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Gross, Histological and Histochemical Characteristics of the Eyeball of the Ostrich, *(Struthio camelus)*: Adaptations for a Terrestrial, Flightless Lifestyle

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Abstract | Recently the ostrich is preferable subject for researches as they are an important source for meat production and entertainment Thirty-five adult ostrich heads were collected from the local abattoir in the Ismailia governorate. The eyeballs were removed and anatomically and histologically studied. The orbit was large and incomplete rostroventrally, formed by the frontal lacrimal, temporal, quadrate bones, vomer, and interorbital septum. The eyeball of the ostrich was of the flat type and located on the lateral side of the head. The eyeball was composed of three layers: The outer layer was sclera and cornea, the middle layer was choroid, ciliary body and iris, and the inner layer was retina. The pecten oculi projected from the optic disc into the vitreous chamber. The layers of the cornea consisted of the Epithelium anterius cornealis, Lamina limitans anterior, Substantia propria cornealis, Lamina limitans posterior, and Epithelium posterius cornealis. The corneal stroma was formed primarily from regularly arranged collagen bundles. The sclera contained an outer fibrous and an inner cartilaginous layers. The cartilaginous layer formed a bony ring near the limbus and a U-shaped bony plate around the optic nerve. The choroid was composed of loose connective tissue containing numerous blood vessels and melanocytes. The retina of the ostrich was whitish, and consisted of a pigment cell layer, photosensitive laver, outer limiting membrane, outer nuclear layer, outer plexiform layer, inner nuclear layer, inner plexiform layer, ganglion cell layer, optic nerve fibers layer, and an inner limiting membrane. The pecten oculi of the ostrich was of the vaned type. Each vane was composed of numerous blood capillaries held together by dense highly pigmented collagenous tissue. The structure of eye ball of ostrich is generally like that of other birds with few differences but this is the first detailed record in the detailed anatomy of eyeball of ostrich.

Keywords | Ostrich, Birds, Eyeball, *Struthio camelus*

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INTRODUCTION

Interest in the avian structures and function has grown with increasing importance of birds as food sources and models in biological research (McLelland, 1990). The adult ostrich common weight is 63.5-145 kilograms and its egg is the largest eggs of any living land animal (Del Hoyo *et al*., 1992). They are the fastest birds on land with the ability to run at 70 km/h (43.5 mph) (Doherty, 1974).The ostrich, *Struthio camelus*, as a member of the family Struthionidae, is the largest living bird and can survive successfully in some of the most open, arid regions of Africa, usually in bands of ten to 50 individuals (Walters, 1980; Young, 1981; Louw and Seely, 1984). The ostrich as well as other members of flightless birds lack the sternal keel (carina) and their wings are reduced, making them unable to fly (Feduccia, 1975; Kent and Carr, 2001). They are fast-running birds and graze on grasslands. The ostrich tends to be of increasing veterinary significance as they are domesticated for meat, eggs, and feathers (King and McLelland, 1984; Louw and Seel, 1984).

Many investigators have been interested in the study of ostrich anatomy like nasal cavity anatomy (Ali *et al*., 2015), skeleton (Pop and Pentea, 2007). However, little information has been recorded on the anatomy of the eye. Therefore, this study aims to provide the first comprehensive quantitative and histochemical analysis of the ostrich eyeball, explicitly linking its unique morphology to the visual demands of its open-habitat, flightless existence.

MATERIALS AND METHODS

The current work was carried out on 35 heads of adult freshly slaughtered ostriches of both sexes aged about 2 years. The age is determined from the farm records, *Struthio camelus*, collected from the slaughter house of the Egyptian Saudi ostrich Co. in the Ismailia governorate, Egypt. Twenty-five ostriches heads used to study the angles of vision, gross morphology of their eyeball. Ostriches's skulls were used to study the bones after dissection. The other ten heads were used for histological examinations.

Gross examination

The eye balls of twenty-five freshly slaughtered heads were thoroughly dissected to describe their gross morphology. The eyeballs were removed, weighed, and the skulls were cleaned from the soft tissues to study the bony orbit. Gross morphometrical measurements were performed using the digital planimeter to measure the area of the orbital cavity as a whole and the area of each bone that contributed to the formation of the orbit (Taha *et al*., 1992). Vernier calipers were used to measure the equatorial (the diameter of the eyeball through the equator) and polar (from the anterior to the posterior poles) diameters of the eyeball as well as the height and width of the pecten oculi, and the various diameters of the eyeballs. The angles of the visual area (monocular, binocular, and blind area) of the eye of the ostrich were demonstrated as shown in Figure 1D. The nomenclature used in this study was adopted according to the Nomina Anatomica Avium (Baumel at al., 1979).

