



A mixed prospective study of the vasculature of the goat's eye via a blended learning approach

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Abstract

The pandemic crisis abruptly altered veterinary medical education, leading to a rapid transition from in-person to online learning. Creating E-learning modules represents a new trend in the teaching and learning veterinary anatomy courses. Therefore, the present study aimed to prepare an educational module for the vasculature of the goat's eye to be used in online anatomy teaching. Two healthy adult female goats were subjected to radiographic examination to demonstrate the vasculature of the goat's eye, and eight goat heads were injected with colored latex. The arterial supply of the eye and orbit in goats was mainly derived from the external ophthalmic and malar arteries, with a minor contribution from the superficial temporal artery. The external ophthalmic artery formed the external ophthalmic rete mirabile, which gave the supraorbital, lacrimal, external ethmoidal, ciliary, and anterior ciliary arteries. Small branches from the malar and superficial temporal arteries supplied the eyelids and conjunctiva. The venous drainage of the eye and orbit mainly occurred via the ventral external ophthalmic and dorsal external ophthalmic veins. The malar vein drained into the ventral external ophthalmic vein. The ophthalmic plexus connected the ventral external ophthalmic vein medially with the dorsal external ophthalmic vein laterally, draining the ventral vorticos vein. The dorsal external ophthalmic vein collected venous blood from the lacrimal and dorsal vorticos veins. The established E-learning module creates a supplemental virtual anatomy tool for every student.

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Introduction

All levels of education, particularly medical education, have been severely affected by the COVID-19 pandemic. About 10 months after the pandemic began, online learning appeared to be the only viable option for medical education, specifically in anatomy teaching. However, any theoretical courses could be successfully provided in virtual classrooms. Teaching anatomy this way is difficult because anatomy learning requires three-dimensional (3D) observation (1). Negash and Wilcox (2) documented six categories of E-learning: 1. E-learning with personal attendance but lacking E-communication (face-to-face); 2. E-learning without

physical presence and E-communication (self-learning); 3. E-learning without attendance but with E-communication (asynchronous); 4. E-learning with online presence and E-communication (synchronous); 5. E-learning with intermittent attendance and E-communication (blended asynchronous); and 6. E-learning with presence and E-communication (blended/hybrid synchronous). Establishing online learning platforms, whether stationary or cooperative, has facilitated the simplified learning of eye anatomy. Establishing a cooperative form of the website did not considerably improve students' exam performance but positively affected their knowledge (3). A future application of the hybrid educational approach, which combines virtual

and traditional classrooms, has been suggested. Hence, assessing veterinary anatomy learning during online teaching and evaluating students' satisfaction is crucial and could be used for future anatomy learning plans (4). Goats are characterized as one of the most essential farm animal species in recent years to meet the demand for goat products in all countries (5-9). The goat is a domesticated, friendly, curious, and intelligent species that provides us with meat, milk, skin, and fur (10). Goats (*Capra hircus*) are domestic ruminant species that play a significant role in the economy of many countries. Investigating the medical characteristics of the goat's eye is of great significance for goats' health effects and economic prospects (11). Despite the importance of goats, there is meager information about goat anatomy in previous research and literature. Therefore, the Department of Anatomy at Zagazig University focused on goats and conducted several educational theses on goats' neuroanatomy, musculature, respiratory, and cardiovascular systems. Further studies on the remaining body parts of goats, such as the eye, are required. Concerning the arterial blood supply of the eye, Ghoshal (12) stated in small ruminants that the maxillary artery originates from the external carotid artery in the region of the pterygopalatine fossa. The maxillary artery then continues as the external ophthalmic artery, which perforates the periorbita and forms the ophthalmic rete mirabile near the beginning of the extrinsic eye muscles. Suzuki and Okuda (13) in goats and Shao *et al.* (14) in yaks recognized that the malar artery originates from the infraorbital artery. In the medial part of the infraorbital border of the lacrimal bone, the malar artery branches into the medial superior and inferior palpebral arteries. The medial superior palpebral artery ramifies in the lacrimal canaliculi and the nasolacrimal canal. Diesem (15) documented in ruminants that, despite the sclera lacking vascularity, it is penetrated by several blood vessels, such as the short ciliary arteries, which nourish the caudal part of the sclera. In a normal eye, the cornea is avascular and transparent. If any injury occurs to the cornea, blood vessels may invade the cornea from the edges of the eye. Popesko and Ghoshal (16) recorded that the dorsal external ophthalmic vein runs along the dorsal aspect of the zygomatic bone toward the orbit. It penetrates the periorbita and forms the ophthalmic plexus between the rectus dorsalis and lateralis muscles. The dorsal external ophthalmic vein receives a branch from the lacrimal gland on the rectus muscle. The arrangement of the ophthalmic plexus is similar in oxen, sheep, and goats, but this plexus communicates with the malar vein in sheep and goats. In bovines, Buda and Budras (17) asserted that the dorsal external ophthalmic vein collects venous blood from the orbit and drains into the superficial temporal vein. Recent research focuses on the diseases of goats (18-21). However, several authors have discussed the details of the blood supply to the eye in oxen (22), yaks (14), sheep and donkeys (23), and camels (24).

Limited studies have revealed the distribution of the blood supply in goats (12,25,26).

Therefore, the present work aims to prepare an educational module for the vasculature of the goat's eye, which will also be used in online anatomy teaching.

Materials and methods

Animals

The present study was performed on the heads of eight goats of both sexes and two living adult female Baladi goats (*Capra hircus*) aged between one and two years and weighing 36.33 ± 1.5 kg. The heads were collected from abattoirs in Sharkia province, and the animals were obtained from the farm at the Faculty of Veterinary Medicine, Zagazig University. The animals were handled following the Institutional Animal Care and Use Committee (IACUC), Zagazig University (ZU-IACUC/2/F/236/2023), Egypt.

Radiography

Two female goats' ventrodorsal and lateral contrast radiographs were performed for radiographic imaging of the vasculature of the goat's eye. Radiographic imaging was conducted using an X-ray machine (Pox-300 BT, Toshiba, Rotanode™, Japan) with 60 kV, 10 mAs, and a 75 cm FFD. Before radiography, food was restricted for 24 hours, and water for 12 hours. For proper securing and positioning, the animals were sedated with an intravenous injection of xylazine HCl 2% (Xylaject, ADWIA Pharmaceuticals Co., 10th of Ramadan City, Egypt) at a dose rate of 0.2 mg/kg body weight. The animals were administered intravenously 10 ml of the contrast media (Omnipaque, IOHEXOL, Alkan Medical), and the radiographs were taken 10 minutes after administration. Digital images were processed and interpreted.

