

Anatomical study of the eye arterial blood supply in adult river buffalo (*Bubalus bubalis*)

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Abstract

Obtaining information about the eye arterial supply in the buffalo can be a criterion for ocular diseases diagnosis and give a morphological basis for even more researches on the related clinical surgery of this animal. The aim of the present study was to describe the course and branches of the arteries supplying the eye in the adult river buffalo (*Bubalus bubalis*). In this study, the heads of eight buffaloes were prepared from the public slaughterhouse and dissected to study the eye arterial supply. This research results showed that the eye blood supply in the buffalo originates from the external ophthalmic, internal ophthalmic, superficial temporal and malar arteries. The external ophthalmic artery was given rise to branches to take part in the ophthalmic rete mirabile formation and also given off lacrimal, external ethmoidal, supraorbital and ciliary arteries as well as muscular branches to supply the eye ball and extra-ocular muscles. The internal ophthalmic artery was one of the sources of lateral posterior long ciliary artery. The superficial temporal artery was detached off some branches to supply the lateral angle of inferior and superior eyelids as well as lacrimal branch to supply lacrimal gland. The malar artery was originated from the infra-orbital artery and its branches were supplied the medial angle of inferior, superior and third eyelids. There were no obvious differences between buffalo and yak regarding arteries supplying the eyes. However, there were minor differences between buffalo and oxen, sheep and goat and there were obvious differences between buffalo and camel and giraffe.

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Introduction

Buffalo is a large ruminant and a domestic multi-purpose animal used mainly for milk and meat productions and plays a vital role in the whole agricultural system having a large influence on the rural economy.¹ The eye is the most important sensory organ and most of the outer information enters brain through visual system.² The eye arterial supply in animals originates mainly from the external ophthalmic artery as a branch of maxillary artery.³⁻⁵ The eye anatomy has been extensively described in the equines, bovines, sheep and dog.³⁻⁵ Also, several anatomical and morphological studies have been conducted to examine the eye arterial supply in the Bactrian⁶ and one-humped camels.⁷ The study of morphological variations of internal ophthalmic artery in the chinchilla has also showed ten variants of the blood supply for the orbit.⁸ The study of eye blood supply in the giraffe has revealed the

existence of two ophthalmic retia mirabilia in this animal.⁹ The horse¹⁰ and mouse¹¹ eyes micro-vascular anatomy has been also studied through methyl methacrylate resin injection via carotid artery and scanning electron microscopy, respectively. Reportedly, the eye arterial supply in camel originates from the external and internal ophthalmic, zygomaticotemporal and malar arteries^{6,7} and in the yak² and oxen,¹² from the internal ophthalmic, external ophthalmic, superficial temporal and malar ones.² The researches on the eye blood supply in the animals, especially ruminants, are few and no reports describing the eye arterial supply in buffalo have been published yet.

The aim of this study was to describe the origin, course and branches of the arteries supplying the eye in the adult river buffalo (*Bubalus bubalis*). It is important to know the details of the eye arterial supply in buffalo to provide a morphological basis for even more researches on the comparative anatomy as well as related clinical surgery

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of this animal. Excluding minor differences, it seems that the eye basic anatomy is similar in all domestic animals.

Materials and Methods

Eight heads of adult buffalo were collected from the Urmia public slaughterhouse, Urmia, Iran. The animals were of varying ages (3 - 5 years). In order to prevent blood coagulation in the vessels, the common carotid artery was dissected in the slaughterhouse and catheterized by an 18G cannula. The artery was flushed by heparinized (5,000 IU mL⁻¹ heparin sodium; Caspian Tamin, Rasht, Iran) saline solution (2,500 IU L⁻¹) frequently until clear saline solution was drained out of the arteries. After transferring of the specimens to the laboratory, hot water was injected into the common carotid artery. As a result, blood vessels of the head and face were completely washed and entirely opened. The arteries were visualized by filling them through the common carotid artery with latex (Wilsor Kunsthasen, Biddinguizen, The Netherlands) having additional dye (Blue Acrylic paint; ADVEO Belgium NV, Deinze, Belgium). The specimens were placed inside commercial acetic acid and after one day, dissection was performed with the help of magnifying glasses (2×) to define the fine details of the vessels and their branches.