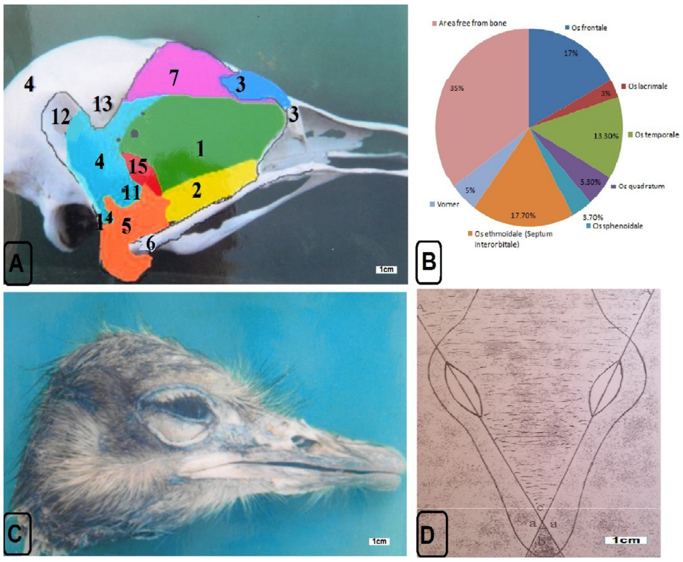

Figure 1: A photograph of the skull and head of an adult ostrich. (A) A photograph of the skull of an adult ostrich. (B) A diagram showing the percentage of the bones entering into the formation of the bony orbit of the adult ostrich. (C) A photograph of head of an adult ostrich showing the lateral position of the eye. (D) A diagram showing the point of meeting of the palpebral axes, angles between them, the blind area as well as the visual field of both eyes of an adult ostrich, showing the palpebral axis (A), monocular field (a), binocular field (b), blind area (c), septum interorbital (1), vomer (2), Os lacrimale (3), Os temporal (4), Os quadratum (5), Os quadratojugal (6), Os frontalis (7), Foramen opticus (8), Foramen trochlearis (9), Foramen orbitalis (10), Foramen maxillomandibularis (11), Fossa temporalis (12), Processuspostorbitalis (of temporal bone)(13), Processus zygomaticus (of temporal bone) (14), and Os sphenoidale (15).

Histological examination

The eyeballs of ten heads were carefully removed and fixed in 10 % neutral buffer formalin solution for 48 hr. The specimens then subjected to routine processing technique for preparation of paraffin blocks. Serial sections (4 to 6 um thick) were cut and stained with Harris Hematoxylin and Eosin, Masson's trichrome, Periodic acid Schiff (PAS, Alcian blue, and Weigert's resorcin fuchsin (Drury and Wallington, 1980; Bancroft *et al*., 1990).

RESULTS

Orbita

The bony orbit was a large, truncated cone-shaped space in the ostrich. It appeared incomplete rostroventrally. Approximately 35% of the total area was free from bones. Both orbits were separated by a relatively thin interorbital septum (Figure 1A). The caudal border of the septum at its junction with temporal bone presented three foramina that were, from dorsal to ventral, trochlear, optic, and orbital. The trochlear foramen was the smallest while the optic foramen was the largest (Figure 1A). The bony orbit was composed of the frontal and lacrimal bones dorsally, the temporal, quadrate, and sphenoid bones caudally, and the interorbital septum of the ethmoidal bone and vomer medially (Figure 1A). The total area of the orbit and the relative percentage of each individual bone included in its formation are shown in Table 1 and Figure 1.

Table 1: The total area of the orbit and the relative percentage of each individual bone included in its formation.

The bone	Bone area in mm^2	Percentage of each individual bone
Os frontale	1,250	26.37
Os lacrimale	210	4.43
Os temporale	970	20.46
Os quadratum	390	8.23
Os sphenoidale	270	5.70
Os ethmoidale	1,290360	27.22
(Septum interorbitale)	4740	7.59
Vomer		35%
Total area		100%

Bulbus oculi

The ostrich eye was extremely large in relation to the head about 36±2.3% of its length and 58 ±1.5% of its height, as it is the largest terresterial birds and it is prey for other birds. It weighed approximately 31 to 34 ±5.2 gms. The eyeball was somewhat flattened, as the equatorial diameter measured 50 to 52±2.4 mm and the pole was 36 to 38± 3.3 mm (Figure 2A, B, C). The eyeball was positioned on the lateral side of the head as it was a prey for predator animals (Figure 1C) and the angle of visual field was 315± 5 while the angle of binocular field measured 45 ±5. This configuration suggests a primary emphasis on panoramic monocular vision.

The eyeball was composed of three layers; outer, middle and inner (Figure 2D). The outer fibrous layer, Tunica fibrosa bulbi, consisted of the sclera and cornea. The middle vascular layer, Tunica vasculosa bulbi, included the Choroidea, Corpus ciliare, and Iris. The inner nervous layer, Tunica nervosa bulbi, was the retina.

Tunica Fibrosa bulbi

Cornea

The cornea was transparent and formed about one fifth of the fibrous tunic. It joined the sclera at a dark brown zone approximately 1.5 to 2.1 mm wide that represented the Limbus comealis (Figure 2). Five layers were observed in the cornea, including the Epithelium anterius cornealis, Lamina limitans anterior (Bowman's membrane), Substantia propria cornealis, Lamina limitans posterior (Descemet's membrane), and Epithelium posterius cornealis (endothelium) (Figure 3A).