Vasculature of the goat's eye

Four heads were thoroughly washed with normal saline and injected with gum milk (Latex 60%) colored red with scib paints through the common carotid artery. The other four heads were injected with blue gum milk with scib paints via the jugular vein. The head specimens were kept in a 10% formalin solution for one week. After that, the eyes were carefully dissected to demonstrate the arterial ramification supplying the orbital fat, eyelids, muscles, conjunctiva, and eyeball. Additionally, the venous tributaries that collected venous blood from the same eye structures were observed and digitally photographed with a camera (32 megapixels, Sony DSC-W690). Finally, the specimens were preserved in a glass jar filled with 10% formalin, 3% glycerin, and 1% thymol in the anatomy department museum for insight learning (26-28).

E-learning module and computer program

The PowerPoint presentation was designed to deliver an engaging and informative video on the vasculature of the goat's eye. This presentation included a quiz section with multiple-choice questions and opportunities for writing in the missing labels, covering most of the scientific material related to the arterial supply and venous drainage of the goat's eye. Adobe Flash Player version 32 explained the vasculature of the goat's eye, which included labeled images. For greater user accessibility, two buttons were present in the upper left corner of the screen to allow users to navigate to the home page or back to a previous page. Two arrows were located in the lower-left corner of the screen to enable users to move forward to the following photo or back to the previous one. Users could move the pointer arrow using the keyboard over different areas of the image. When the arrow hovered over a labeled structure, the name of that structure appeared on the image. Leaving the program at any stage could be done simply using the home button. The PowerPoint presentation video and the Adobe Flash Player program were offered to undergraduate and postgraduate students.

Survey and statistical analysis

Two surveys were planned. The first survey was of undergraduate students: One hundred third-year veterinary medicine students from the Anatomy Department of Zagazig University participated in this descriptive survey. The second survey of postgraduates: Twenty demonstrators, assistant lecturers, and lecturers from the Faculty of Veterinary Medicine at Zagazig University participated in this survey. Analyzing the survey results involved comparing traditional teaching methods with blended learning. The data acquired were subjected to analysis using R 4.1.0 software (R Foundation for Statistical Computing, Vienna, Austria). A one-sample z-test for proportion was used to test the statistical difference between the undergraduate and postgraduate students who recommended or did not recommend using self-directed learning as an additional teaching method. This test was chosen due to the qualitative nature of the dependent variable, which involves categorizing responses as either recommending or not recommending self-directed learning. A significance level of $P < 0.05$ was set to determine the statistical significance.

Results

Arterial supply of the eye

The arterial blood supply of the eye originated mainly from the external ophthalmic and malar arteries, with a minor contribution from the superficial temporal artery. The arteries that arose from these sources can be divided into two groups: the first group supplied the eyeball, while the second group supplied the adnexa of the eye (Figures 1A, B and 2A). The external ophthalmic artery was the last branch that arose from the maxillary artery and was considered a

direct continuation in the caudal part of the pterygopalatine fossa, ventral to the orbit. The external ophthalmic artery penetrated the periorbita and formed the external ophthalmic rete mirabile about 1 cm from its origin (Figure 2B). This rete was located dorsolaterally to the eyeball, near the origin of the recti muscles, in the vicinity of the optic foramen. The central part of the ophthalmic rete was situated deeply between the ventral aspect of the dorsal rectus muscle and the retractor bulbi muscle. A small part of this rete was more superficial and was found laterally between the dorsal rectus and lateral rectus muscles (Figures 2C and D). The rostral epidural rete mirabile was located in the middle of the ventral surface of the brain and was covered by the cerebral meninges. The mentioned rete received rostral and caudal branches from the maxillary artery (Figures 2E and F). Additionally, fine muscular branches originate from the external ophthalmic rete mirabile, supplying the extraocular muscles (Figure 2G).

Arteries supplying the eyeball included the anterior ciliary, short posterior ciliary, and long posterior ciliary arteries. After reflecting a part of the retractor bulbi and lateral rectus muscles, the anterior ciliary artery appeared to originate from the external ophthalmic artery. The anterior ciliary arteries pierce close to the limbus and supply the anterior parts of the choroid, iris, and ciliary body, and they also send branches to the conjunctiva (Figure 2/H). The ciliary artery originated from the external ophthalmic rete mirabile. It passed dorsolaterally to the optic nerve along part of its course and gave off a branch supplying it (Figure 3A). Before the ciliary artery reached the cribriform area, it was divided into medial and lateral branches. Each branch gave off short posterior ciliary arteries that supply the choroid and retina. The medial branch of the ciliary artery was divided near the optic papilla into medial and lateral long posterior ciliary arteries. The long posterior ciliary arteries were distinguished by their tortuous course to reach the ciliary body and iris. They pass anteriorly on the globe but penetrate the sclera before reaching the eye's equator. The retina's blood vessels arose from the ciliary arteries, mainly the short ciliary arteries (Figure 3B).

The arteries supplying the eye's adnexa included the lacrimal artery, which arose from the cranial part of the external ophthalmic rete mirabile. It passed along the dorsal rectus muscle and then ran between the rectus and lateral rectus muscles to reach the lacrimal gland. The lacrimal artery was ramified into three to four branches on the deep surface of the gland (Figures 2H and 3B). The supraorbital artery originated from the cranial aspect of the external ophthalmic rete mirabile and ran between the dorsal rectus and levator palpebrae superioris muscles before passing through the supraorbital foramen. The external ethmoidal artery originated from the caudal aspect of the external ophthalmic rete mirabile. It ran between the dorsal rectus and medial rectus muscles and then passed through the ethmoidal foramen to reach the cranial cavity (Figure 3C).

The eyelids and conjunctiva were supplied by the lateral superior and lateral inferior palpebral arteries, which originate from the superficial temporal artery via a shared trunk termed the lateral palpebral artery. The superficial temporal artery arose from the external carotid artery via a common trunk with the transverse facial artery. Additionally, the eyelids were supplied by the medial superior and medial inferior palpebral arteries, as well as a small branch to the third eyelid that arose from the malar artery. Moreover, the medial superior palpebral artery supplied the Puncta lacrimalis and Saccus lacrimalis, while the medial inferior palpebral artery supplied the caudal part of the nasolacrimal duct. The malar artery arose from the maxillary artery via a common trunk with the infraorbital artery in the rostral part of the pterygopalatine fossa, ventral to the orbit. The malar artery extended rostroventrally over the eyeball, crossing the infraorbital nerve to reach the medial angle of the eye (Figure 3D-F).

