinus play a role in enchancing the heat exchange mechanism. In several places, a few thick-walled arteries were present having up to 12 smooth muscles layers. Arteriovenous anastomosis between arterial rete branches and the venous plexus of the cavernous sinus was reported in the cat (Gillilan and Markesbery, 1963). In the monkey, Rajendran and Ling (1985) described the cavernous sinus as being predominantly one main venous channnel that together with the internal carotid artery occupied a meningoendocranial compartment lateral to the pituitary gland.

The existence of bolsters have been reported in other species. Dahl (1976) stated that they may represent developmental defects; some other functions have been attributed to bolsters include: to influence the blood flow to a side branch, to increase the peripheral resistance (Hassler, 1961), and to occlude or narrow the lumen of certain arteries (Elias and Pauly, 1966), and cell skimming (Fourman and Moffat, 1961). In infants, the bolsters seemed to be normal structural components (Stehbens, 1960). In the camel, the function cited above could be accomplished by the thickness of the arterial wall. Further, the presence of both circular and longitudinal muscle fibers may regulate the blood flow which is influenced by both the metabolic rate of the brain and vasoactive substances released by nervous structures. The local blood flow in the cortex showed spontaneous rhythmical fluctuations that were independent of both the arterial pressure and of the respiratory cycle (Cropp, 1969). On the other hand, Owman et al. (1974) proposed that the blood flow velocity in both the rete and the sinus, etc. plays a role in enhancing the heat exchange.

The myelinated and unmyelinated axons in the adventitia of carotid rete branches were easily recognizable. Pease and Paule (1960) indicated that the lack of innervation of tunica media in the thoracic aorta was suggestive of its functional activity that must depend upon intrinsic activity rather than upon nervous stimulation. The autonomic innervation of the cerebral arteries participates in the control not only of the cerebral circulation but also of associated intracranial pressure.

SUMMARY AND CONCLUSIONS

The gross and microscopic anatomy of the blood vessels of the nasal cavity of 25 camels (18 for gross and 7 for histomorphology) were described. Another five camels were used for angiographic study to complement gross observations. The morphology of the carotid rete cavernous sinus complex was also studied on these animals. Various injectable intravascular plastic materials were used to depict their detailed structures. For light, scanning and transmission microscopic study, several stains were employed to describe the histomorphology of these structures. The microscopic structure of the nasal mucosa was investigated for of thickness and number of smooth muscle layers of the tunica media of blood vessels, disposition of arteries and veins in relation to surface epithelium, type and distribution of nasal glands and their relationship to blood vessels, presence of elastic and collagen fibers, free smooth muscles, arteriovenous anastomoses, and thick-walled veins in the propria submucosa. The carotid rete and cavernous sinus complex were examined for the tunica intima, the thickness of the tunica media of rete branches, and the relationship of venous plexuses of the cavernous sinus to the rete branches.

Sections from the dorsal nasal, angularis oculi, and facial veins were microscopically examined. Both longitudinal and circular smooth muscle layers were discernible on their walls. The segment of the facial vein between the confluences of the superior labial and common trunk for both dorsal and lateral nasal veins had a very thick tunica media and it has been speculated that it might play a role in directing cool nasal venous blood either toward the angularis oculi or the facial vein. This fact has been reported to be true for other species.

The venous drainage of the nasal cavity and its surrounding structures had the following connections: (1) toward the external jugular vein via the facial; (2) to the ophthalmic plexus via the infraorbital; (3) to the angularis oculi vein via the common trunk of dorsal and lateral nasal; (4) to the ophthalmic plexus via the medial superior and medial inferior palpebral veins; and (5) toward the deep facial and the ophthalmic plexus via the facial vein or to the maxillary vein via the deep facial and buccal veins and the pterygoid plexus. The infraorbital, angularis oculi, medial superior and medial inferior palpebral, and deep facial veins were devoid of valves and, therefore, blood could flow on either direction contingent upon many physiological factors influencing the direction of the venous blood flow under extraneous circumstances and according to physiological needs. They provide various venous pathways connecting the nasolabial, buccal, frontal, temporal and auricular regions of the head to the ophthalmic plexus and dural sinuses.