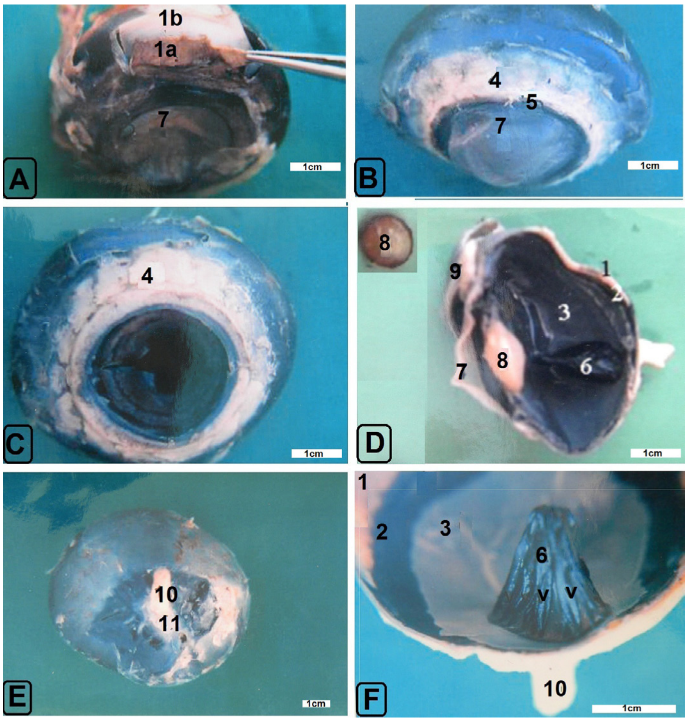

Figure 2: Aphotograph of an eyeball of an adult ostrich. (A) dorsal view, (B) dorso-lateral view, (C) lateral view, (D) Meridian section, (E) medial view and (F) equatorial section. showing, Sclera (1), Fibous layer of sclera (1a), Cartilagenous layer of sclera (1b), Choroid (2), Retina (3),Ossiculum sclerale (4), Limbus cornealis (5),Pecten (6) Cornea (7),Lens (8), Third eyelid (9), N. opticus (10), and Os nervi optici (11).

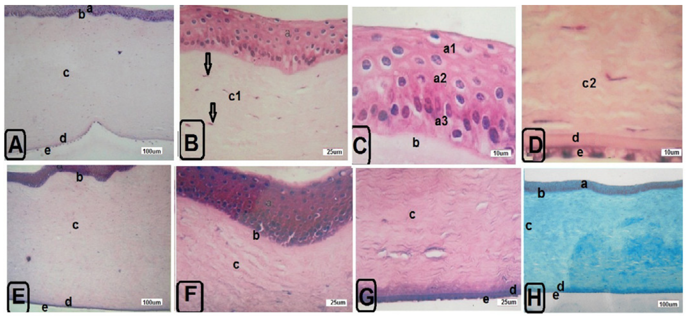

Figure 3: A cross section of an adult ostrich cornea. A, B, C and D (H and E stain), E, F and G (PAS stain) and H (Masson's trichrome stain), showing, Epithelium (a), Bowman's membrane (b), Stroma (c), Descemet's membrane (d) and Endothelium (e), Superficial layer of flattened squamous cells(a1), Middle layer of polygonal cells (a2), Basal columnar cells layer (a3), Anterior stroma (c1), Posterior stroma (c2), and Keratocytes (arrow).

The corneal epithelium was non keratinized stratified squamous (Figure 3B). It was about 47um thick which approximately represented 7% of the total corneal thickness. It was differentiated into three cell layers, including an outer flattened squamous cell layer, a middle polyhedral cell layer, and a single layer of columnar basal cells (Figure 3B).The outermost layer was made up of two to three layers of squamous cells with deeply stained flat nuclei (Figure 3B) and some cells showed signs of cell death such as pyknosis and karyolysis (Figure 3B).The middle layer of the corneal epithelium was composed of three to five layers of polygonal cell s that were differentiated into light and dark cells with heterochromatic nuclei that revealed mitotic figures (Figure 3B).

The basal layer appeared as a single layer of columnar cells that were closely packed and their oval nuclei were located in the apical region and arranged into two levels showing mitotic figures. Most of the nuclei were surrounded by an unstained area (Figure 3B). These cells were differentiated into light and dark cells (Figure 3B) that were resting on an undulating basement membrane. The corneal epithelium gave a positive PAS reaction (Figure 3E, F) and very weak alcian blue reaction.

Lamina limitans anterior was the second layer of the cornea that appeared as a faint acidophilic non-nucleated zone (Figure 3A, B, C) about 10 um in thickness representing about 1.5% of the total corneal thickness. The PAS reaction was negative (Figure 3E, F)

The stroma formed the majority of the corneal mass (Figure 3A). It measured about 597 um thick and represented about 89% of the total thickness of the cornea. It was composed of collagen fibers arranged in parallel lamellae (Figure 2A, B). Keratocytes made up the cellular component of the stroma, which were fibroblast-like cells that were arranged in parallel to the collagen bundles with a higher density in the anterior stroma than the posterior stroma (Figure 3C). It was strongly PAS positive (Figure 3E, F, G), but negative for alcian blue.

Lamina limitans posterior appeared as a homogenous, structureless eosinophilic layer. It measured approximately 10 um in thickness, representing about 1.5% of the total corneal thickness. It gave intense reaction with PAS (Figure 3G), while it was negative for alcian blue. With it gave a weak reaction Masson's trichrome stain (Figure 3H).

The endothelium consisted of a single layer of flattened cells that lined the inner surface of the cornea (Figure 3A, C). It measured about 7 um thick that represented1% of the total corneal thickness.