Results

This research observation revealed that the eye arterial blood supply in buffalo originates mainly from the external ophthalmic, internal ophthalmic, superficial temporal and malar arteries.

External ophthalmic artery. The external ophthalmic artery was originated from the dorsal surface of the maxillary artery following the buccal artery origin. It gave off rete mirabile epidurale branches into cranial cavity close to the orbit apex (Fig. 1A). External ophthalmic artery was then passed from lateral side of the maxillary nerve, entered the orbit and formed ophthalmic rete mirabile between the retractor bulbi and dorsal and lateral rectus muscles. Ophthalmic rete mirabile gave off some small muscular branches to supply the rectus, dorsal oblique, retractor bulbi and levator superior eyelid muscles. Also, ophthalmic rete mirabile along with external ophthalmic artery was participated in external ethmoidal, supraorbital and lacrimal arteries formation. In the dorso-medial side of eyeball, a common trunk for the supraorbital and external ethmoidal arteries also originated from the external ophthalmic artery. Supraorbital artery gave off a muscular branch to the dorsal oblique muscle and then entered the frontal region via supraorbital foramen. The external ethmoidal artery was the continuation of external ophthalmic artery giving off a branch from its origin to dorsal oblique muscle, conjunctive and superior eyelid.

The external ethmoidal artery left the orbit accompanied by ethmoidal nerve through the ethmoidal foramen and entered nasal cavity. The external ophthalmic artery gave off lacrimal artery in dorsal side of the eyeball and lacrimal artery following giving off first anterior ciliary artery close to its origin coursed dorsally to lacrimal gland. Some branches emerged from the lacrimal artery beneath the lacrimal gland and participated in the second anterior ciliary artery formation through joining to the muscular branch of external ophthalmic artery. Some muscular branches also emerged from external ophthalmic artery and ophthalmic rete mirabile supplying most of the eyeball muscles, whereas one of them participated in the second anterior ciliary artery formation (Figs. 1A, 2A, 2B and 3A).

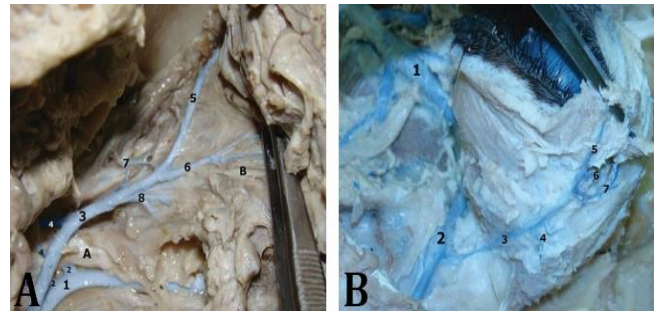


Fig. 1. A) Arteries of the eye (lateral view of the right eye). 1) Maxillary artery; 2) Carotid rete mirabile branches; 3) External ophthalmic artery; 4) Epidural rete mirabile branches; 5) Common trunk of supraorbital and external ethmoidal arteries; 6) Lacrimal artery; 7) Ophthalmic rete mirabile; 8) Muscular branch of external ophthalmic artery; A) Maxillary nerve; B) Lacrimal nerve. **B)** Branches of the malar artery (medial view of the right eye). 1) Maxillary artery; 2) Infra-orbital artery; 3) Malar artery; 4) Muscular branch of malar artery; 5) Medial inferior palpebral artery; 6) Third eyelid artery; 7) Medial superior palpebral artery.