Venous drainage of the eye

The malar vein collected the venous drainage of the eyelids and conjunctiva. The small dorsal and ventral branches of the tiny network of veins drain blood from the Punctum lacrimalis dorsalis and Saccus lacrimalis, respectively. These veins drain into the ventral external ophthalmic vein, located at the eye's medial angle. It then passed between the ventral rectus and medial rectus muscles to empty into the ophthalmic plexus (Figure 4A).

There was a clear ophthalmic plexus present on the dorsal surface of the eyeball, ventral to the dorsal rectus muscle, and it filled the space between the lateral rectus muscle and the ventral rectus muscle, passing over the medial rectus muscle. This plexus connected the ventral external ophthalmic vein medially to the dorsal external ophthalmic vein laterally (Figure 4B and C). The supraorbital vein, the muscular veins, and the ventromedial vorticosae vein drain into the ophthalmic plexus. The muscular veins were two in number and were located on the lateral and ventral rectus muscles. The ventromedial vorticosae vein passed between the ventral rectus and medial rectus muscles to terminate in the ophthalmic plexus (Figure 4C-E).

The ophthalmic plexus continued laterally as the dorsal external ophthalmic vein, extending rostrally between the dorsal rectus and lateral rectus muscles. The dorsal external ophthalmic vein collected blood from the lacrimal vein, the dorsolateral vorticosae vein, and a branch from the periorbital fat. The lacrimal vein drained venous blood from the lacrimal gland, which ramified on the ventral surface of the gland. The dorsolateral vorticosae vein drained the eyeball and passed between the lateral rectus and dorsal rectus muscles. In the temporal region, the dorsal external ophthalmic vein continued as the superficial temporal vein, which accompanied the superficial temporal artery (Figure 4F). The superficial temporal vein drained into the maxillary vein, which joined the lingofacial vein and terminated in the

external jugular vein (Figure 5A). At the medial angle of the eye, the angular oculi vein drained venous blood from Puncta lacrimalis and Caruncula lacrimalis and drained into the facial vein (Figure 5B).

E-learning module and Computer program for teaching the vasculature of the goat's eye

The current E-learning module concerned the arterial supply and venous drainage of the goat's eye. This module covered the external ophthalmic, malar, and superficial temporal arteries and their branches. Additionally, it elucidated the dorsal external ophthalmic vein, the ventral external ophthalmic vein, and the ophthalmic plexus, which drained into the superficial temporal vein. Both of these components were clarified in a PowerPoint presentation video. Finally, a test used for comprehensive evaluation measured participants' performance and understanding of the material presented in the PowerPoint.

Computer-assisted instruction improved anatomy learning by allowing first-year students to use computer programs that provided effective short-term and long-term learning methods. The Adobe Flash Player version 32 explained the vasculature of the goat's eye, which included labeled images. It had a home page containing the article's title and the authors. Additionally, there was a list of buttons through which the user could navigate to different parts of the program (Figure 6).

Instructions

During the course, students must monitor the practical laboratories in the dissecting hall. The prepared specimens must be studied in the department museum. Student performance has increased through the department's notes, websites, and library texts. Students should contact the course professor and not hesitate to discuss matters with them, whether directly face-to-face or through any accessible means of communication.

Learning objectives

At the end of this module, the student will be able to describe the arterial blood supply of the goat's eye, identify the venous drainage of the goat's eye, and conduct self-evaluation.

Contents

An interactive PowerPoint presentation video that explained the vasculature of the eye in detail. Adobe Flash Player version 32 provides various images of the formalized goat's eye and associated blood vessels. Learners must visit the departmental museum to study the preserved specimens.

The first survey of undergraduate students

The results of the present questionnaire administered to third-year students (Table 1) showed the number and percentage of students who agreed to use self-directed

learning. This survey revealed that 94% of students recommended online learning, while 6% did not.

The second survey of postgraduates

The outcomes of the questionnaire administered to demonstrators, assistant lecturers, and lecturers in the

Faculty of Veterinary Medicine, Zagazig University (Table 2) revealed that 15% of them recommended online learning, while 5% did not recommend its use. Both undergraduate and postgraduate students recommended the use of self-directed learning rather than traditional learning methods $P < 0.001$ and $P = 0.02$, respectively (Figures 1-7).

Table 1: Results of research questionnaire carried out on 100 undergraduate students (third year)

Variables	Average \pm St. error			Total
	Same	Better	Much better	
Independence	25 (25.0%)	60 (60.0%)	15 (15.0%)	100 (100.0%)
Creation and motivation	14 (14.0%)	60 (60.0%)	26 (26.0%)	100 (100.0%)
Communication skills	35 (35.0%)	55 (55.0%)	10 (10.0%)	100 (100.0%)
Teamwork and interesting	13 (13.0%)	62 (62.0%)	25 (25.0%)	100 (100.0%)
Proficiency and efficiency	9 (9.0%)	68 (68.0%)	23 (23.0%)	100 (100.0%)
Permanent reference	5 (5.0%)	25 (25.0%)	70 (70.0%)	100 (100.0%)
Availability and comfortability	4 (4.0%)	24 (24.0%)	72 (72.0%)	100 (100.0%)
Time - consuming	9 (9.0%)	63 (63.0%)	28 (28.0%)	100 (100.0%)
Problem-solving abilities	25 (25.0%)	35 (35.0%)	40 (40.0%)	100 (100.0%)
Integration	5 (5.0%)	22 (22.0%)	73 (73.0%)	100 (100.0%)

Table 2: Results of the research questionnaire on 20 postgraduates (demonstrators, assistant lecturers, and lecturers)

Variables	Average \pm St. error			Total
	Same	Better	Much better	
Independence	3 (15.0%)	10 (50.0%)	7 (35.0%)	20 (100.0%)
Creation and motivation	7 (35.0%)	8 (40.0%)	5 (25.0%)	20 (100.0%)
Communication skills	10 (50.0%)	5 (25.0%)	5 (25.0%)	20 (100.0%)
Teamwork and interesting	10 (50.0%)	8 (40.0%)	2 (10.0%)	20 (100.0%)
Proficiency and efficiency	4 (20.0%)	9 (45.0%)	7 (35.0%)	20 (100.0%)
Permanent reference	5 (25.0%)	10 (50.0%)	5 (25.0%)	20 (100.0%)
Availability and comfortability	4 (20.0%)	12 (60.0%)	4 (20.0%)	20 (100.0%)
Time - consuming	2 (10.0%)	12 (60.0%)	6 (30.0%)	20 (100.0%)
Problem-solving abilities	4 (20.0%)	10 (50.0%)	6 (30.0%)	20 (100.0%)
Integration	3 (15.0%)	12 (60.0%)	5 (25.0%)	20 (100.0%)

