Eye muscle nerves and the ciliary ganglion of *Malpolon monspessulana* (Colubridae, Ophidia)

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Abstract In *Malpolon monspessulana*, the nervus oculomotorius arises from the ventral side of the pars peduncularis mesencephali of the midbrain by a single root. It runs closely applied to both the nervus abducens and the ramus nasalis of the nervus trigeminus. These nerves together with the nervus trochlearis leave the cranial cavity through the foramen orbitale magnum. Within this foramen the nervus oculomotorius divides into two rami: superior and inferior. The two rami innervate the rectus superior, rectus inferior, rectus medialis and the obliquus inferior muscles. The nervus trochlearis arises from the lateral side of the mesencephalon by a single root and passes to innervate the obliquus superior muscle. The nervus abducens arises from the ventral side of the medulla oblongata by a single root and passes for a distance through the vidian canal excavated in the parachordal cartilage. It innervates the rectus lateralis muscle. The eye muscle nerves carry special somatic motor fibres. The ciliary ganglion receives the preganglionic parasympathetic fibres from the ramus inferior of the nervus oculomotorius via the radix ciliaris brevis. Both the radix ciliaris longa and sympathetic root are absent. The ciliary ganglion is a well defined mass located in the postorbital region, irregular in shape formed of one type of neuron and gives off only one ciliary nerve.

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Introduction

Snakes together with lizards constitute about 95% of the living reptiles. They are the representative of the suborder ophidia (serpents) of the order squamata. The study of the anatomy of the cranial nerves is very important not only behaviourally but also systematically and phylogenetically.

The earliest works on the cranial nerves of ophidians were those of Vögt (1840), Owen (1866) and Gaupp (1888). Although these works are primitive and incomplete, they are useful for other investigators. The first valuable work was that of Hegazy (1976), who presented a detailed anatomical study on the cranial nerves of the three ophidians: *Psammophis sibilans*, *Eryx jaculus* and *Cerastes vipera*. He gave a full analysis for each cranial nerve. Later studies on the eye muscle nerves and ciliary ganglion were reported by Mostafa (1990a) working on the colubrid snake *Spalerosophis diadema*, El-Ghareeb et al. (2004) on *Natrix tessellata* and Abdel-Kader (2006) on *Telescopus dhara*. Recently, Mostafa et al. (2013) studied the eye muscle nerves and the ciliary ganglion of *Coluber rogersi*.

The scope of the present study was the description of the anatomy of the eye-muscle nerves and ciliary ganglion of the snake *Malpolon monspessulana*. In addition, the analysis of each of these nerves into its component fibres and the relations between each other and to other structures of the head as well as the nature and structure of the ciliary ganglion were described in detail.

Materials and methods

The snake *M. monspessulana* is mostly found in the semi desert, sandy areas of northern Delta, around vegetated salt marshes and in cultivated land. It feeds on small mammals, lizards, frogs and birds.

Three specimens of the fully formed embryos of the snake *M. monspessulana* were collected from Baltim, northern coast of Egypt and the heads of these specimens were cut and fixed in aqueous Bouin's solution for 24 h, followed by washing for several days with 70% ethyl alcohol.

The specimens were decalcified using 14.5% EDTA solution (pH 7.3) for six weeks by changing the solution every four days. This was followed by washing in 70% ethyl alcohol for about four hours.

Thereafter the heads were treated with ascending series of ethyl alcohol and cleared in xylene followed by embedding in paraffin wax. Then the heads were cut transversely at 10 μm and followed by staining of the serial sections using haematoxylin–eosin stain.

The serial sections were then drawn with the help of a projector and from these sections; an accurate graphic reconstruction for the eye muscle nerves and ciliary ganglion was made in a lateral view diagram. The serial sections were examined carefully under the microscope to describe the relations of nerves and ganglia to the other structures in the head region. In order to show the position of the nerves and their relations to the different structures of the head, some serial sections were photographed.

Results

Nervus oculomotorius

In *M. monspessulana*, the nervus oculomotorius (N.III) arises from the ventral side of the pars peduncularis mesencephali of the midbrain by a single root (Figs. 1 and 2, RO.III). Directly after its origin, it penetrates the pia mater and extends anteriorly within the cranial cavity passing dorsomedial to both the nervus trochlearis and the ramus ophthalmicus profunds of the nervus trigeminus and ventral to the brain. Shortly forwards, the nervus oculomotorius passes medial to the nervus trochlearis and dorsomedial to the ophthalmic ganglion. Thereafter, this nerve penetrates the dura mater and becomes medial to the rami frontalis and nasalis of the nervus trigeminus and dorsal to the nervus abducens. The nervus oculomotrius continues its anterior course in the same position, and gradually approaches the ramus nasalis of the nervus trigeminus forming separable bundles. These bundles run dorsal to the nervus abducens and ventromedial to the ramus frontalis of the nervus trigeminus and the nervus trochlearis. These bundles extend anteriorly in a lateral direction for a distance; during this course the nervus abducens gradually approaches the latter bundle from its ventral side forming a common bundle (Fig. 3). This common bundle comprises the nervus oculomotorius, the nervus abducens and the ramus nasalis of the nervus trigeminus and lies in a position dorsolateral to the trabecula cranii, ventromedial to the nervus
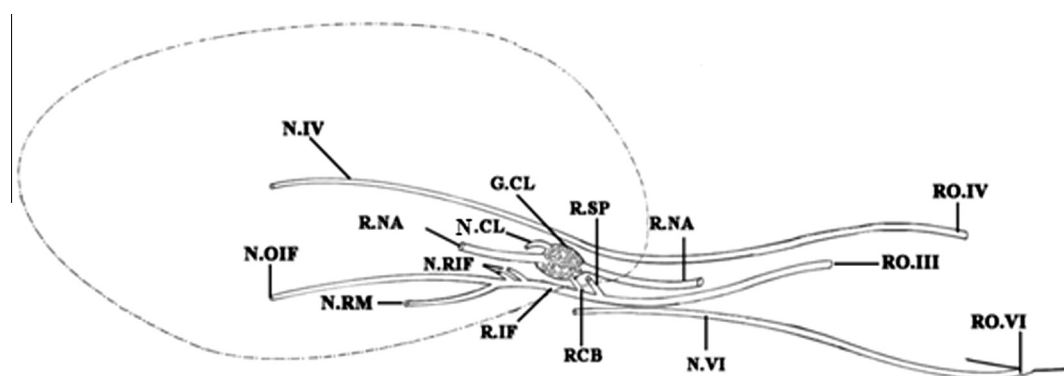

Figure 1 Graphic reconstruction of the eye muscle nerves and the ciliary ganglion of *Malpolon monspessulana* in a lateral view.

trochlearis and the ramus frontalis of the nervus trigeminus and ventrolateral to the brain. This common bundle passes anteriorly for a distance, and then it leaves the cranial cavity through the foramen orbitale magnum (Fig. 3, FORM). There, the nervus oculomotorius divides into two rami: ramus superior and ramus inferior.