A branch called posterior long ciliary artery or bulbar artery originated from ventral aspect of external ophthalmic artery or sometimes ophthalmic rete mirabile coursed cranially along the medial side of the retractor bulbi muscle and entered the fibrous sheath of optic nerve. It was then extended towards the eyeball along the medio-ventral side of the optic nerve and parallel to internal ophthalmic artery and finally divided into the lateral and medial posterior long ciliary arteries (Fig. 3B). The medial posterior long ciliary artery was coursing rostrally along the medial border of the optic nerve and entered the eyeball from the posterior half of the eyeball and lateral posterior long ciliary artery was coursed rostrally along the lateral side of the optic nerve, joined with internal ophthalmic artery and then entered the eyeball from the posterior half of the eyeball. The medial posterior long ciliary artery gave off the central retinal artery from its origin passing from area cribrosa and supplying the retina. There were two posterior short ciliary arteries originating from the medial and lateral posterior long ciliary arteries entering the eyeball close to optic nerve (Fig. 3B).

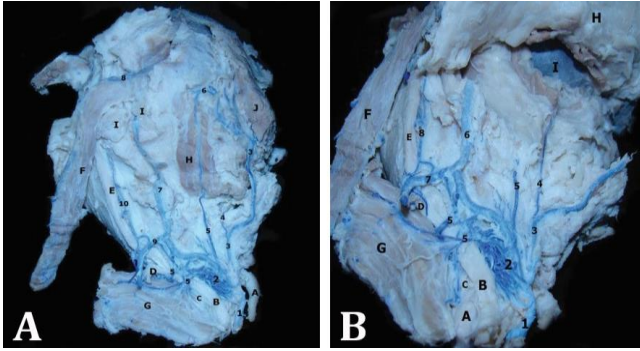


Fig. 2. A) Arteries of the right eye (dorsal view). 1) External ophthalmic artery; 2) Ophthalmic rete mirabile; 3) Lacrimal artery; 4) First anterior ciliary artery; 5) Muscular branch of External ophthalmic artery; 6) Second anterior ciliary artery; 7) Supraorbital artery; 8) Muscular branch of supraorbital artery; 9) External ethmoidal artery; 10) Muscular branch of external ethmoidal artery; A) Optic nerve; B) Nasociliary nerve; C) Long ciliary nerve; D) Ethmoidal nerve; E) Infra-trochlear nerve; F) Dorsal oblique muscle; G) Proximal part of dorsal rectus muscle; H) Distal part of dorsal rectus muscle; I) Trochlear cartilage; J) Lacrimal gland. **B)** Arteries of the right eye (dorsal view). 1) External ophthalmic artery; 2) Ophthalmic rete mirabile; 3) Lacrimal artery; 4) First anterior ciliary artery; 5) Muscular branch of external ophthalmic artery; 6) Supraorbital artery; 7) External ethmoidal artery; 8) Muscular branch of external ethmoidal artery; A) Optic nerve; B) Nasociliary nerve; C) Long ciliary nerve; D) Ethmoidal nerve; E) Infra-trochlear nerve; F) Dorsal oblique muscle; G) Dorsal rectus muscle; H) Orbital fat; I) Dorsal surface of sclera.

Internal ophthalmic artery. The internal ophthalmic artery was originating from the rete chiasmaticum in the cranial cavity. It was accompanying with optic nerve and entered the fibrous sheath of the optic nerve laterally and then coursed ventrally to the orbital fossa, where it was joining with the lateral posterior long ciliary artery. Therefore, the internal ophthalmic artery was a source of posterior long ciliary artery (Fig. 3B).

Superficial temporal artery. The superficial temporal artery was the last branch of the external carotid artery and following its arising, the external carotid artery was extended as a maxillary artery. After giving off transverse facial, rostral auricular, caudal auricular and parotid arteries, superficial temporal artery was ascending towards the frontal region. Under the parotid gland and auricular muscles, it became superficial, placed lateral to zygomatic arch and gave off the lateral palpebral artery towards lateral angle of the eye. It was passed under the horn and after a short course; it gave off the cornual branch from its caudal border supplying the horn. Finally, lateral palpebral artery was divided into three branches including lateral superior palpebral, lateral inferior palpebral and lacrimal branches. The lateral superior palpebral artery was relatively slender and it was coursing caudal and dorsal to the lateral angle of the eye and towards the orbicularis oculi muscle and superior eyelid and also detached off some branches to frontal region.