The role of the nasal mucous membrane and the carotid rete in regulating the brain temperature was demonstrated and the functional significance of the above relationship was reported in many species, including man.

In the literature, the following functions have been attributed to the carotid rete-cavernous sinus complex in different animals: 1) to regulate blood flow to the brain under normal circumstances (Ask-Umpark, 1935; Daniel et al., 1953); 2) to regulate mechanically the cerebral circulation by diminishing the arterial pulsation (De Boissezon, 1941); 3) to maintain adequate arterial blood flow in the event of interruption of flow in one of the carotid arteries ensured by extensive collateral anastomoses within the rete (Daniel et al., 1953; Edelman et al., 1972); 4) to assist in venous return from the cranium due to absence of valves in the venous system of the cranial circulation (Barnett and Marsden, 1961); 5) to protect the brain from unordinarily high perfusion pressure while allowing the augmentation of cerebral blood flow in physiological circumstances (Edelman et al., 1972); 6) to act as a capacitor which lowers high systolic pressures with a minimum effect on mean perfusion pressure, an ideal situation to the brain which is very sensitive to edema formation but requires relatively high blood flow for proper function (Edelman et al., 1972); 7) to act as a site for internal countercurrent heat exchange system to cool the blood destined for the brain and the eye and to selectively regulate the brain temperature (Magilton and Swift, 1967, 1968, 1969; Baker and Hayward, 1967, 1968 a, b, c, d; Young et al., 1976; Baker and Chapman, 1977; Krabill and Ghoshal, 1982, 1983; Ohale and Ghoshal, 1982a,b,c,d; Booth and Ghoshal, 1983); 8) to monitor air humidity by the thermosensitive structures of the hypothalamus, which are thermally linked to the respiratory surfaces by the carotid rete heat exchanger in the goat (Jessen et al., 1984); and 9) to exchange oxygen between the venous blood and the arterial blood in birds, thereby providing an extrapulmonary gas exchange enhancing brain oxygen supply (Bernstein et al., 1984).

Kamau et al. (1984) studied the design and the role of nasal passages in temperature regulation in the dik-dik antelope and reported the presence of carotid rete and profuse vascularization of the nasal conchae. They suggested that the dik-dik may possess an efficient brain cooling and water conserving system. The design of the upper respiratory system in these antelopes may help these animals to tolerate the extremes of temperature and insolation encountered in their habitat. A similar thermoregulatory mechanism has been described in pigeons (Bernstein et al., 1984). They mentioned that blood in the mouth, nose and eye tissues of birds cools by evaporation, then it flows to a cephalic vascular-heat exchanger, the ophthlamic rete. There, acting as a heat sink, blood from the evaporative surfaces cools arterial blood flowing countercurrent to it toward the brain. The brain thus remains cooler than the body core. According to these researchers, blood perfusing the evaporative surfaces also exchanges oxygen and carbon dioxide with the air. In the heat exchanger, this blood apparently gives up oxygen to, and gains carbon dioxide from, the arterial blood. The consequent increase in oxygen and decrease in carbon dioxide in the brain's arterial blood enhance diffusion of these gases in, and oxygen supply to, the brain.