Limbus cornealis

On reaching the corneoscleral junction, the epithelium decreased in thickness to approximately two to three cell layers (Figure 4B, C). The limbal stroma was made up of dense irregularly arranged collagen (4B) with a few elastic fibers (Figure 4A) and contained connective tissue cells and melanocytes. Numerous blood vessels also were present (Figure 4A, B, C, D, E). Bowman's membrane, Desemet's membrane, and the endothelium could not be detected (Figure 4C, E).

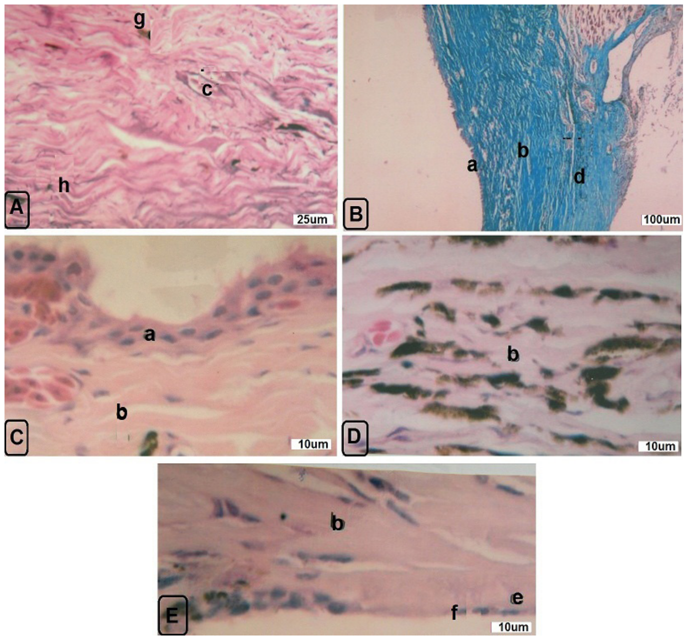

Figure 4: A cross section in the corneoscleral limbus of an adult ostrich. A (Weigert's Resorcin-Fuchsin stain), B (Masson's trichrome stain), C, D and E (H and E stain),showing, limbal epithelium (a), limbal stroma (b), blood vessels(c), melanophores (d), Descemet's membrane (e), endothelium (f), chromatophores (g), and elastic fibers (h).

Sclera

The sclera appeared as a white layer composed of atough outer fibrous layer (Figure 5A) and an inner hard layer. The latter appeared to be divided into an anterior osseous and posterior cartilagenous portions (Figure 2B, C). The osseous part was composed of 14-16 thin overlapping small quadrilateral bony plates (*Ossiculum sclerae*) of various sizes (Figure 2B, C) forming a type of ring (*Annulus ossicularis sclera*).The posterior margin of the ossicles overlapped the anterior edge of the cartilagenous portion (Figure 2B, C). At the perforation of the *N. optica* from the sclera it was surrounded by a thin U-shaped bony plate (*Osnervi optici*) that was firmly attached to the adjacent cartilagenous portion (Figure 2E). Microscopically, the sclera was formed of an outer layer of collagen fibers and an inner one of hyaline cartilage, the lamina cartilaginea sclerae (Figure 5A, B).

Vasculosa bulbi

The Choroidea appeared as a darkly pigmented layer that lined the sclera up to the limbus (Figure 2F). The ciliary processes, Processus ciliare, were attached with the lens by the zonular fibers, Fiberae zonulares. Microscopic examination revealed that the choroid and ciliary processes were composed of dense collagen fibers, rich in blood capillaries and melanocytes (Figures 5A, B; 6A, B).

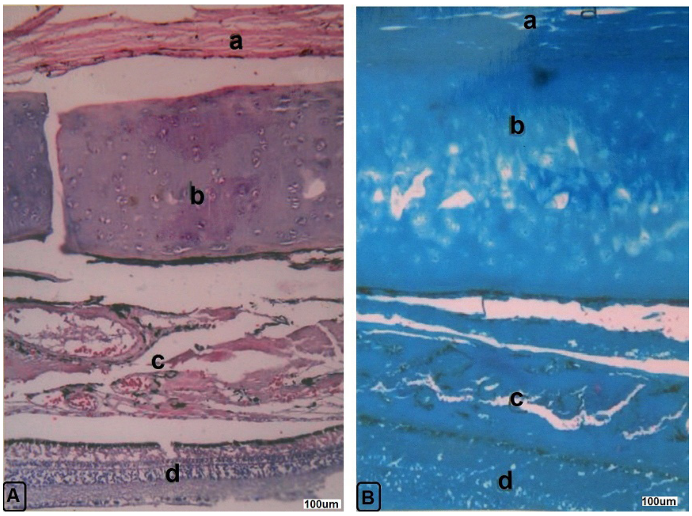

Figure 5: A cross section in the eyeball of an adult ostrich. A (H and E stain) and B (Masson'strichrome stain), showing, outer fibrous layer of sclera (a), inner hyline cartilagenous layer of sclera (b), choroid, containing blood vessels of different sizes (c), and retina (d).