The lateral inferior palpebral artery was coursing caudally and ventrally towards the orbicularis oculi muscle and inferior eyelid. The lacrimal branch was lying between two lately arteries and originated from cranial aspect of lateral palpebral artery or sometimes was arisen in a common trunk with lateral inferior palpebral artery supplying lacrimal gland (Figs. 4A and 4B).

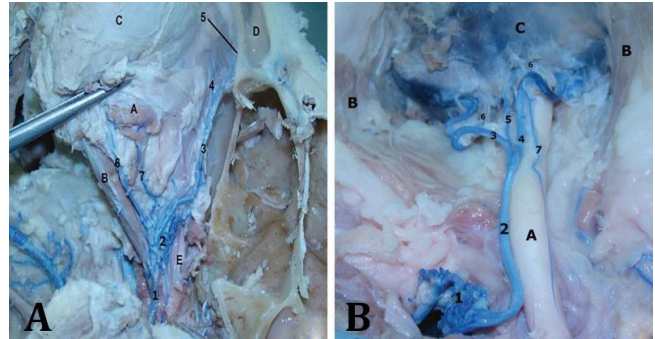


Fig. 3. A) Arteries of the left eye (dorsal view). 1) External ophthalmic artery; 2) Ophthalmic rete mirabile; 3) Supraorbital artery; 4) Muscular branch of supraorbital artery; 5) Supraorbital foramen; 6) Lacrimal artery; 7) Muscular branch of external ophthalmic artery; A) Levator palpebrae superior muscle; B) Lateral rectus muscle; C) Lacrimal gland; D) Frontal sinus; E) Dorsal rectus muscle. **B)** Branches of the left eye bulbar artery (ventral view). 1) Ophthalmic rete mirabile; 2) Bulbar or ciliary artery; 3) Medial posterior long ciliary artery; 4) Lateral posterior long ciliary artery; 5) Central retinal artery; 6) Posterior short ciliary arteries; 7) Internal ophthalmic artery; A) Optic nerve; B) Retractor bulbi muscle; C) Sclera.

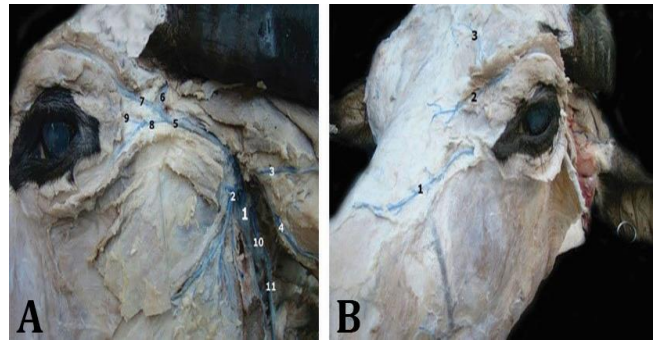


Fig. 4. A) Superficial arteries of the head and face. 1) Superficial temporal artery; 2) Transverse facial artery; 3) Rostral auricular artery; 4) Medial auricular artery; 5) Lateral palpebral artery; 6) Cornual branch; 7) Lateral superior palpebral artery; 8) Lateral inferior palpebral artery; 9) Lacrimal branch; 10) Caudal auricular artery; 11) Parotid artery. **B)** Superficial arteries. 1) Dorsal nasal artery (branch of malar artery); 2) Lateral superior palpebral artery (branch of superficial temporal artery); 3) Frontal branch of lateral superior palpebral artery.

Malar artery. The malar artery was arising from dorsal wall of the infra-orbital artery near the maxillary foramen. It was coursing rostrally in the orbital fossa to the medial angle of the eye. During its course, it gave off a branch to the orbital fat. The malar artery was coursing to the medial angle of the eye and dividing into three

branches including medial inferior palpebral artery towards inferior eyelid, medial superior palpebral artery after turning medial angle of the eye towards superior eyelid and third eyelid branch lying between two lately arteries supplying third eyelid. The continuation of the malar artery was dorsal nasal artery coming out from medial angle of the eye supplying dorsal surface of the nose (Figs. 1B and 4B).