Studies have shown that the temperature of the brain is primarily controlled in mammals by the rate of heat removed from the brain by the cerebral arterial blood. Serota and Gerard (1938) suggested that for heat to be removed from the brain, the arterial blood supply must be cooler than the brain tissue,which has been shown to be true in different mammals. Deviation of cool blood to deeper venous sinuses has been shown to be an important thermoregulatory mechanism (Winquist and Bevan, 1980). In the absence of venous valves in dural sinuses and their extracranial connections with surrounding veins draining extensively the nasolabial, buccal and other regions of the head of camel via the infraorbital, angularis oculi, deep facial, medial superior and medial inferior palpebral veins and the ophthalmic plexus, blood flow can occur in either direction depending upon relative pressure, environmental temperature, and other physical factors. Further, the presence of both rostral and caudal intercavernous sinuses in the camel could facilitate the temperature changes between both cavernous sinuses as cyclic alternation of airflow through both nostrils has been reported to occur in many species. Therefore, it can be assumed that for certain time intervals, countercurrent heat exchange mechanism functions more efficiently in one nostril than in the other, thus influencing the temperature gradient of the venous blood of the homolateral cavernous sinus bathing the carotid rete. Experimental evidences are available in the literature indicating that there is countercurrent heat exchange between the cool venous blood, draining the nasobuccal region, to the ophthalmic plexus and the cavernous sinus, and the core temperature arterial blood in the ophthalmic rete and the rostral epidural rete mirabile, respectively. Also, cooled venous blood circulating through the dural sinuses along the floor of the cranial cavity can affect directly the diencephalic temperature by exchanging heat with the cerebrospinal fluid.

In both the superior and inferior lips of the camel, extensive arteriovenous anastomoses were noticed and from this it has been hypothesized that these structures could play an important role in the regulation of the brain temperature in this species, in addition to the nasal cavity.

Selective cooling of the brain becomes more important and its intensity increases when the animal is subjected to hyperthermic conditions. During this time great demand is placed on the availability of cool venous blood returning from the nasal cavity and its surrounding structures, and both the brain and the trunk seemingly compete to share this cool pool of blood. For optimum functioning of the internal countercurrent heat exchanger, more cool venous blood from the nasobuccal regions would be flowing toward the cavernous sinus for maintaining an effective temperature gradient between the cool venous blood in the cavernous sinus and the core temperature blood in the carotid rete branches. This is possible by a functional local regulatory mechanism directing blood either toward the angularis oculi vein and the cavernous sinus, or toward the facial vein and the external jugular vein to meet physiological needs. In this study, the tunica media of the facial vein was observed to be conspicuously thick in the segment between the confluences of the superior labial and the common trunk for both dorsal nasal and lateral nasal veins. The muscular coat of this segment of the facial vein has been shown to act like sphincters in other species when environmental temperature rises, thus cool venous blood from the nasolabial, buccal and other regions of the head is directed toward the angularis oculi vein against gravity. Therefore, a competition exists between the trunk and the brain for sharing cool nasal blood in hyperthermic goat (Caputa et al., 1986). Further, the sweat glands of the dorsum of the nose, frontal and temporal regions, and the external ear of the camel could dissipate heat by evaporation; thus they could assist in cooling the venous blood returning from the nasolabial and buccal areas which is destined for the ophthalmic plexus and the cavernous sinus.

Dahlborn et al. (1987) reported that the carotid rete in the camel is very effective in protection of brain temperature in the desert environment when ambient temperature is below body temperature. The cooling of cerebral arterial blood by means of the carotid rete located in the cavernous sinus has been suggested as a means of preventing cerebral overheating, and to be partly responsible for high heat tolerance. The brain cooling system has a second survival effect for desert antelope, conserving water (Taylor, 1969; Kamau et al., 1984). Instead of sweating to lose heat, these animals allowed their body temperatures to increase storing the heat until ambient temperature decreased at night. However, to survive against thermal load the brain temperature must be kept lower, which they were able to do by panting. Under normal conditions, the anatomical arrangement of the carotid rete-cavernous sinus complex allows the exchanges of heat between the two bloodstreams which is enhanced by the fact that they are flowing in opposite directions and are, in effect, a countercurrent heat exchanger.