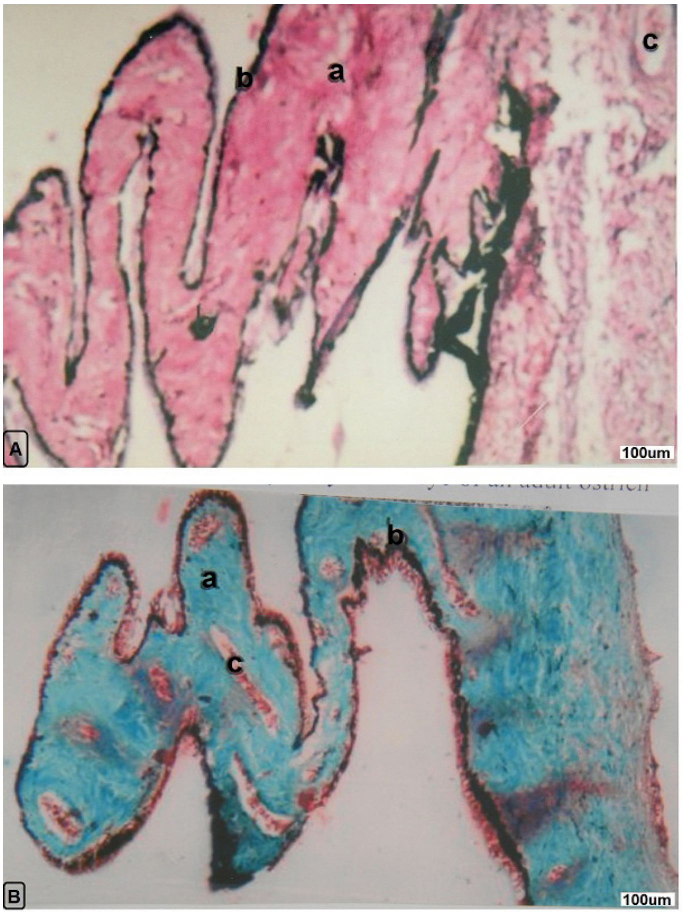

Figure 6: A cross section in the ciliary body of the eye of an adult ostrich. A (H and E stain) and B (Masson's trichrome stain), showing, dense collagenic tissue (a), melanocytes (b) and blood vessels (c).

Tunica nervosa bulbi (Retina)

The retina appeared as an avascular white layer (Figure 2F). Microscopically, it consisted of ten layers, including the pigment cell layer, photosensitive layer, outer limiting membrane, outer nuclear layer, outer plexiform layer, inner nuclear layer, inner plexiform layer, ganglion cell layer, optic nerve fibers layer, and inner limiting membrane (Figure 7).

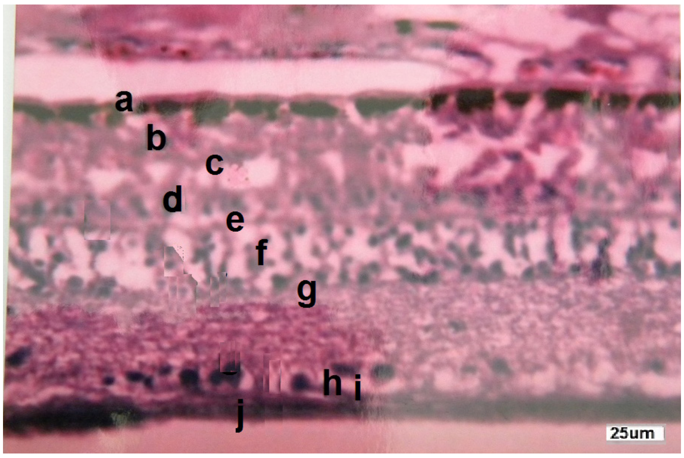

Figure 7: A cross section in the eyeball of an adult ostrich (H and E stain) showing the layers of retina;pigment cell layer (a), photosensitive layer (b), outer limiting membrane (c), outer nuclear layer (d), outer plexiform layer (e), inner nuclear layer (f), inner plexiform layer (g), ganglion cell layer (h), optic nerve fibers layer (i), and inner limiting membrane (j).

The lens

The lens of the ostrich was biconvex. Its diameter through its equator was about 19.3mm while its thickness was about 7.2 mm.

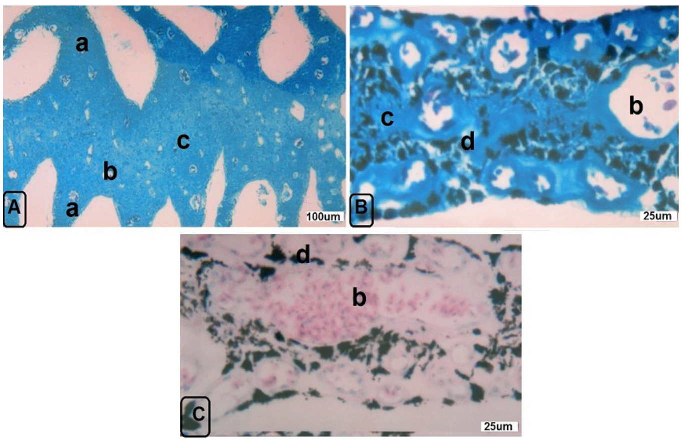

Figure 8: A cross section of the pecten oculi of an adult ostrich. A and B (Masson's trichrome stain) and C (H and E stain), showing, vanes (a), blood vessels (b), collagen (c), and melanocytes (d).