Discussion

In humans, the external ophthalmic artery is called ophthalmic artery and originated from the internal carotid artery.¹³ The external ophthalmic artery in all mammals such as yak,² sheep,^{3,4} camel,^{6,7} giraffe,⁹ mouse,¹¹ oxen¹² and horse¹⁴ originates from the maxillary artery; but, in the cat, it arises rostro-dorsally from the maxillary rete mirabile⁴ and in the birds³ and humans,¹³ it arises from the internal carotid artery in the cranial cavity. The external ophthalmic artery crosses the maxillary nerve laterally in all domestic mammals and then enters the orbit. In the carnivores, the external ophthalmic artery gives off the central retina, posterior long ciliary and posterior short ciliary arteries, while it arises from the bulbar artery in other animals like buffalo.³ After arising from the maxillary artery, the external ophthalmic artery enters the orbit and forms the ophthalmic rete mirabile between the lateral and dorsal rectus and retractor bulbi muscles through giving off some branches (about 3 - 5 branches). According to the previous studies, the ophthalmic rete mirabile is only seen in ruminants^{2,6,9} and birds³. The position, shape and relationship of the ophthalmic rete mirabile in buffalo are similar to the yak,² sheep,³ and oxen¹² have some differences with camel^{6,7} and giraffe.⁹ Unlike other ruminants, the giraffe has two ophthalmic rete mirabile; the superior ophthalmic rete mirabile is formed by external ophthalmic artery and the inferior ophthalmic rete mirabile is formed by some branches of the carotid rete mirabile, external ophthalmic artery and some branches of internal ophthalmic artery.⁹ In camel, the ophthalmic rete mirabile is related to the epidural rete mirabile via some branches;^{6,7} but, there is no relationship between the ophthalmic rete mirabile and epidural rete mirabile in yak² oxen,¹² sheep^{3,4,15} and buffalo as seen in this study. In all ruminants, the ophthalmic rete mirabile participates in supraorbital, external ethmoidal and lacrimal arteries formation and also gives off muscular branches to the eyeball muscles,^{2,9,12} that was like what observed in buffalo. The supraorbital artery arises independently from the external ophthalmic artery in cat, pig,^{3,4} camel,^{6,7} chinchilla,⁸ human,¹³ horse;¹⁴ and but, it arises in a common trunk along with the external ethmoidal artery in yak² and other ruminants^{3,4} similar to the findings in buffalo in this study. However, in horse, it may arise from the rostral deep temporal artery or the maxillary artery.³ The supraorbital

artery is not seen in dogs^{3,4} and it arises from the ophthalmic rete mirabile in birds supplying the superior eyelid.³ Before traversing through supraorbital foramen, the supraorbital artery gives off a branch into the superior eyelid in oxen^{4,12} and a branch into the dorsal oblique muscle in camel^{6,7} similar to buffalo. However, according to the former reports, the supraorbital artery in yak does not give off any branches into the orbit.² The external ethmoidal artery is the continuation of the external ophthalmic artery and arises in a common trunk along with the supraorbital artery in most of ruminants including yak,² giraffe,⁹ oxen,¹² sheep,^{4,15} and as well as buffalo in our study. However, in Bacterian⁶ and dromedary⁷ camels, it is not the continuation of the external ophthalmic artery and arises from the maxillary artery. The lacrimal artery is large and arises from the external ophthalmic artery into the lacrimal gland in pig,^{3,4} horse,¹⁰ human¹³ and most of ruminants.^{3,4} However, it arises from ventral branch of the external ethmoidal artery¹⁶ or muscular branch of the external ophthalmic artery in dog.¹⁷ The lacrimal artery arises from the maxillary artery or maxillary rete mirabile in cat,⁴ from the superficial temporal artery in giraffe,⁹ from the zygomaticotemporal artery in camel^{6,7} and from the external ophthalmic artery and its rete mirabile in yak² same as findings observed in this study.