Ramus superior

Directly after its separation from the dorsal side of the common bundle, the ramus superior (Figs. 1 and 4, R.SP), passes anteriorly in the dorsal direction. It extends dorsal to both the ramus nasalis of the nervus trigeminus and the ciliary ganglion and ventrolateral to the nervus trochlearis and the ramus frontalis of the nervus trigeminus. The ramus superior continues its course in a position dorsal to the ramus nasalis of the nervus trigeminus, the ciliary ganglion and the ramus inferior of the

nervus oculomotorius and the rectus lateralis muscle, and ventrolateral to the rectus superior muscle (Fig. 5). After that, the ramus superior approaches the rectus superior muscle and gives off a dorsal branch that enters the lateral side of the muscle. Finally the ramus superior terminates between fibres of the latter muscle.

Ramus inferior

After its separation from the ventral side of the common bundle, the ramus inferior (Figs. 1 and 4, R.IF) passes anteriorly in a position between the ramus nasalis of the nervus trigeminus dorsally, the nervus abducens laterally and the trabecula cranii ventromedially. Where, it gives off a dorsolateral branch which is the radix ciliaris brevis that will be described later (Figs. 1 and 3, RCB). Then it extends forward dorsal to the rectus lateralis muscle, ventral to the ramus nasalis of the nervus trigeminus
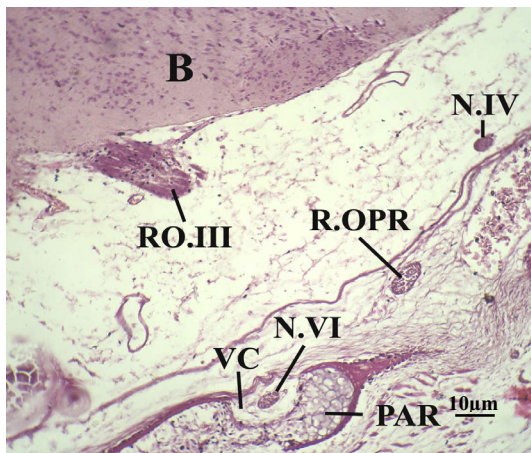
Figure 2 Photomicrograph of a part of transverse section through the mesencephalon showing the root of the nervus oculomotorius and the passage of the nervus abducens through the vidian canal.

Figure 4 Photomicrograph of a part of transverse section through the orbital region illustrating the two rami of the nervus oculomotorius and coalescence between the ramus nasalis of the nervus trigeminus and the ciliary ganglion.

Figure 3 Photomicrograph of a part of transverse section through the orbital region demonstrating the common bundle and the radix ciliaris brevis.
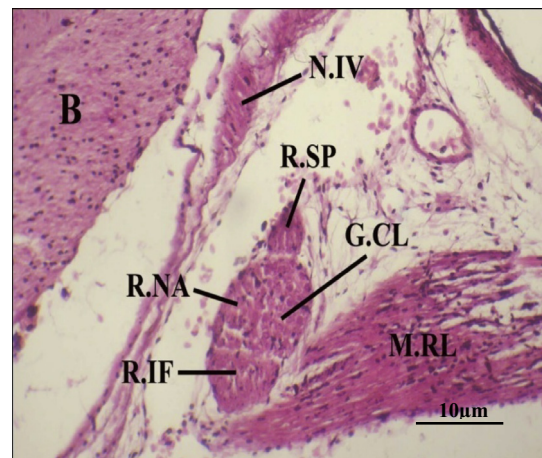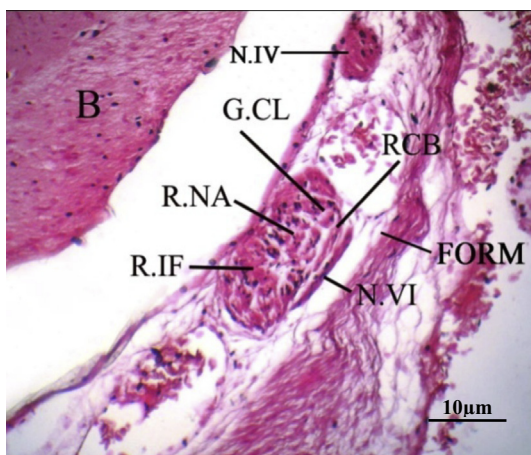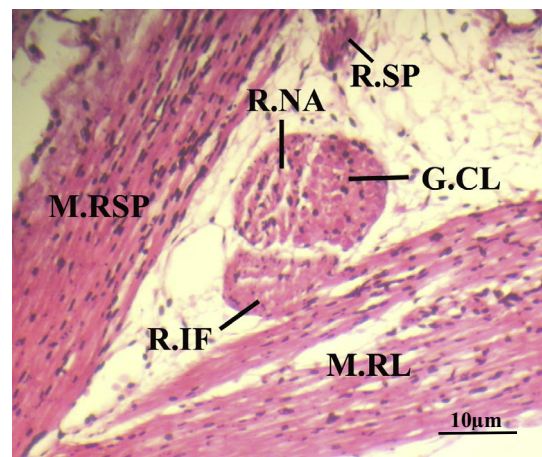