In Australian camel placed in a climate chamber and subjected to a high temperature (46°C), Schroter et al. (1986) (personal communication) reported that the brain temperature was 0.2°C higher than body temperature; this rise followed a vasoconstriction of the nose. The greatest blood-brain temperature difference observed (0.7°C) occurred in a dehydrated animal when its body temperature exceeded 39.5°C. In Moroccan camel, several brain and body temperatures have been reported (Dalhborn et al., 1987). During rest, a camel brain temperature measured 38.0°C when the body temperature did not exceed 39°C cooler than the body temperature. In a hydrated camel, the body temperature was kept below 39°C. When dehydrated, the body temperature rose rapidly to 40.5°C until forced to rise by the high level of body temperature. However, even at high body temperature the carotid rete was able to cool the brain by 1.5°C. In the first experiment, the inspired air could not sufficiently cool the nasal mucosa due to vasoconstriction because of high temperature and warm blood was carried to the ophthalmic plexus and to the cavernous sinus; therefore, the venous blood in the cavernous sinus could not cool the carotid rete blood. In the second experiment, inspired air did cool the surface mucosaof the nasal cavity and the venous blood returning to the cavernous sinus was cool where countercurrent heat exchange took place between the cooled venous blood and the core temperature arterial blood within the carotid rete. Further, Schroter et al. (personal communication) reported that when a dehydrated camel started drinking, brain temperature rose to 38.25°C and equaled that of the body temperature. After stopping drinking, brain temperature was 0.37°C below body temperature. This demonstrates the conspicuous difference in the brain temperature of the camel with air flowing over the nasal mucosa during normal nasal breathing after stopping drinking and the lack of airflow through the nasal cavity when the camel was drinking water. Therefore, it would be obvious that when the camel was drinking water, there would be no significant loss of heat from the circulating venous blood in the nasal mucosa to the ambient air. Although the venous blood was cooler, there would also be less of it entering the cavernous sinus. So, the total amount of heat that could be transferred to the venous blood may have decreased with less heat transfer but with the same arterial flow, carotid rete temperature would rise reflecting on a relatively high brain temperature.

From the foregoing experimental data in the literature from other anmals, including the camel and birds, it could be concluded that the camel has been endowed with efficient heat regulating system that operates within certain physiological parameters. Gross and histological investigations revealed high vascularity of the nasal conchae and presence of a carotid rete in the camel. The angioarchitecture of the upper respiratory tract is suggestive of efficient brain cooling and water conserving systems in this species, which is especially useful in the desert environment. The anatomic requirements expected of a countercurrent heat exchanger are present in the ophthalmicrete and ophthalmic plexus, as in the carotid rete and the cavernous sinus complex. Both these pair of vascular complexes are arranged in such a manner that core temperature blood in the arterial rete branches and relatively cool venous blood in the plexus and/or sinus accommodating blood flow in the opposite direction. Thus, they are able to maintain a temperature differential between the two sources of blood supply in the corresponding structures. To estimate the amount of heat loss in the carotid rete-cavernous sinus complex, the rate of blood flow in both the cavernous sinus and the rete branches need to be determined. Besides, perfusion pressure used for fixing this vascular complex would prove to be essential while measuring the total length of all rete branches from various sources, as well as the circumference, the thickness of tunica media and luminal diameters of these vessels.

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APPENDIX

Material injected and route of injection used for gross anatomical investigation:

Number of animals used	Material injected	Route of injection
3	Red latex	Common carotid arteries
3	Blue latex	Facial vein Deep facial vein Angularis oculi vein Dorsal nasal vein (both sides)
3	Double injection with red and blue latex	Common carotid arteries and veins cited above
3	Batson's # 17 (red)	Common carotid arteries
3	Batson's # 17 (blue)	Facial vein Deep facial vein Angularis oculi vein Dorsal nasal vein (both sides)
3	Double injection with red and blue Batson's # 17	Arteries and veins cited above
4	Hypaque sodium 50	Dorsal nasal vein
1	Hypaque sodium 50%	Common carotid artery

Histological techniques

Paraffin section stain

Van Gieson's stain

Preparation:

A) Weigert's iron hematoxylin solution

-Solution I

Hematoxylin crystals	1.0 gm
Alcohol 95%	100.0 ml

-Solution II

Ferric chloride 29% aqueous	4.0 ml
Distilled water	95.0 ml
Hydrochloric acid conc.	1.0 ml

Working solution

Equal parts of Solution I and Solution II

B) Van Gieson's solution

Acid fuchsin, 1% aqueous	2.5 ml
Picric Acid, saturated aqueous	97.5 ml

Staining

1) Deparaffinize and hydrate to distilled water
2) Weigert's hematoxylin solution for 10 minutes
3) Wash in distilled water
4) Van Gieson's solution for 1 to 3 minutes
5) Hydrate in 95 % alcohol, absolute alcohol, and clear

in toluene, two changes each

6) Mount with permout.