In the current study, the external ophthalmic artery in buffalo similar to most of animals was originated from the maxillary artery and like other ruminants formed the ophthalmic rete mirabile giving off supraorbital, external ethmoidal and lacrimal arteries and muscular branches.

The anterior ciliary arteries arise from the muscular branch of external ophthalmic artery in carnivores and horses, while they arise directly from the external ophthalmic artery in pig^{3,4} and from the internal ophthalmic artery in giraffe.⁹ The anterior ciliary arteries arise from the lacrimal artery or the muscular branch of external ophthalmic artery in large ruminants^{2,3,6,9} and just from the muscular branch of external ophthalmic artery in horse,^{3,4} sheep¹⁵ and goat.¹⁸ These arteries arise from the lacrimal artery in yak² and human¹³ from the ophthalmic rete mirabile in birds.³ Interestingly, there are no anterior ciliary arteries in rat.¹⁹ In the present study, similar to large ruminants except giraffe, it was observed that the anterior ciliary arteries in buffalo originate from the lacrimal artery and muscular branch of the external ophthalmic artery.

The muscular branches after arising from the external ophthalmic artery supply the eyeball muscles. These branches arise from the external ophthalmic artery in humans,¹³ horses, carnivores and pigs³⁻⁵ and from the external ophthalmic artery and its rete mirabile in ruminants. The muscular branches give off the anterior ciliary arteries in ruminants,^{2,6,9,12} carnivores and horses.^{3,4} Accordingly, the muscular branch of external ophthalmic

artery in buffalo in this study was similar to carnivores, horses and other ruminants.

The ciliary artery or the bulbar branch²⁰ named posterior long ciliary artery³ arises directly from the external ophthalmic artery in carnivores,^{3,4} humans,¹³ horses¹⁴ and rats,¹⁹ from the muscular branch of external ophthalmic artery in pig,³ sheep,¹⁵ goat¹⁸ and from the external ophthalmic artery or ophthalmic rete mirabile in birds³ and large ruminants including yak² and camel.^{6,7} However, the ciliary artery arises from the internal ophthalmic artery in giraffe.⁹ In all domestic animals, the ciliary artery or the posterior long ciliary artery is divided into lateral and medial posterior ciliary arteries.^{3,4} According to our findings, the ciliary artery or the bulbar branch or posterior long ciliary artery in buffalo was similar to the other large ruminants except giraffe and it was different from small ruminants.

The short posterior ciliary arteries in the horse arise with the posterior long ciliary artery from the external ophthalmic artery or its muscular branches and arise from the posterior long ciliary artery in ruminants.^{3,4} The short posterior ciliary arteries arise from the external ophthalmic artery in carnivores, from the ophthalmic rete mirabile^{3,4} in birds and from the ophthalmic artery or the posterior long ciliary artery in rat¹⁹ and human.¹³ They arise just from the posterior long ciliary artery in yak², camel^{6,7} and chinchilla⁸ and from the internal ophthalmic artery in giraffe.⁹ Reportedly, the number of short posterior ciliary arteries is 2-4 branches in rat,¹⁹ three branches in yak² and 4 - 6 branches in camel;^{6,7} in other animals, the number of these arteries is not mentioned. Our observations showed that similar to large ruminants except giraffe; short posterior ciliary arteries in buffalo originate from the posterior long ciliary artery.

The central retinal artery arises from the external ophthalmic artery in carnivores,^{3,4} mice¹¹ and rats¹⁹, from the external ophthalmic or short posterior ciliary arteries in horse¹⁴ and from the posterior long ciliary artery or muscular branch of the external ophthalmic artery in pig.³ The central retinal artery arises from the lateral and medial posterior long ciliary arteries in most of ruminants such as yak.² However, it arises from the internal ophthalmic artery in giraffe⁹ and from the ophthalmic rete mirabile in camel.^{6,7} This artery is not seen in birds.³ Based on the results of this study, the central retinal artery in buffalo was originated from the medial posterior long ciliary artery, similar to most of ruminants except giraffe and camel.