Figure 5 Photomicrograph of a part of transverse section through the orbital region showing the ramus inferior of the nervus oculomotorius, the ramus nasalis of the nervus trigeminus and the ciliary ganglion.
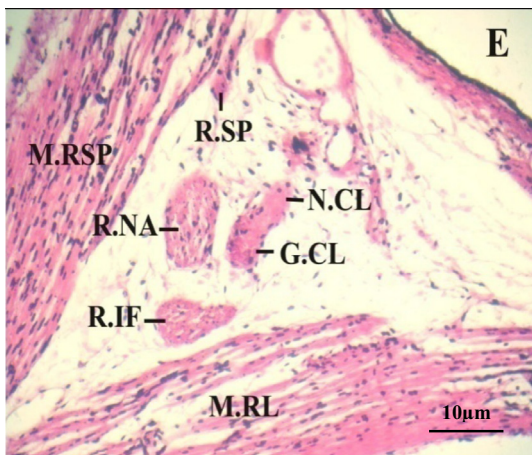
Figure 6 Photomicrograph of a part of transverse section through the postorbital region showing the ciliary nerve and ciliary ganglion.

and ventrolateral to the rectus superior muscle. The ramus inferior continues its anterior course ventral to the ramus nasalis of the nervus trigeminus and the ciliary ganglion, dorsal to the rectus lateralis muscle (Fig. 5), and ventrolateral to the optic chiasma. After a distance the ramus inferior becomes in a position between the rectus inferior muscle ventrally and the optic nerve dorsomedially. Where, it gives off two successive lateral branches. These branches extend anteriorly lateral to the ramus inferior of the nervus oculomotorius, ventrolateral to the optic nerve, dorsomedial to the lacrimal gland, and dorsal to the rectus inferior muscle. Shortly anterior, the two branches enter the latter muscle from its dorsal side and terminate between its fibres (Fig. 1, N.RIF). The main ramus inferior continues dorsal to the rectus inferior muscle and ventral to the optic nerve. At this position, the ramus inferior divides into two branches one is dorsomedial and the other is ventrolateral (Fig. 1).

The dorsomedial branch runs anteriorly and dorsally passing ventromedial to the optic nerve, dorsolateral to the trabecula cranii, and dorsomedial to the rectus inferior muscle where, it gives off a ventral branch. This branch extends anteriorly in a dorsomedial direction for a distance and finally enters the rectus medialis muscle from its lateral side and terminates between its fibres. After that, the main dorsomedial branch continues anteriorly passing dorsal to the latter branch, ventromedial to the eyeball, dorsolateral to the trabecula cranii, lateral to the rectus medialis muscle, and ventral to the ramus nasalis of the nervus trigeminus. During its course it gives off some branches to the rectus medialis muscle. Finally it enters the same muscle from its lateral side and ends between its fibres (Fig. 1, N.RM).

The ventrolateral branch extends anteriorly in a position between the eyeball dorsolaterally, the lacrimal gland and trabecula cranii medially, and the obliquus inferior muscle laterally. After a short distance anteriorly, it enters the latter muscle from its dorsal side and terminates between its fibres (Fig. 1, N.OIF) (Fig. 7).

From the distribution of the nervus oculomotorius, it is obvious that this nerve carries special somatic motor fibres innervating four of the ocular muscles in addition to general visceromotor fibres (parasympathetic) to the ciliary ganglion (Fig. 8).

Ciliary ganglion

In the *M. monspessulana* investigated, the ciliary ganglion is a well defined ganglionic mass of cells located in the postorbital region (Figs. 1 and 5, G.CL). It measures about 240 μm in length. This ganglion was irregular in shape and formed of one type of neurons, as it appears in the transverse sections. In addition, the ciliary ganglion is located in a position surrounded by the ramus superior of the nervus oculomotorius and the rectus superior muscle dorsomedially, the ramus inferior of the nervus oculomotorius ventromedially, the rectus lateralis muscle ventrally, the ramus nasalis of the nervus trigeminus medially, and the eye ball dorsally (Fig. 5).

Moreover, the ciliary ganglion receives preganglionic parasympathetic fibres from the nervus oculomotorius through a special motor root, the radix ciliaris brevis (Figs. 1 and 3, RCB). This root arises from the dorsolateral side of the ramus inferior of the nervus oculomotorius that extends dorsally passing dorsolateral to the latter ramus, lateral to the ramus nasalis of the nervus trigeminus, and medial to the nervus abducens to enter the ciliary ganglion from its lateral side. These fibres terminate in the ganglion in synapse with the postganglionic cell bodies. The sensory fibres arises from the eye ball are conveyed to the ramus nasalis of the nervus trigeminus via the ciliary nerve and ciliary ganglion without synapse. The radix ciliaris longa is absent and the ramus nasalis is in direct contact with the medial wall of the ciliary ganglion (Fig. 4). From the ciliary ganglion a single strong ciliary nerve arises (Fig. 6, N.CL). This nerve runs anteriorly and laterally to enter the sclera of the eye through a special foramen. This foramen lies ventral and posterior to the entrance of the optic nerve.

Nervus trochlearis

In *M. monspessulana,* the nervus trochlearis (N. IV) arises from the lateral side of the mesencephalon by a single root (Figs. 1 and 7, RO.IV). It runs anteriorly, in a lateral direction, penetrating the pia mater that lies dorsal to the ramus ophthalmicus profunds of the nervus trigeminus, dorsomedial to the maxillomandibular ganglion, and ventromedial to the auditory capsule.
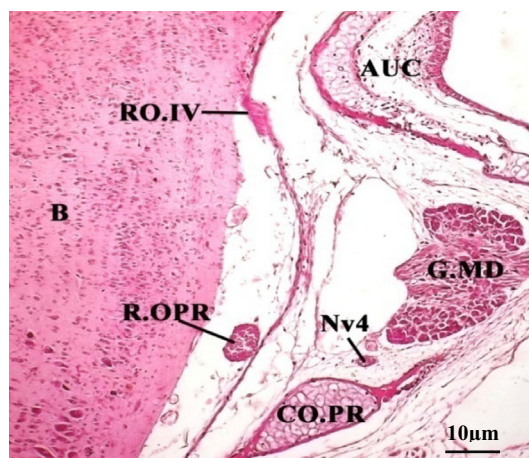