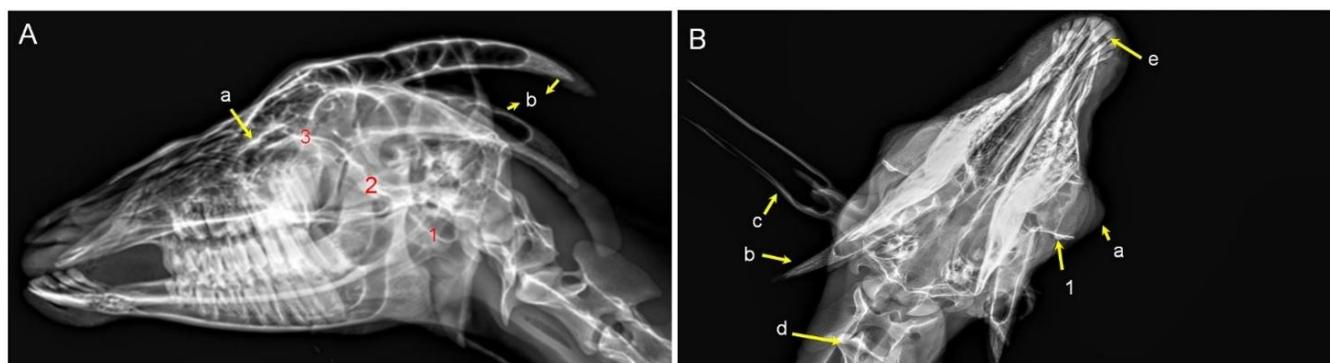


Figure 1: (A) A radiograph of a goat's head (Lateromedial view) showing: a. Bony orbit, b. Two horns. 1- Common carotid artery, 2- Maxillary artery, 3- External ophthalmic artery. (B) A radiograph of the goat's head (Ventrodorsal view) showing: a. Rim of the bony orbit, b. Horn, c. Ear, d. Cervical vertebrae, e. Incisors. 1- Supraorbital artery.