Pecten oculi

The pecten oculi (Figure 2F) was a black, cone-shaped structure. Its base was situated over the optic disk and it projected into the vitreous body. It was of the vaned type and consisted of 18-22 thin projections (vanes). Its width measured about 15mm at its base, 4 mm at its apex, and it measured approximately18 mm in height. Microscopically, the vanes appeared variable in size and length, each one was constructed of numerous blood capillaries held together by dense collagenous tissue (Figures 8A, B, C) and was highly pigmented due to the presence of melanocytes.

DISCUSSION

The bony orbit of the ostrich was very large reflecting the pig size of ratites eyeball ,the orbit is incomplete rostroventrally resembling the description provided by Nickel *et al*. (1977), McClelland (1990) and König *et al.* (2016) in the domestic birds. The bones forming the orbit in the ostrich had a great similarity to that in the chicken (Chamberlain, 1943) and the orbital cavities in the ostrich were separated by a thin vertical interorbital septum. This observation mirrored the findings of Chamberlain (1943) in the chicken, but he did not observe the trochlear foramen in the chicken. The eye of the ostrich was laterally positioned in relation to the head, which might increase the field of vision, helping the bird in searching for food, and detection of predators. In this connection, King and McLelland (1984) and König *et al.* (2016) observed that the lateral position of the eye in herbivorous birds, as pigeon and chicken, while in carnivorous birds, such as falconiforms, the eye is placed more frontally. The visual field of a bird reflects the amount of information that can be come from the environment surrounding it, using the eyes (Lucas *et al*., 2024)

The current study estimated the visual field in the ostrich as about 315-5 while, the binocular field was about 45-5. Similarly, King and McLelland (1984) and König *et al.* (2016) measured the visual field as 300 in the pigeon and 150 in falconiforms, while the binocular field is 24 in the pigeon and 60% in falconiforms. These observations indicate that, in spite of the wide visual field of the herbivorous birds, the binocular field of carnivorous birds was larger to increase the sharpness of vision. It has been stated that the differences in binocular field among birds are mainly influenced by species-specific sensory requirements of foraging, rather than other factors like ancestry or the guidance of locomotion (Cantlay *et al*., 2023). There is a relationship between visual fields and foraging in Anatidae (Cantlay *et al*., 2023) and Strigidae (Potier *et al*., 2023).

The eyeball of the ostrich is of the flat type, which might explained by the diurnal activity of this herbivorous grazing bird need searching for food and detection of the poredators. This result is similar to that described by King and McLelland (1984), König *et al.* (2016) and Lőw *et al.* (2016) for the domestic fowl. They added that the eyeball of birds with wide head as birds of prey is globular and in nocturnal birds of prey like owl the eyeball is tubular. The polar diameter of the eyeball in the ostrich was approximately 37.8± 3.3 mm, while the equatorial diameter about 50.5±2.4 mm and this reflect the enormous size of eyeball in ostrich as it is the largest terrestrial bird. In this connection, Harrison and McGinnis (1967) recorded that, the polar diameter of the chicken eyeball is approximately 14.2 mm and the equatorial diameter is about 18mm. In addition, King and McLelland (1984) and König *et al.* (2016) mentioned that the eyeball of the flat type have a polar diameter that is less than the equatorial diameter. On the other hand, the globular eyeball has nearly equal polar and equatorial diameters, and the tubular eyeball has a longer polar diameter than the equatorial diameter. The weight of the eyeball was about 32 +5.2 g in the adult ostrich compared to the adult chicken, which was about 2.34 g, as reported by Harrison and McGinnis (1967).

The eyeball of the ostrich consisted of three layers simulating that in the domestic birds (Harrison and McGinnis, 1967; King and McLelland, 1975, 1984; Nickel *et al*., 1977; Abdul-Aziz et. al., 2016; König *et al*., 2016; Lőw *et al*., 2016; Dyce *et al*., 2017; Liebich, 2019). The corneal thickness in the ostrich was approximately 671 um, while it is about 450 um in the adult chicken (McLelland, 1990). The five layers of the cornea described in the ostrich are similar to those provided by Meyer and O' Rahilly (1959), Nickel *et al*. (1977), King and McLelland (1984), McLelland (1990), König *et al*. (2016), Lőw *et al*. (2016) and Abdelftah *et al*. (2021) in other birds.

In this respect, Hazlett (1993) and Sridhar (2018) observed the same layers in the human eye, however Shively and Ebling (1970) and Partha and Brinda (1962) demonstrated six layers of cornea, including the tear film, corneal epithelium, basement membrane of epithelium, stroma, Descemet's membrane, and mesothelium. On other hand, the anterior limiting membrane is absent in the camel (Ahmed and Kareiogolu, 1997; Abdel-Aleim, 2002). The corneal epithelium of the ostrich was stratified squamous non keratinized, the result which is consistent with that found in domestic birds (Meyer and O'Rahilly, 1959; King and McLelland, 1984; Nickel *et al*., 1977; Mc Lelland, 1990; Bacha And Bacha (2000) and König *et al.* (2016), in humans (Ehlers, 1970; Gilbard *et al*., 1984; Bergmanson and Wilson, 1989) and in the camel (Rahi *et al*., 1980; Amira, 2001; Abdel-Aliem, 2002).