Figure 7 Photomicrograph of a part of transverse section through the otic region showing the root of the nervus trochlearis.
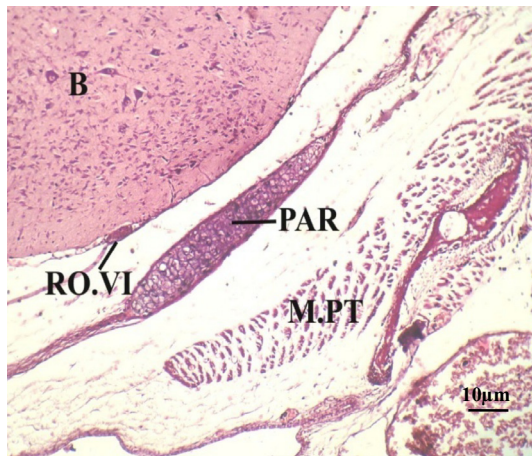
Figure 8 Photomicrograph of a part of transverse section through the otic region showing the root of nervus abducens.

After a long distance anteriorly, this nerve extends ventrally within the cranial cavity passing dorsolateral to the ramus ophthalmicus profunds of the nervus trigeminus and ventrolateral to the root of the nervus oculomotorius (Fig. 2). More forwards, the nervus trochlearis penetrates the dura mater and passes dorsolateral to the ophthalmic ganglion and lateral to the nervus oculomotorius. The nerve continues anteriorly in a position ventrolateral to the brain and dorsolateral to the ramus frontalis, the ramus nasalis of the nervus trigeminus and the nervus oculomotorius. After a distance forwards, it extends dorsal to the common bundle and the ramus frontalis of the nervus trigeminus. Thereafter, the nervus trochlearis passes dorsal to the common bundle and closely attached to the ramus frontalis of the nervus trigeminus. The nervus trochlearis continues dorsolaterally passing ventral to the ramus frontalis of the nervus trigeminus, dorsal to the common bundle, and ventrolateral to the brain (Fig. 3). After a short distance anteriorly, the nervus trochlearis exits from the cranial cavity through the foramen orbitale magnum (FORM). After that, it passes dorsomedial to the common bundle and ventral to the ramus frontalis of the nervus trigeminus. Shortly anterior, the nervus trochlearis passes ventrolateral to the brain and dorsomedial to both the common bundle and the rectus lateralis muscle and then, it becomes in a position between the brain dorsomedially and the rectus superior muscle ventrolaterally. After that, the nerve runs medial to the rectus superior muscle and dorsolateral to the optic chiasma. Thereafter, the nervus trochlearis runs ventromedial to the rectus superior muscle, and dorsal to the ramus nasalis of the nervus trigeminus and the optic nerve. After a distance anteriorly, it extends medial to the eyeball, dorsal to the ramus nasalis of the nervus trigeminus, and dorsolateral to the rectus medialis muscle. After a long distance anteriorly, the nervus trochlearis acquires a position between the ramus nasalis of the nervus trigeminus and the rectus medialis muscle ventrally, the eye ball laterally, and the obliquus superior muscle dorsolaterally. Finally, it enters the obliquus superior muscle from its ventral side and terminates between its fibres.

From the anatomy of the nervus trochlearis it is clear that it carries special somatic motor fibres to the obliquus superior muscle.

Nervus abducens

In *M. monspessulana*, the nervus abducens (N.VI) arises from the ventral side of the medulla oblongata by a single root (Figs. 1 and 8, RO.VI). Directly after its origin, it penetrates the pia mater and extends ventral to the brain and dorsomedial to the parachordal cartilage. After that, the nervus abducens penetrates the dura mater and passes anteriorly between the brain dorsally and the parachordal cartilage ventrally.

After a long distance, this nerve extends forward and passes through a canal excavated in the parachordal cartilage (Fig. 2, VC.). After a distance, the nervus abducens leaves the latter canal to the cranial cavity and becomes ventral to the nervus oculomotorius and ventromedial to the ophthalmic ganglion. Then, it passes anteriorly being ventral to the nervus oculomotorius, dorsolateral to the trabecula cranii, dorsomedial to the constrictor dorsalis nerve of the nervus trigeminus, and ventromedial to the ophthalmic ganglion. Shortly anterior, the nervus abducens extends laterally passing dorsal to the constrictor dorsalis nerve of the nervus trigeminus, ventral to the nervus oculomotius, the rami nasalis and frontalis of the nervus trigeminus, and dorsolateral to the trabecula cranii. Intracranially, the nervus abducens gradually approaches the bundle formed from the nervus oculomotrius and the ramus nasalis of the nervus trigeminus from its ventral side forming a common bundle (Fig. 3). This bundle lies in a position dorsolateral to the trabecula cranii, ventromedial to the nervus trochlearis and the ramus frontalis of the nervus trigeminus, and ventrolateral to the brain as previously described with the nervus oculomotorius. After a long anterior course, the nervus abducens separates from the common bundle and leaves the cranial cavity through the foramen orbitale magnum (FORM). Then, the nervus abducens passes dorsomedial to the lacrimal gland and ventromedial to the rectus lateralis muscle. Finally it enters the latter muscle and terminates between its fibres.

The nervus abducens carries special somatic motor fibres to the rectus lateralis muscle.

Discussion

In *M. monspessulana*, the nervus oculomotorius originates as a single root from the ventral side of the pars peduncularis mesencephali of the mid brain. The previous studies reported that the emergence of the nervus oculomotorius from the ventral side of the mesencephalon is considered as a general character among Squamata (Soliman and Hegazy, 1969) in *Chalcides ocellatus*, (Mostafa, 1990a) in *S. diadema*, (Mostafa, 1990b) in *Acanthodactylus opheodurus*, (Ramadan, 2009) in *Agama sinaita* and (Mostafa et al., 2013) in *C. rogersi* .On the other hand, this nerve arises from the crura cerebri in both *E. jaculus* and *C. vipera* (Hegazy, 1976; Hammouda et al., 1976). In the present study the intracranial decussation of the fibres of nervi oculomotorius and trochlearis is absent. The same finding was reported in *A. sinaita* (Ramadan, 2009) and *C. rogersi* (Mostafa et al., 2013). On the other hand, in *T. dhara* (Abdel-Kader, 2006) reported that decussation of the fibres of the nervi oculomotorius and trochlearis is present. This decussation was also reported in *Chamaeleon vulgaris* (Shanklin, 1930) and *Varanus* monitor (Shrivastava, 1964).