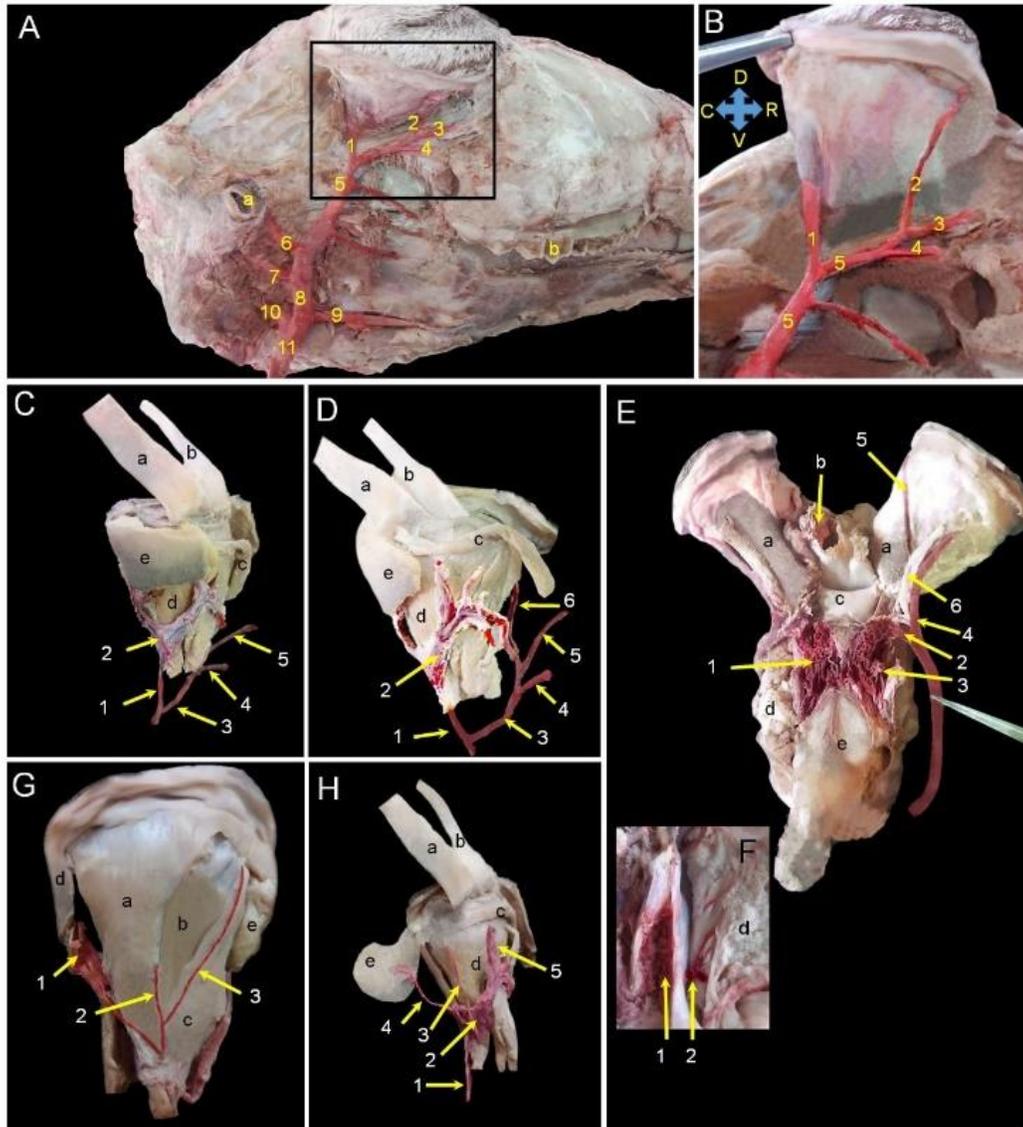


Figure 2: (A) A photomicrograph of a goat's head injected with red latex (lateral view) after removal of the mandible. (B) A higher magnification of the square area of (A) shows: a. External acoustic meatus, b. Molar teeth, (C). Caudal, (D). Dorsal, (R). Rostral, (V). Ventral. 1- External ophthalmic artery, 2- Malar artery, 3- Infraorbital artery, 4- Descending palatine artery, 5- Maxillary artery, 6- Rostral auricular artery, 7- Caudal auricular artery, 8- External carotid artery, 9- Lingual artery, 10- Occipital artery and 11- Common carotid artery. (C) A photomicrograph of a goat's eye (dorsal view). (D) A photomicrograph of a goat's eye (dorsal view) showing: a. M. rectus dorsalis and b. M. levator palpebrae superioris (reflected), c. M. obliquus dorsalis, d. M. retractor bulbi, e. Glandula lacrimalis, 1- External ophthalmic artery, 2- External ophthalmic rete mirabile, 3- maxillary artery, 4- Descending palatine artery, and 5-infraorbital artery, and 6- Malar artery. (E) A photomicrograph of goat's eyes and brain (ventral view) showing: a. M. rectus ventralis, b. Olfactory bulb, c. Optic chiasma, d. Brain tissue, e., meninges of the brain, 1- Rostral epidural rete mirabile, 2- Rostral branch of the rete mirabile, 3- Stump of a caudal branch of the rete mirabile, 4- Maxillary artery, 5- Malar artery and 6- Maxillary nerve. (F) A higher magnification of the ventrolateral aspect of the goat's brain shows: a. Brain tissue. 1- Rostral epidural rete mirabile and 2- Internal carotid artery. (G) A photomicrograph of a goat's eye (ventral view) showing: a. M. rectus ventralis, b. M. retractor bulbi, c. M. rectus medialis, d. M. rectus lateralis, e. Third eyelid (cartilaginous part). 1- External ophthalmic rete mirabile, 2- Muscular branch to M. rectus ventralis, and 3- Muscular branch to M. rectus medialis. (H) A photomicrograph of a goat's eye (dorsal view) showing: a. M. rectus dorsalis and b. M. levator palpebrae superioris (reflected), c. M. obliquus dorsalis, d. M. retractor bulbi, e. Glandula lacrimalis (reflected). 1- External ophthalmic artery, 2- External ophthalmic rete mirabile, 3-Anterior ciliary artery, 4- Lacrimal artery, and 5- Supraorbital artery.

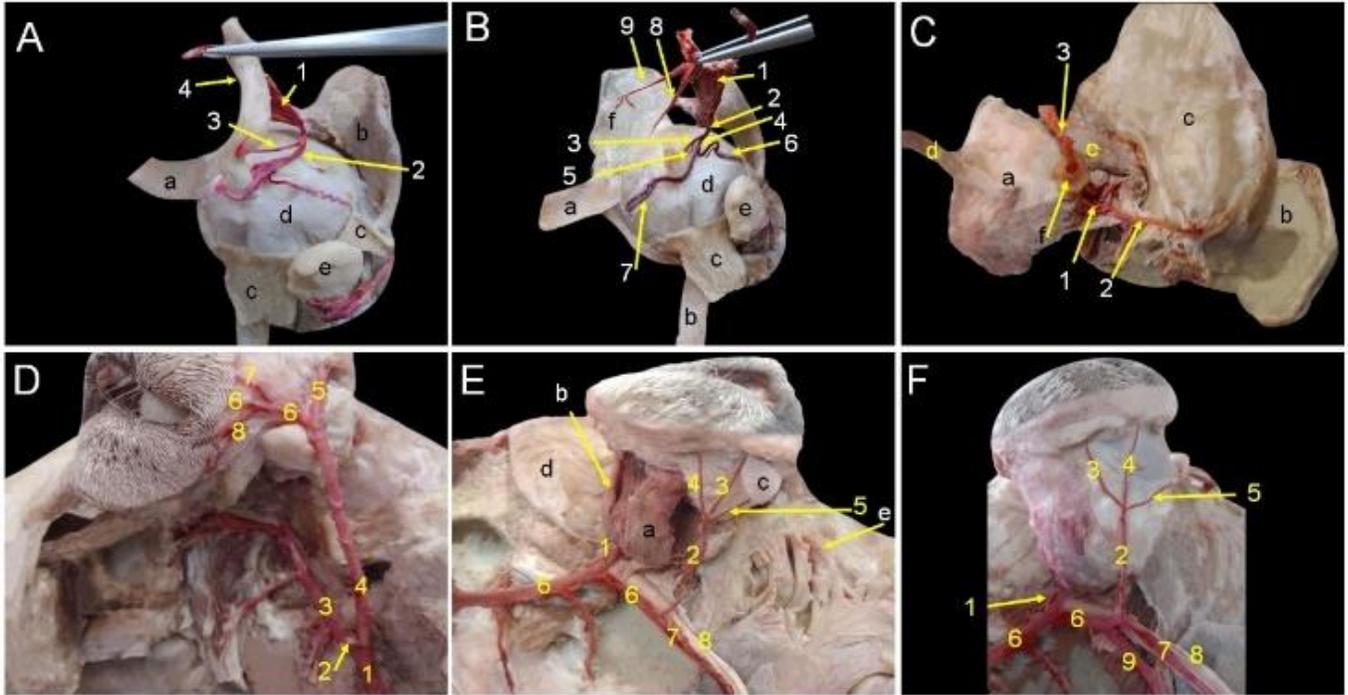


Figure 3: (A) A photomicrograph of a goat's eyeball showing: a. M. rectus lateralis, b. M. rectus medialis and c. M. retractor bulbi (reflected), d. Sclera, e. The third eyelid (cartilaginous part), 1- External ophthalmic rete mirabile, 2- Ciliary artery, 3- Branch to the optic nerve and 4- Optic nerve. (B) A photomicrograph of a goat's eyeball showing: a. M. rectus lateralis, b. M. rectus ventralis and c. M. retractor bulbi (reflected), d. Sclera, e. Third eyelid (cartilaginous part), f. Glandula lacrimalis (reflected), 1- External ophthalmic rete mirabile, 2- Ciliary artery, 3- Lateral branch of ciliary artery, 4- Medial branch of ciliary artery, 5- Short posterior ciliary arteries, 6- Medial long posterior ciliary artery, 7- Lateral long posterior ciliary artery, 8- Anterior ciliary artery, 9- Lacrimal artery. (C) A photomicrograph of goat's eyes and brain (dorsal view) showing: a. Right eye, b. Left eye, c. Meninges of the brain, d. M. levator palpebrae superioris (reflected), e. M. rectus dorsalis, 1- External ophthalmic rete mirabile, 2- External ethmoidal artery, 3- Supraorbital artery which passed through the supraorbital foramen (f). (D) A photomicrograph of a goat's eye (lateral view) showing: 1- External carotid artery, 2- Transverse facial artery (cut), 3- Maxillary artery, 4- Superficial temporal artery, 5- Cornual artery, 6- Lateral palpebral artery (Common trunk of lateral superior and lateral inferior palpebral arteries), 7- Lateral superior palpebral artery and 8- Lateral inferior palpebral artery. (E and F) Photomicrographs of a goat's eye (ventral view) showing: a. M. rectus ventralis, b. M. rectus lateralis, c. Third eyelid (cartilaginous part), d. Brain meninges, e. Nasal concha, 1- External ophthalmic artery, 2- Malar artery, 3-Medial superior palpebral artery, 4- Medial inferior palpebral artery, 5-branch to the third eyelid, 6- Maxillary artery, 7- Infraorbital artery, 8- Infraorbital nerve and 9- Descending palatine artery.