The corneal epithelium in the ostrich was measured about 47 um, representing 7% of the total cornea thickness. However, in the human the corneal epithelium measured 50 um (about 10% of the total cornea thickness) as given by Ahmed and Karciogolu (1997), whereas it is about 200 um in the camel, forming about 24% of the total cornea thickness (Abdel-Aliem, 2002). The current investigation revealed that the corneal epithelium in the ostrich was composed of 6-9 cell layers arranged in three zones, including an outer flattened squamous zone of two to three layers, a middle zone of three to five polygonal cells, and a single layer of columnar basal cells. However, these respective zones composed of one to two layers, one to two layers, and a single layer in the human corneal epithelium (Maurice, 1957; Hanna and O'Brien, 1960; Wheater *et al*., 1999). However, the corneal epithelium consisted of three to five layers, seven to nine layers, and a single layer in the camel (Amira, 2001; Abdel-Aliem, 2002). Whereas in the mouse and rat such zones were, in order, composed of six to ten layers, two layers, and a single layer (Teng, 1960; Pedler, 1962; Sheldon, 1965). The recent work demonstrated that the corneal epithelium in the ostrich stained positively with PAS, similar to that observed by Maurice (1957) in Humans and Amira (2001) and Abdel Aliem (2002) in the camel.

The Bowman's membrane detected in the cornea of the ostrich is similar to that in other birds (Meyer and O' Rahilly, 1959; Nickel *et al*., 1977; King and McLelland, 1984; McClelland, 1990; König *et al*. (2016), in the buffalo (Kassab, 2001), and in the canine (Shively and Epling, 1970). However, it was absent in the camel (Rahi *et al*., 1980; Ahmed and Kareiogolu 1997; Abdel Aliem, 2002). It measured approximately 10 um representing 1.5% of total corneal thickness. It is also present in the human, and measured 8-12 um (Moses, 1975; Ahmed and Karciogolu, 1997). The Bowman's membrane in the present study revealed a negative reaction with PAS as in the human cornea (Ahmed and Karciogolu, 1997). However, the small areas of randomly oriented fibrils in the Bowman's membrane of the dog (Shively and Epling, 1970) were not observed in the ostrich.

The corneal stroma in our investigation comprised 89% of the total corneal thickness, similar to the human cornea (Birk and Linsenmyer, 1994; Wheater *et al*., 1999; Young *et al*., 2014), in the horse (Lavach, 1990), in the dog (Helpar, 1989). However, it comprises 50 to 80% in the camel cornea (Abdel Aliem, 2002; Rahi *et al*., 1980; Ahmed and Karciogoln, 1997; Eurell and Frappier, 2006) in domestic animals, 70% in the mouse, and 80% in the rat (Martin and Anderson, 1981). Concerning the structure of the corneal stroma, it was composed of parallel collagen bundles with a few elastic fibers near the limbus. This organization was similar to that found in domestic birds (Meyer and O Rahilly 1959), the horse (Lavach, 1990), the camel (Abdel Aliem, 2002), the buffalo (Kassab, 2001), the rat and mouse (Martin and Anderson, 1981), and the cat (Carrington *et al*., 1984). This parallel arrangement of collagen bundles gives transparency to the cornea of the human being (Maurice, 1957; Hart and Farrel, 1969; Cox *et al*., 1970; Farrel *et al*., 1973; Birk and Linsenmyer, 1994; Wheater *et al*., 1999). The cellular component of the stroma in the ostrich comprised flattened keratocytes, which are located in between and parallel to the collagen bundles. This finding is in accordance with the human eye (Moses, 1975) and in the camel (Ahmed and Karciogolu, 1997; Abdel Aliem, 2002)

The present study determined that Descemet's membrane of the ostrich cornea appeared as a homogenous structureless eosinophilic layer similar to that observed in domestic birds (Meyer and O' Rahilly, 1959; Nickel *et al*., 1977; King and McLelland, 1984; König *et al*., 2016), in the camel (Abdel Aliem, 2002) and dog (Shively and Epling, 1970). In the ostrich, Descemet's membrane is measured about 10 um, representing 1.5% of the total corneal thickness, while in camel it is about 9 to 12 um, representing 4.5% (Abdel-Aliem, 2002). Descemet's membrane was intensely PAS positive in the ostrich. These findings agree with the observations of Ahmed and Karciogolu (1997) in humans and Amira (2001) and Abdel-Aliem (2002) in the camel.

The current work revealed that the corneal endothelium of the ostrich is a single layer of flattened cells lining the inner corneal surface. This result agreed with the information provided by Meyer and O' Rahilly (1950), King and McLelland (1984), McLelland (1990) and König *et al*. (2016) in the domestic birds, Koa *et al*. (2001) in the human and Rahi *et al*. (1980) in the camel.

The limbal epithelium in the ostrich was stratified squamous non-keratinized, similar to that of the cornea but exhibited a lower number of layers. These results were in accordance with the camel (Ahmed and Karciogolu, 1997; Abdel-Aliem, 2002). However, the pigmentation of the limbal epithelium in the human cornea (Ahmed and Karciogolu, 1997) and in the camel (Ahmed and Karciogolu, 1997; Abdel-Aliem, 2002) was not observed in the present work.