Shanklin (1930) suggested that this decussation may have a role in the eye movement of *C. vulgaris*.

According to Shanklin (1930), such decussation is rare. On the other hand, the trochlear decussation is of wide occurrence among reptiles.

Among Ophidia, it was observed in the serpents *P. sibilans* (Hegazy, 1976; Hammouda et al., 1976) and *S. diadema* (Mostafa, 1990a). In Lacertilia, this decussation was described in the lizards *C. ocellatus* (Soliman and Hegazy, 1969), *Tarentola mauritanica* (Soliman and Mostafa, 1984), *Agama pallida* and *Ptyodactylus hasselquistii* (Abdel-Kader, 1990), in the limbless blind *Diplometopon zarudnyi* (Dakrory, 1994), *Acanthodactylus boskianus* (El-Ghareeb, 1997) and in *Uromastyx aegyptius* (Mahgoub and Al-Fitouri, 2010).

Among Amphibia, such decussation was absent (Mostafa and Soliman, 1984; Shaheen, 1987 and Dakrory, 2002). Edgeworth (1935) reported that the trochlear nerve undergoes a decussation with its fellow above the midbrain (trochlear decussation) and innervates the obliquus superior muscle of the opposite side in nearly all vertebrates.

In the present study, the nervus oculomotorius and the ramus nasalis of the nervus trigeminus form a common bundle with the nervus abducens but remain separable. In *C. rogersi*, the eye muscle nerves together with the ramus ophthalmicus profundus of the nervus trigeminus are fused forming a common trunk (Mostafa et al., 2013). In ophidians studied by Hammouda (1963), Hammouda et al. (1976), Hegazy (1976) and El-Ghareeb et al. (2004), the eye muscle nerves and the ramus ophthalmicus profundus of the nervus trigeminus leave the cranial cavity separately through the foramen orbitale magnum, i.e., it appears to be an ophidian character.

In some members of the suborder Lacertilia and order Rhincocephalia, the nervi oculomotorius and trochlearis leave the cranial cavity through the metoptic fenestra. This condition was mentioned in *Sphenodon punctatum* (Howes and Swinnerton, 1901), *Lacerta agilis* (Gaupp, 1911), *C. ocellatus* (Soliman and Hegazy, 1969), *T. mauritanica* (Soliman and Mostafa, 1984), *P. hasselquistii* (Abdel-Kader, 1990), *A. opheodurus* (Mostafa, 1990b), *A. boskianus* (El-Ghareeb, 1997), *A. sinaita* (Ramadan, 2009) and in *Mabuya quinquetaniata* (Madboly, 2011).

Among chelonians, the nervi oculomotorius and trochlearis in *Trionyx cartilaginous*, *Nanemys guttata* and *Clemmys decussate* emerge from the cranium through special separate foramina found in the membrano-cartilagenous lateral wall (Shiino, 1912). Recently, Paluh and Sheil (2013) confirmed this view. On the other hand, De Beer (1937) mentioned that the two nerves exit from the cranial cavity through incisura metoptica in *Emys lutaria*; while in *Chrysemys marginata*, he observed a separate foramen as an outlet for each nerve.

In crocodilians, Shiino (1914) reported that the nervus oculomotorius leaves the cranial cavity through the metoptic fenestra, while the nervus trochlearis exits from the cerebral cavity through its own foramen which is located on the posterior part of the taenia parietalis media.

In amphibians, the eye-muscle nerves leave the cerebral cavity through a special foramen for each nerve as demonstrated in the previous studies (Dakrory, 2002). On the other hand, Haas and Richard (1998) found that the nervus trochlearis leaves the cranial cavity together with the optic nerve through the optic foramen.

In the majority of birds, a closed sphenoid fontanelle is found, through which the nervi opticus, oculomotorius and trochlearis emerge. This finding was confirmed by De Beer and Barrington (1934) and De Beer (1937) in *Anas* and *Struthio*, May (1961) in *Strix*, Müller (1961) in *Rhea* and by Til Macke (1969) in *Fulica*. However, this sphenoid fontanelle is lacking, and each of the three nerves passes through special foramen in the birds studied by Cords (1904) and Ābrahām and Stammer (1966). This was also the case described by Bellairs (1958) in *Pyromelana*, Soliman et al. (1986) in *Upupa*, *Passer* and *Steptopellia* and Abdel-Kader and Fathy (2000) in *Merops albicollis*.

In the current study, the nervus abducens leaves the cranial cavity through excavated canal in the parachordal cartilage. In the previous studies, there have been three different conditions about the exit of the nervus abducens from the cranial cavity in ophidians. the first is that the nervus abducens leaves the cranial cavity through a special canal excavated in basal plate as in *Tropidonotus natrix* (Gaupp, 1902; De Beer, 1937), *Viperaaspis* (Peyer, 1912), *Thamnophis rodinoides* (Auen and Langebartel, 1977), *N. tessellata* (El-Gareeb et al., 2004), *T. dhara* (Abdel-Kader, 2006), *A. sinaita* (Ramadan, 2009), *U. aegyptius* (Mahgoub and Al-Fitouri, 2010) and *C. rogersi* (Mostafa et al., 2013). The second is that this nerve passes into a depression, groove or fossa not a canal in the snakes *Lamprophis inornatus*, *Dasypeltis scabra*, *Causus rhombeatus* and *Hemachatus hemachatus* (Pringle, 1954) and *P. sibilans* (Hegazy, 1976); (Hammouda et al., 1976). On the other hand, there is neither a canal nor a depression in *Elaphe obsolete quadrivittata* (Auen and Langebartel, 1977).