Discussion

In the present study, the arterial blood supply of the goat's eye originated from the external ophthalmic artery, malar artery, superficial temporal artery, and lacrimal artery. This result was consistent with Ghoshal (12) in ruminants, Noor and El-Bably (24) in camels, and Beyrami *et al.* (29) in buffalo. Nevertheless, the latter authors added that there were maxillary tubercular and zygomaticotemporal arteries. The external ophthalmic artery originated from the maxillary artery in the pterygopalatine fossa in goats. Similar findings have been observed by Nickel *et al.* (30) in pigs and

ruminants. The latter authors noted that the external ophthalmic artery arose within the alar canal from the maxillary artery in horses. The external ophthalmic rete mirabile was located dorsolateral to the eyeball in the current work. This outcome varied from that of Steven (22), who found that the ophthalmic rete mirabile of the ox extended medially and was slightly triangular in outline. The present finding was in accordance with the results of Beyrami *et al.* (29) in buffalo, who demonstrated that the ophthalmic rete mirabile, along with the external ophthalmic artery, contributed to the formation of the lacrimal, supraorbital, and external ethmoidal arteries.

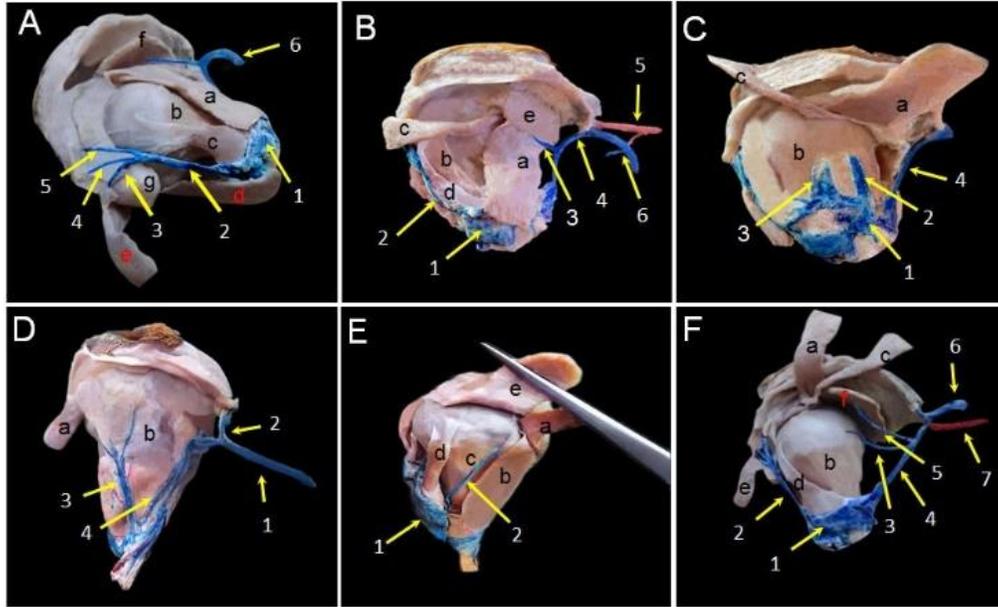


Figure 4: (A) A photomicrograph of a goat's eye (mediodorsal) view injected with blue latex showing: a. M. rectus dorsalis, b. M. retractor bulbi, c. M. rectus medialis, d. M. rectus ventralis, e. M. obliquus ventralis, f. Glandula lacrimalis, g. Third eyelid (cartilaginous part), 1- Ophthalmic plexus, 2- Ventral external ophthalmic vein, 3- Malar vein, 4- Small dorsal branch of the tiny network veins drain the blood from punctum lacrimale dorsalis, 5- ventral branch of the tiny network veins drain Saccus lacrimale and 6- Superficial temporal vein. (B) A photomicrograph of a goat's eye (dorsal view) showing: a. M. rectus dorsalis, b. M. retractor bulbi, c. M. dorsus obliquus, d. M. rectus medialis, e. Glandula lacrimalis, 1- Ophthalmic plexus, 2- Ventral external ophthalmic vein, 3- Lacrimal vein, 4- Dorsal external ophthalmic vein, 5- Superficial temporal artery and 6- Superficial temporal vein. (C) A photomicrograph of a goat's eye (dorsal view) showing: a. M. rectus dorsalis, b. M. retractor bulbi, c. M. obliquus dorsalis, 1- Ophthalmic plexus, 2- Supraorbital vein, 3- Medial branch of the ophthalmic plexus, and 4- Dorsal external ophthalmic vein. (D) A photomicrograph of a goat's eye (ventral view) showing: a. Reflected M. obliquus ventralis, b. M. rectus ventralis, 1- Dorsal external ophthalmic vein, 2- Branch drains periorbital fat, and (3 and 4)- Muscular branches. (E) A photomicrograph of a goat's eye (ventral view) showing: a. Reflected M. obliquus ventralis, b. M. rectus ventralis, c. M. retractor bulbi, d. M. rectus medialis, e. Reflected third eyelid (cartilaginous part), 1- Ophthalmic plexus, and 2- vorticose vein (ventromedial). (F) A photomicrograph of deep dissection of a goat's eye (dorsal view) showing: a. Reflected M. rectus dorsalis, b. M. retractor bulbi, c. Reflected M. obliquus dorsalis, d. M. rectus medialis, e. M. obliquus ventralis, f. Glandula lacrimalis, 1- Ophthalmic plexus, 2- Ventral external ophthalmic vein, 3- vorticose vein (dorsolateral), 4- Dorsal external ophthalmic vein, 5- Lacrimal vein, 6- Superficial temporal vein and 7- Superficial temporal artery.