This study proved that the limbal stroma of the ostrich was formed from loosely and irregularly arranged collagen bundles with various connective tissue cells like fibroblasts, macrophages, and lymphocytes in addition to numerous blood vessels. Such findings agree with those reported for the human (Hogan *et al*., 1971; Srinivasan *et al*., 1987) and in the camel (Ahmed and Karciogolu, 1997; Abdel-Aliem, 2002). The limbial stroma in the ostrich contained a few elastic fibers, resembles that recorded in the camel (Abdel-Aliem, 2002) and in the adult cat (Carrington *et al*., 1984). However, the ostrich corneal stroma was free from blood vessels and melanocytes except the peripheral part, which contained some melanocytes resembling that recorded in the camel (Abdel-Aliem, 2002).

The sclera in the ostrich is composed of an outer fibrous layer and an inner cartilaginous one, which is osseous near corneoscleral junction forming 14-16 scleral ossicles confirming that recorded by Bezuidenhout (1999) in ostrich. The number of the ossicles is similar to that of the chicken (11 to 15) and function to reinforce the eyeball and provide the origin of the ciliary muscles (Jollie, 1957; Nickel *et al*., 1977; King and McLelland 1984; Lőw *et al*., 2016). Moreover, the site of perforation of the optic nerve into the sclera was surrounded by a U-shaped bony plate (Os nervi optici), resembling the reports for the domestic birds (King and McLelland 1984). Cartilaginous structures that turn into ossicles and ossification with the growth stages were recorded in chickens (Franz-Odendaal, 2006b). There are 17 ossicles in Athene cunicularia's eye (Lima *et al*., 2009); however, there were 15 ossicles observed in Asio otus (Zehtabvar *et al*., 2022). The eyeball of otrich has the highest number of sclral ossicles as it is the largest teresterial bird. Franz-Odendaal (2020) suggested that the scleral ossicles are likely functionally important for vision. In the striped owl (Asio clamator), Rodarte-Almeida observed one scleral sesamoid was located anteriorly and medially, close to the anterior margin of the scleral ossicle ring and the scleral cartilaginous lamina was fused with the posterior margin of the ossicle ring (Rodarte-Almeida *et al*., 2013).

The choroid of the examined specimens was deeply pigmented and contained loose connective tissue with numerous blood vessels of different sizes and numerous chromatophores. These findings are similar to that mentioned by Bezuidenhout (1999) for the ostrich and by Nickel *et al*. (1977) in domestic birds. In addition, no tapitum lucidum was present in the ostrich such as that reported in the domestic chicken.However, the tapitum lucidum is present in the nocturnal goatsucker (King and McLelland 1984) and in domestic animals to aid with night vision (McLelland, 1975).

The structure of the ciliary body in this study resembled the observations of Franz (1934), Nickel *et al*. (1977) in the domestic fowl and King and McLelland (1984), König *et al*. (2016) and Liebich (2019) in domestic birds. The iris of the ostrich was dark with a round pupil as described by Bezuidenhout (1999) in the ostrich. Meanwhile, it is yellowish in owl (King and McLelland 1984). In addition, the pupil in the chicken is surrounded by a pigment free zone (McLelland, 1975), which was not seen in the ostrich.

The retina of the ostrich was avascular and constructed of ten layers like that were reported in domestic birds (Mclelland, 1975; Nickel *et al*., 1977; King and McLelland 1984; König *et al*., 2016; Dyce *et al*., 2017; Liebich, 2019). However, the shallow fovea present in the retina of the domestic turkey, duck and goose (Slonaker, 1997; Nickel *et al*., 1977) was not seen in our study of the ostrich.

In the ostrich, the pecten oculi is of vaned type, the result which is in accordance with that mentioned by Walls (1942), Meyer (1977), and King and McLelland (1984) in the ostrich and rheas. Eighteen to 22 vanes were observed in our study. However, King and McLelland (1984) recorded 25-30 vans in the ostrich. The length, width, and height of the pecten oculi in the present study were15 mm,4 mm, and 18 mm, respectively, confirming the report by Bezuidenhout (1999). The pecten oculi in the ostrich is a highly vascular pigmented organ, similar to that described in domestic birds (Prince, 1965; Nickel *et al*., 1977), which may indicate its role in the nutrition of the avascular retina as described by King and McLelland (1984) and König *et al*. (2016) in domestic birds. It is stated that pecten might has a role in thermoregulation and absorption of light (Orhan *et al*., 2011).

In conclusion, the ostrich's eye anatomy is related to its specific ecological niche as a large, flightless, diurnal, grazing bird living in open, arid environments as eyeball is laterally placed, flat type so it has wide visual field.

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NOVELTY STATEMENT

This study provides the first comprehensive description of the macro and microscopic structure of the eye of the ostrich, establishing baseline for normal anatomy,

AUTHOR'S CONTRIBUTION

The research strategy did by Prof. Sanaa El-Nahla. While Prof. Dr. Said Ahmed Mhamed Hassan composed the article and conduct the experimental conditions . and the language was revised by Prof. Sanaa El-Nahla. The finished manuscript was examined by Aref Abdul-Mughni and Hisham Imam.

Generative AI and AI-assisted technology statement

The authors declare that no Genrative AI was used in the creation of this manuscript.

Conflict of interest

The authors declare there is no conflict of interest.

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