An abducens tunnel was recorded in most lacertilian species. This was found in *Lacerta agilis* (Gaupp, 1902; De Beer, 1937), *Anolis carolinensis* (Willard, 1915), *Platydactylus annularis* (Hafferl, 1921), *Ablepharus pannonicus* (Haas, 1930), *Platydactylus maculosa* and *Lygodactylus capensis* (Brock, 1932), *Loposaura ventralis* (Brock, 1941), *Calotes versicolor* (Ramaswami, 1946), *Anniella pulchra* (Bellairs, 1950), *Hemidactylus turcica* (Kamal, 1961), *C. ocellatus* (Soliman and Hegazy, 1969), *A. pallida* (Soliman et al., 1984) and *T. mauritanica* (Soliman and Mostafa, 1984). This canal was also mentioned in the amphisbaenian *D. zarudnyi* (Dakrory, 1994). However, an abducens depression was described in the lizard *Tropiocolotes tripolitanus* (Kamal, 1960).

Regarding other reptilian groups, the abducens tunnel was also found in the Rhynchocephalian *Sphenodon punctatus* (Hows and Swinnerton, 1901), in the chelonians *C. marginata* and *E. lutaria* (Kunkel, 1912) and in the crocodilian *Crocodilus biporcatus* (Shiino, 1914). This was also asserted by (De Beer, 1937). However, in the chelonians *Cyclanorbis* (Siebenrock, 1897) and in both *Trionyx* and *Podocnemis* (Gaupp, 1911), the abducens tunnel is absent.

The presence of the abducens tunnel in birds was mentioned by Cords (1904), Müller (1961) and Ābrahām and Stammer (1966). However, in *Streptopelia senegalensis*, an abducens tunnel is not represented (Soliman et al., 1986). It appears from the cut strip references that the presence of a vidian canal and the passage of the nervus abducens through it, are unique sauropsidan characters.

In *M. monspessulana*, the nervus abducens innervates the rectus lateralis muscle. On the contrary in both *T. dhara* (Abdel-Kader, 2006) this nerve innervates the rectus lateralis

and retractor oculi muscles. Edgeworth (1935) reported that the retractor oculi muscle is present in ophidian, *Sphenodon* and *Chamaeleo* and in birds. On the other hand, other authors denied the presence of this muscle in the ophidians investigated by them (Hegazy, 1976; Auen and Langebartel, 1977 and El-Ghareeb et al., 2004).

In the present study, there is no connection between the ocular nerves and the ramus ophthalamicus of the nervus trigeminus or other cranial nerves. In addition, there is no anastomosis between the nervus trochlearis and the ramus nasalis of the nervus trigeminus. This was reported in *T. dhara* (Abdel-Kader, 2006). In *C. rogersi* (Mostafa et al., 2013) there is a complete fusion between the ocular nerves and the ramus ophthalmicus profundus of the nervus trigeminus. An anastomosis between the eye muscle nerves and the nervus trigeminus seems to be widely spread among reptiles, birds and mammals. The connection of the nervi oculomotorius and trochlearis with the nervus trigeminus was mentioned in reptiles by many authors. For the nervus oculomotorius, an anastomosis between the ramus superior and the ramus nasalis was described in *P. sibilans* and *E. jaculus* (Hegazy, 1976; Hammouda et al., 1976).

Among Lacertilia, this connection was found in *C. ocellatus* (Soliman and Hegazy, 1969) while in the gecko *Gymnodactylus kotschyi* (Evans and Minckler, 1938), it was found between the ramus superior and the radix ciliaris longa. On the other hand, Belogolowy (1910) and Soliman (1964), dealing with the chelonians *E. lutaria* and *Chelone imbricate*, respectively, observed a connection between the nervus oculomotorius and the trigeminal ganglion. Such connection represents a shared primitive character between the two species.

Regarding the nervus trochlearis, an anstomosis with the ramus ophthalmicus was described in the snakes *P. sibilans*, *C. vipera* and *E. jaculus* (Hegazy, 1976; Hammouda et al., 1976). Among Lacertilia, it was found in the gecko *G. kotschyi* and *T. mauritanica* (Evans and Minkler, 1938; Soliman and Mostafa, 1984) respectively and in the agamid *A. pallida* (Soliman et al., 1984). This connection was also found in the chelonians *Chelydra serpentine* and *Chelone imbricata* (Soliman, 1964). This represents an independent character.

The nervus abducens has no relation with the nervus trigeminus in reptiles. This condition seems to be a common unique character in reptiles. However, Vögt (1840) described a connection between the nervus abducens and the facial nerve in *Chelone mydas*. On the other hand, Hoffman (1886) and Ogushi (1913) mentioned that this connection was absent in Chelonia.

In Amphibia, Norris (1908) found two connections in *Amphiuma means*, one between the nervus oculomotorius and the Gasserian ganglion of the nervus trigeminus and the other between the nervus oculomotorius and the ramus ophthalmicus profundus. Mostafa and Soliman (1984) and Dakrory (2002) reported a connection between the nervus oculomotorius and the ramus ophthalmicus profundus in *Bufo viridis* and *Rana bedriage*, respectively. With respect to the nervus trochlearis, Herrick (1894) found a connection between this nerve and the ramus ophthalmicus profundus of the nervus trigeminus in *Amblystoma punctatus*. In *Amblystoma tigrinum*, Wiedersheim (1909) and Coghill (1902) reported a connection between the nervus abducens and the Gasserian ganglion.

In birds, there is no connection recorded between the nervi oculomotorius and trigeminus (Abdel-Kader, 1999; Soliman et al., 1986 and Abdel-Kader and Fathy, 2000). With respect to the nervus trochlearis, there is no connection between this nerve and the ramus ophthalmicus profundus in the hen (Cords, 1904), *Upupa epops* (Soliman et al., 1986) and *M. albicollis* (Abdel-Kader and Fathy, 2000). In *Corvus cornix*, Bonsdorff (1852) mentioned the presence of a connection between the nervus abducens and both the radix ciliaris brevis of the ciliary ganglion and the ganglion itself. Cords (1904) reported the presence of the connection between the ciliary ganglion and the nervus abducens. In *U. epops* and *Passer domesticus*, Soliman et al. (1986) mentioned the presence of a connection between the nervus abducens and both the ciliary ganglion and one of its ciliary nerves. Dakrory and Abdel-Kader (2011) stated that the radix ciliaris longa receives a branch from the nervus abducens in *Pterocles alchata*.