The internal ophthalmic artery is a thin artery on the ventral surface of optic nerve.²¹ It arises from the rostral part of epidural rete mirabile in the cranial cavity in yak,² oxen,¹² sheep¹⁵ and similar to buffalo in this study. The internal ophthalmic artery arises from the internal carotid artery in rat¹⁹ and rabbit;^{22,23} but, it arises from the carotid

rete mirabile in other animals.^{3,4} The internal ophthalmic artery is not seen in human.¹³ It has been reported that external and internal ophthalmic arteries are connected indirectly by the posterior long ciliary artery in ruminants,² same as what observed in this study.

The superficial temporal artery is the last branch of the external carotid artery.³ It arises directly in carnivores, horses and ruminants³; but, arises in a common trunk along with the transverse facial artery in pig³ and giraffe.⁹ The superficial temporal artery is not involved in the eye blood supply in camel.^{6,7} The lacrimal branch of superficial temporal artery is only seen in yak,² giraffe,⁹ oxen¹² and sheep.¹⁵ It is accompanied by lacrimal artery from external ophthalmic artery and supplies the lacrimal gland.^{2,4,9} The superior and inferior lateral palpebral arteries are the branches of superficial temporal artery in carnivores³ and most of ruminants including yak,² giraffe,⁹ oxen¹² and sheep.¹⁵ However, they arise from the lacrimal artery in pig³ and horse¹⁴ and from the zygomaticotemporal artery in camel.^{6,7} It was observed in this study that the superficial temporal artery in buffalo similar to other ruminants except giraffe originates directly from the external carotid artery and gives off three branches into the eye similar to other ruminants except camel.

The malar artery arises from infra-orbital artery in yak,² carnivores, ruminants,³ camel,^{6,7} and giraffe⁹ and horses;¹⁴ but, it arises from maxillary artery in pig.⁴ The malar artery gives off the superior and inferior medial palpebral and the third eyelid arteries in the medial angle of the eye in buffalo similar to most of animals including yak,² camel,^{6,7} sheep,¹⁵ and goat.¹⁸ However, the inferior medial palpebral artery arises from the ophthalmic artery in human¹³ and from the buccal artery in pig.⁴ The superior medial palpebral artery arises from supra-trochlear artery in human¹³ and pig⁴ and it is not seen in oxen³ and giraffe.⁹ The third eyelid artery arises from the malar artery in ruminants, carnivores and pigs; but, it arises from the muscular branch of external ophthalmic artery in horse.^{3,4}

According to results of the present study, there were no obvious differences between buffalo and yak regarding the arteries supplying eyes. However, there were minor differences between buffalo and oxen, sheep and goat and there were obvious differences between buffalo and camel and giraffe. The only difference observed between buffalo and yak was the absence of muscular branch of the supraorbital artery in yak. The difference observed between buffalo and sheep and goat was difference in the origin of posterior long ciliary artery and the difference observed between buffalo and oxen was the absence of medial superior palpebral artery in oxen. There was no difference regarding other arteries among these animals. Differences between buffalo and camel were as follows: not contributing of the superficial temporal artery in the eye blood supply in camel, origin of the external ethmoidal

artery from the maxillary artery and origin of the lacrimal artery and superior and inferior lateral palpebral arteries from the zygomaticotemporal artery instead of the external ophthalmic artery, difference in origin of the central retinal artery and also the existence of some communicating branches between the ophthalmic rete mirabile and the epidural rete mirabile in camel. Differences between buffalo and giraffe included absence of the superior medial palpebral artery in giraffe, origin of the anterior and posterior ciliary and central retinal arteries from the internal ophthalmic artery and origin of the lacrimal artery from the superficial temporal artery instead of the external ophthalmic artery, high contributing of the internal ophthalmic artery in the eye blood supply in giraffe compared to buffalo and existence of two ophthalmic retia mirabilia in giraffe.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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