Figure 5: (A) A photomicrograph of a goat's head (lateral view) injected with blue latex showing: a. External acoustic meatus, b. Eye. 1- Superficial temporal vein, 2- Maxillary vein, 3- Transverse facial vein, 4- Lingofacial vein and 5- Jugular vein. (B) A higher magnification of the square area of (A) of the goat's head shows 1- Angular oculi vein, 2- Facial vein, 3- Dorsal nasal vein, and 4- Lingofacial vein.



Figure 6: A photomicrograph showing the (Adobe Flash player version 32) explained the vasculature of a goat's eye, which included labeled images. It had a home page containing the title of the article and the authors. In addition, it contains a list of buttons through which the user can move to the different parts of the program.

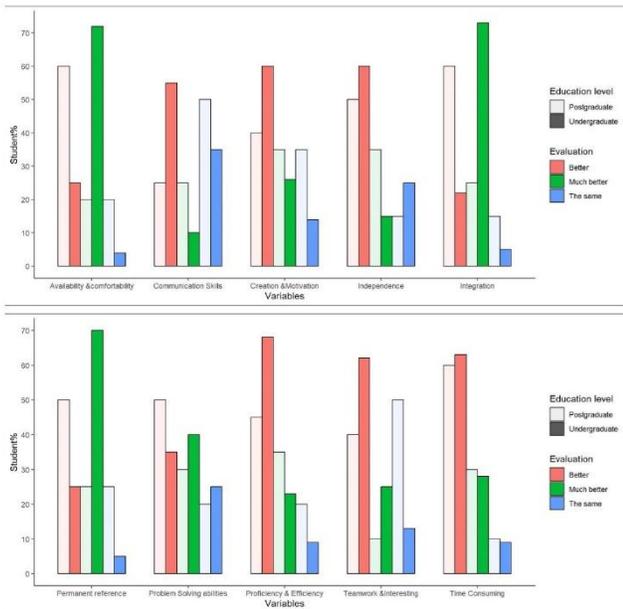


Figure 7: A bar graph showing the statistical analysis of a questionnaire carried out on undergraduate and postgraduate students.

The rostral epidural rete mirabile in goats was formed from the rostral and caudal branches originating from the maxillary artery. At the same time, Noor and El-Bably (24) and Jerbi *et al.* (31) in camels stated that the rostral epidural rete mirabile was formed from the external ophthalmic artery and the dorsal wall of the maxillary artery. This result was consistent with findings by Zdun *et al.* (32) in bovines and Wang *et al.* (33) in yaks and cattle.

The anterior ciliary artery of the goat's eyeball originated from the external ophthalmic artery. This outcome was agreed with Diesem (15) in ruminants. However, Beyrami *et al.* (29) in Buffalo revealed that the ciliary artery originated from the lacrimal artery, which arose from the external ophthalmic artery. The ciliary artery, its branches in the goat's eye, and its course generally concurred with the results of Diesem (15) in ruminants. This finding conflicts with the work of Beyrami *et al.* (29) in Buffalo, who mentioned that there were lateral and medial posterior long ciliary arteries derived from the bulbar artery or posterior long ciliary artery. The medial and lateral posterior long ciliary arteries comprised two posterior short ciliary arteries. The central retinal artery arose from the medial posterior long ciliary artery.

The present investigation declared that the supraorbital artery was derived from the rostral aspect of the external ophthalmic rete mirabile. This result varied with Smut and Bezuidenhout (34) in dromedary camels, Dyce *et al.* (35) in large ruminants, Noor and El-Bably (24) in camels, and Frackowiak *et al.* (36) in twin cattle. The authors above noted that the supraorbital artery originated from the dorsal part of the external ophthalmic artery. Meanwhile, Wang (37), in Bactrian camels, recorded that the supraorbital artery derived from the zygomaticotemporal artery. Additionally, Beyrami *et al.* (29) demonstrated that the supraorbital artery in buffalo gave off a muscular branch to the dorsal oblique muscle and then entered the frontal region via the supraorbital foramen.

Smut and Bezuidenhout (34) in dromedary camels and Beyrami *et al.* (29) in buffalo noted that the external ethmoidal artery was considered a continuation of the external ophthalmic artery. The latter authors added that the external ethmoidal artery gave off a branch from its origin to the dorsal oblique muscle, conjunctiva, and superior eyelid. These results did not align with the current finding, which observed that the external ethmoidal artery originated from the external ophthalmic rete mirabile and did not supply any structures in the eye.

The present study revealed that the lacrimal artery originated from the external ophthalmic rete mirabile and branched on the deep surface of the gland into 3 to 4 branches. This result was in line with those found by Ghoshal (12) in sheep and goats, Ocal *et al.* (38), Wang (37), Ibrahim *et al.* (39) in Bactrian camels, and Shao *et al.* (14) in yaks. However, Henker *et al.* (40) in pigs, Park *et al.* (41), and El-Naseer *et al.* (42) in dogs validated that a main lacrimal artery was considered a continuation of the external

ophthalmic artery. Additionally, Ghoshal (12) in sheep and Beyrami *et al.* (29) in buffalo noted that the lacrimal gland received another lacrimal branch from the superficial temporal artery. Meanwhile, Noor and El-Bably (24) in camels observed that there was no main lacrimal artery; instead, 4 to 5 branches nourished the lacrimal gland, with 3 to 4 branches originating from the zygomaticotemporal artery and one branch from the external ophthalmic artery.

The zygomaticotemporal artery was not detected in the current study; this result was concurred by Smut and Bezuidenhout (34) in dromedary camels and Dyce *et al.* (35) in domestic animals. However, this result differed with Wang (37) in the Bactrian camel, who recorded that the zygomaticotemporal artery emerged from the external ophthalmic artery and gave off the lateral superior palpebral, lateral inferior palpebral branches, 2-3 lacrimal branches, and some muscular branches. In this finding, the eyelids and conjunctiva were supplied by the lateral superior and lateral inferior palpebral arteries, which originated from the superficial temporal artery. These results coincided with those of Beyrami *et al.* (29) in buffalo.