Regarding mammals, a connection between the main nervus oculomotorius and the ramus ophthalmicus profundus was described in the baboon embryo by Gasser and Hendricks (1969). On the other hand, an anastomosis between the ramus inferior of the nervus oculomotorius and the ramus maxillaris was mentioned by many authors (Mobillio, 1912; Winckler, 1937; Godinho and Getty, 1971). A connection between the nervus trochlearis and the ramus frontalis of the nervus trigeminus was found by Gasser and Hendricks (1969) and Gasser and Wise (1972). A connection between the nervus abducens and the nervus trigeminus was also mentioned by Quiring (1950).

In *M. monspessulana*, the ciliary ganglion consists of one type of neurons. On the contrary, two types of neurons were recognized; large neurons at the periphery and small ones at the centre, in *N. tessellata* and *C. rogersi* (El-Ghareeb et al., 2004; Mostafa et al., 2013). In ophidian literature, it is reported that, the ciliary ganglion was found to be consisting of one structure and was formed of one type of neuron. Galvao (1917) described the ciliary ganglion of ophidians as formed of strictly unipolar cells. Hegazy (1976) found similar results in the serpents *P. sibilans*, *E. jaculus*, and *Cerastes vipra*. The same finding was also observed in the lacertilian studied by Abdel-Kader et al. (2007), El-Bakry et al. (2007) and Dakrory (2009). Moreover, two types of neurons were observed in the lacertilian studied by Mostafa and Hegazy (1990) and Dakrory (1994, 2009).

In this respect, Haller von Hallerstein (1934) described the ciliary ganglion of reptiles and birds and confirmed the existence of two parts; the first is composed of small neurons, while the second is formed from large ones. This finding was mentioned in birds by Oehme (1968), Soliman et al. (1976) and Abdel-Kader and Fathy (2000). In this context, Bullock et al. (1977) stated that the ciliary ganglion of chick is composed of two cell populations, one controls the smooth muscles in the choroid while the other is for the iris and ciliary body. The same assumption was mentioned by Radzimirska (2003) in the domestic turkey, *Meleagris gallopavo domesticus*.

In mammals, the ciliary ganglion is undivided into two regions. This pattern of structure was observed in the cat (Taylor and Weber, 1969), guinea pig (Watanabe, 1972), in man (Stefani, 1972) and in the hedgehog and bat (Hegazy and Mostafa, 1990).

In the present study, the ciliary ganglion is connected with the ramus inferior of the nervus oculomotorius by the radix ciliaris brevis. Similar finding was reported by El-Ghareeb et al. (2004) in *N. tessellata*. While in *C. rogersi* there is no radix

ciliaris brevis and the parasympathetic fibres arising from the nervus oculomotorius reaching the ganglion through one common mixed branch (Mostafa et al., 2013). On the other hand, the radix ciliaris brevis is extremely short so that the ganglion appears to touch the nervus oculomotorius in *L. agilis* and *Lacerta muralis* (Lenhossék, 1912) and *P. hasselquistii* (Soliman, 1968; Abdel-Kader, 1990). In contrast, the ciliary ganglion is firmly attached to the ramus inferior of the nervus oculomotorius, i.e., the radix ciliaris brevis is absent and the preganglionic parasympathetic fibres are transmitted directly to the ganglion through the intermingling surface in the geckos *T. mauritanica* (Soliman and Mostafa, 1984), *Stenodactylus slevini* (Mostafa and Hegazy, 1990) and *Tropiocotes tripolitanus* (El-Bakry et al., 2007) and in the amphisbaenian *D. zarudnyi* (Dakrory, 1994).

Among birds, the preganglionic parasympathetic fibres, carried by the nervus oculomotorius are transmitted to the ciliary ganglion either through an anastomosing branch; the radix ciliaris brevis or through the direct attachment of the ganglion to the ramus inferior of the nervus oculomotorius. The radix ciliaris brevis is previously mentioned in *Struthio* (Webb, 1957), in *U. epops* and *P. domesticus* (Soliman et al., 1976) and in *M. albicollis* (Abdel-Kader and Fathy, 2000). On the other hand, the ciliary ganglion is firmly attached to the ramus inferior of the nervus oculomotorius with the absence of the radix ciliaris brevis in the chick (Carpenter, 1906), in *S. senegalensis* (Soliman et al., 1976) and in *Gallinula chloropus* (Abdel-Kader, 1999).

Concerning mammals, Schwalbe (1879) reported that not all the higher vertebrates possess a short root, as is the case in many mammals (sheep, calf, dog, rabbit), and the ganglion is situated directly on the trunk of the nervus oculomotorius. The same condition was described by Christensen (1935) in the cat, Godinho (1972) in the ruminants, Watanabe (1972) in the guinea pig, Hegazy and Mostafa (1990) in both the hedgehog and bat, Sinnreich and Nathan (1981) in the man and Nowak et al. (2004) in the Egyptian spiny mouse, *Acomys cahirinus*. In the baboon *Papio cenocephalus*, on the other hand, the ciliary ganglion receives two branches from the ramus inferior (Gasser and Wise, 1972).

Among fishes, the preganglionic parasympathetic fibres of the nervus oculomotorius are transmitted to the ciliary ganglion by the radix ciliaris brevis in *Lampancyctus teucopsorus* (Ray, 1950), *Pseudorhombus arsius* (Marathe, 1955) *Polypterus senegulus* (Piotrowski and Northcutt, 1996) and *Tilapia zillii* (Dakrory, 2003; Ali, 2005). On the other hand, such fibres are transmitted directly to the ganglion through the intermingling surface between them, i.e., no radix ciliaris brevis in *Polycentrus schomburgkii* (Freihofer, 1978), *Trichiurus lepturus* (Harrison, 1981), *Ctenopharyndodon idellus* (Dakrory, 2000) and in both *Mugil cephalus* and *Gambusia affinis* (Dakrory, 2003).