Results:

Collagen red.

Muscle and cornified epithelium: yellow.

Nuclei: blue to black.

Weigert's resorcin fuchsin stain

Preparation:

To 100 ml of distilled water, 1 gm of basic fuchsin and 2 gm of resorcin were added. The mixture was boiled, then 12.5 ml of freshly prepared 30% ferric chloride solution was added and boiling continued for 5 minutes. The mixture was then cooled, filtered and the filtrate was discarded. The precipitate was dissolved in 100 ml ethanol using a hot water bath to control heating and at the same time 2 ml of concentrated hydrochloric acid (HCL) was added to the mixture.

Working solution

Resorcin-fuchsin stock	10.0 ml
Alcohol 70%	100.0 ml
Hydrochloric acid conc.	2.0 ml

Staining

1) Deparaffinize and hydrate to distilled water

2) Weigert's hematoxylin solution for 10 minutes

3) Wash well in water to intensify stain

4) Resorcin-fuchsin for 30 minutes or more

5) Rinse in 95% alcohol
6) wash in tap water
7) Counterstain with Van Gieson's for 1 minute
8) Dehydrate in 95% alcohol, absolute alcohol, and clear in toluene, two changes each

Results:

Elastic fibers : Blue-black or black
Nuclei : Blue-black or black
Collagen : Pink to red
Other tissue element : Yellow

Osmication and dehydration of the samples for electron microscopic study were accomplished as follows:

1) Scanning electron microscopy:

Phosphate buffer	2 changes
Osmium tetroxide	1 hour (1% OsO4 in phosphate buffer)
Phosphate buffer	3 x 15 minutes
Distilled water	5 minutes
25% acetone	5 minutes
50% acetone	5 minutes
70% acetone	5 minutes
95% acetone	5 minutes
100% acetone	5 minutes
100% acetone	5 minutes

The samples were freeze-fractured in liquid nitrogen. Later, the critical point drying was performed after the replacement of acetone by carbon dioxide. Finally, the specimens were mounted on stubs, sputter coated with palladium-gold for three minutes and were examined with JSM-35 JEOL Scanning Electron Microscope.

2) Light and transmission electron microscopy:

Phosphate buffer	3 changes
Osmium tetroxide	1-2 hours (1% $OsO4$ in phosphate buffer)
Phosphate buffer	2 x 5 minutes
25% acetone	5 minutes
50% acetone	5 minutes
70% acetone	5 minutes
95% acetone	10 minutes
100% acetone	5 x 20 minutes
50% Epon-Araldite: 50% acetone	2-3 hours
75% Epon-Araldite: 25% acetone	2-3 hours
100% Epon-Araldite	2-3 hours

Tissue pieces were taken out of the vials, and placed at the bottom of plastic BEEM capsules or flat embedding molds. The capsules or molds were filled with a fresh plastic mixture and placed in a paraffin oven at 60°C for 48-72 hours.

The semi-thin sections were stained using the following protocol:

1. Oxidize in 1% periodic acid at room temperature for 5 minutes.

2. Rinse with distilled water.
3. Stain with 0.15% basic fuchsin in 50% ethanol for 2 minutes at 50°C place jar in water bath).
6. Rinse in distilled water.
7. Air dry.
8. Dip slide in xylene, and while slide is still moist, adhere coverslip to slide with permount.

The thin sections were examined by Transmission Electron Microscope (Zeiss 10).