In the present study, the malar artery originated from the maxillary artery via a common trunk with the infraorbital artery at the rostral part of the pterygopalatine fossa. Smut and Bezuidenhout (34) agreed with this result in dromedary camels. Nevertheless, Wang (37) in the Bactrian camel and Beyrami *et al.* (29) in buffalo demonstrated that the infraorbital artery gave the malar artery, which, in turn, divided into the medial superior palpebral, medial inferior palpebral, and artery of the third eyelid. The latter authors added that the malar artery gave off a branch to supply the orbital fat.

The maxillary tubercular artery was not recognized in goats. This result corresponded to that mentioned by Smut and Bezuidenhout (34) in dromedary camels. However, Wang (37) in the Bactrian camel showed that the infraorbital artery gave off the maxillary tubercular artery just rostral to the malar artery, supplying the ventral oblique and medial rectus muscles.

The malar vein collected the venous blood at the medial angle of the eye. Additionally, the small dorsal and ventral branches of the tiny network of veins drained into the ventral external ophthalmic vein, contributing to the ophthalmic plexus. This finding was in line with those reported by Popesko and Ghoshal (16) in ox and dogs, Motwally (43) in mules, and El-bahery (23) in sheep and donkeys. Hayreh (44) in humans added that the inferior ophthalmic vein originated at the floor and medial wall of the orbit and provided drainage for the inferior part of the orbit.

The present work revealed that the position of the ophthalmic plexus in goats was on the dorsal surface of the eyeball. This result was consistent with the findings of Wilkens and Munster (45) in domestic animals. However, in pigs, the ophthalmic plexus was replaced by the ophthalmic

sinus, which was considered a continuation of the deep facial vein.

In goats, the venous blood from the eyeball was collected by two vorticoses veins: the ventromedial and dorsolateral veins. The ventromedial vein terminated in the ophthalmic plexus, while the dorsolateral vein drained into the dorsal external ophthalmic vein. On the other hand, Hayreh (44) observed four vortex veins in humans: the superior lateral and medial vortex veins, which emptied into the superior ophthalmic vein, and the inferior lateral and medial vortex veins, which drained into the inferior ophthalmic vein.

In the current study, the lacrimal vein collected venous blood from the lacrimal gland and drained into the dorsal external ophthalmic vein. This result corresponded with the findings of Popesko and Ghoshal (16) in ox, sheep, and goats, Buda and Budras (17) in bovines, and Ibrahim *et al.* (39) in camels. The dorsal external ophthalmic vein continued as the superficial temporal vein; this finding was reported by Buda and Budras (17) in bovines. On the other hand, there was a variance between Diesem (15) and Popesko and Ghoshal (16) in horses, who stated that the lacrimal vein drained into the ventral external ophthalmic vein, which was drained by the deep facial vein near the lateral angle of the eye. Roy (46) confirmed this finding in dogs. All discrepancies in arterial origins, exact branches, and venous drainage in different animals are due to species-specific variations.

The study questionnaire revealed that most students and postgraduates preferred blended learning over traditional learning. However, Totlis *et al.* (47) noted that traditional anatomy learning was the most favored and effective learning modality. The improvement of online learning methods has increased students' active participation in anatomy courses, but students' performance has been adversely affected in exams. Therefore, anatomy programs could include online courses as a supplementary tool. On the other hand, Khan *et al.* (48) reported that 73.7% of students were dissatisfied with online education. Despite the development of online teaching strategies among youth, some disadvantages of online education were recorded by Khan *et al.* (48) and Ostrovsky *et al.* (49). They found that prolonged usage of electronic devices during online learning affected students' health and could lead to many complications, such as headaches, neck and shoulder ache, and eye complaints like eye fatigue, dryness, irritation, tearing, redness, and blurry vision.

Numerous limitations of the study are worth mentioning. Fluorescein angiography was needed to study retinal blood vessels. Using Adobe Flash Player was not ideal. Other more universally compatible software, such as Hypertext Markup Language 5 (HTML5) or newer interactive tools, is much better. The number of participants in the questionnaire needs to be increased. Therefore, further research is recommended to address the current study's lacunae.

Conclusion

The existing study establishes an online educational module for the vasculature of the goat's eye as a new trend in teaching and learning veterinary anatomical courses, especially during the pandemic. This E-learning module creates a supplemental virtual anatomy tool that is available to every student twenty-four hours a day. Furthermore, it minimizes the learning costs, especially for practical sessions and the replacement of animal cadavers with prepared specimens.

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Conflict of interest

The authors state that they have no conflicts of interest.

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دراسة مستقبلية مختلطة للأوعية الدموية في عين الماعز من خلال نهج التعلم المدمج

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الخلاصة

لقد أحدثت أزمة جائحة كوفيد-19 تغييراً مفاجئاً في التعليم وتحول العلم بسرعة من التعليم وجها لوجه إلى التعليم عبر الإنترنت. إن إنشاء وحدات التعلم الإلكتروني يمثل اتجاهاً جديداً في تدريس وتعلم المقررات التشريحية البيطرية. لذلك، تهدف الدراسة الحالية إلى إعداد وحدة تعليمية للأوعية الدموية في عين الماعز لاستخدامها في تدريس التشريح عبر الإنترنت. لتوضيح الأوعية الدموية في عين الماعز، تم إجراء فحص بالأشعة على اثنتين من إناث الماعز البالغة السليمة، كما تم حقن ثمانية رؤوس ماعز باللاتكس الملون. كان الإمداد الشرياني للعين والحجاج في الماعز مستمداً بشكل رئيسي من الشرايين العينية الخارجية وشرايين الخد، مع مساهمة طفيفة من الشريان الصدغي السطحي. شكل الشريان العيني الخارجي الشبكة العينية الخارجية، والتي أعطت الشرايين الأتية؛ فوق الحجاج، والدمعي، والغربالي الخارجي، والهدبي، والهدبية الأمامية. تم تزويد الجفون والملتحمة بفروع صغيرة من الشرايين الخدية والصدغية السطحية. يتم التصريف الوريدي للعين والحجاج بشكل رئيسي عبر الأوردة العينية الخارجية البطنية والأوردة العينية الخارجية الظهرية. يصب الوريد الخدي في الوريد العيني الخارجي البطني. تربط الشبكة العينية بين الوريد العيني الخارجي البطني من الداخل والوريد العيني الخارجي الظهرى من الخارج، ويصب فيها الوريد البطني المتعرج. يجمع الوريد العيني الظهرى الدم من الأوردة الدمعية والمتعرجة الظهرية. تُنشئ هذه الوحدة التعليمية الإلكترونية أداة افتراضية إضافية للتشريح متاحة لكل طالب.