In *M. monspessulana*, the radix ciliaris longa is absent. The ciliary ganglion is quite touching the ramus nasalis of the nervus trigeminus and the sensory fibres from the eye ball are conveyed to the ganglion by the intermingling surface between them. In other species, the ciliary ganglion is connected with the ramus nasalis of the nervus trigeminus by the radix ciliaris longa. This was found in the snakes *P. sibilans* and *C. vipera* (Hegazy, 1976), *S. diadema* (Mostafa, 1990a), *N. tessellata* (El-Ghareeb, 2004) and *T. dhara* (Abdel-Kader, 2006). The same finding was also found in the lizards *Lacerta viridis*,

Acanthodactylus boskiana, *Agama mutabilis* and *Mabuya quinquetaeniata* (Soliman, 1968), *A. pallida* (Soliman et al., 1984), *A. sinaita*, *S. slevini* and *Eumeces schneidri* (Mostafa and Hegazy, 1990) and *Varanus griseus* (Dakrory, 2009). In the gecko *G. kotschyi* (Evans and Minckler, 1938), in the amphisbaenian *D. zarudnyi* (Dakrory, 1994). However, the radix ciliaris longa joins both the ciliary ganglion and the ciliary nerve distal to the ganglion in the lizard *C. ocellatus* (Soliman and Hegazy, 1969) and in the snake *E. jaculus* (Hegazy, 1976), the radix ciliaris longa occupies a small area in the dorsal side of the ciliary ganglion. Then, it passes across the ganglion to enter the ciliary nerve. However, Santamaria-Arnaiz (1959) and Dakrory (2009) dealing with *C. ocellatus* and *Sphenops sepesoides* respectively, stated that the radix ciliaris longa passed in contact with the ciliary ganglion but did not enter it. Also, Osawa (1898) found that the radix ciliaris longa did not enter the ganglion, but it joined the ciliary nerves in *Hatteria punctata*. In *C. rogersi* Mostafa et al. (2013), the parasympathetic fibres are carried from the ramus nasalis to the ciliary ganglion together with the sensory fibres originating in the Gasserian ganglion by one common mixed branch.

In birds, no direct connection exists between the ciliary ganglion and the ramus ophthalmicus. Such connection, however, is carried out between the latter ramus and the ciliary nerves distal to the ganglion. This appears to be common in birds; as described by Soliman et al. (1976). However, a direct connection between the ramus ophthalmicus and the ciliary ganglion was described in *Struthio* (Webb, 1957), *U. epops* (Soliman et al., 1976) and in *M. albicollis* (Abdel-Kader and Fathy, 2000). On the other hand, Bonsdroff (1952) described, for the crona, two rami from the nervus trigeminus, which have the typical relations of the long root (radix ciliaris longa) of the ganglion.

In mammals, the sensory fibres are carried to the ciliary ganglion through the ramus ophthalmicus of the trigeminal nerve. In the rhesus monkey (Christensen, 1933), and in both the hedgehog *Hemiechinus auritus* and the bat *Rhosettus aegyptiacus* (Hegazy and Mostafa, 1990), the ganglion receives sensory fibres from its sensory root via a branch which connects it with the long ciliary nerve of the nasociliary branch. This communicating branch, i.e., the sensory root, however, is directly given off from the nasociliary branch in the rhesus monkey (Kuntz, 1933), in the domestic ruminants (Godinho and Getty, 1971) and in the baboon (Gasser and Wise, 1972). However, there is no direct connection between the ciliary ganglion and the nasociliary branch in the cat (Dupas, 1924; Christensen, 1935) and in the rhesus monky (Bast, 1933), hence the so-called sensory root of the ganglion is not found. In such species, the connection, however, is carried out between the long ciliary nerve of the nasociliary branch and one of the short ciliary nerves arising from the ganglion. At the point of union between the long and short ciliary nerves distal to the ganglion, the accessory ciliary ganglia are usually found, as stated by Christensen (1935).

A connecting branch between the ciliary ganglion and the ramus maxillaries of the trigeminal nerve was recorded in several mammalian species. It was described in the ox by Mobillio (1912), in the baboon by Gasser and Hendricks (1969) and in the goat, sheep and ox by Godinho and Getty (1971). Only, Mobillio (1912) considered such branch as a sensory root entering the ciliary ganglion in addition to another root originating from the nasociliary branch. Schawlbe (1879) did not

find any connection between the ciliary ganglion (ganglion oculomotorius) and the nervus trigeminus in several vertebrate species. Jegorow (1887), however, asserted that such connection is constant and necessary for the existence of the ganglion throughout the vertebrate series. On the other hand, Holtzmann (1896) found that the ciliary ganglion in amphibians, birds and mammals is more intimately connected with the nervus oculomotorius than with the trigeminal one.

In *M. monspessulana,* no direct connection was observed between the carotid sympathetic plexus and the ciliary ganglion or nerve. Sympathetic innervations of the eye may be derived from the ramus nasalis of the nervus trigeminus and its anastomosis with ramus palatinus of the nervus facialis and median sympathetic ramus. The same case was reported by Auen and Langebartel (1977) in the two colubrid snakes *Elaphe obsolete* and *Thamnophis ordinoides,* Mostafa (1990a) in the snake *S. diadema,* El-Ghareeb et al. (2004) in *N. tessellata,* Mostafa et al. (2013) in *C. rogersi.* Among lizards, it is absent as mentioned by Soliman (1968) in *A. boskiana* and *L. viridis,* Mostafa and Hegazy (1990) in the agamid *A. sinaita.* Again it is not found in Chelonia as recorded by Soliman (1964) in *C. serpentine* and *C. imbricate.* However, a sympathetic connection is established with the ciliary nerves distal to the ganglion in the snakes *P. sibilans* and *C. vipera* (Hegazy, 1976). It is also mentioned in the lizard *A. mutabilis* (Soliman, 1968), *C. ocellatus* (Soliman and Hegazy, 1969), *A. pallida* (Soliman et al., 1984) and in the amphisbaenian *D. zarudnyi* (Dakrory, 1994).

In birds, there is no connection between the ciliary ganglion or the ciliary nerves and the internal carotid plexus. This was confirmed by several authors (Schwalbe, 1879; Holtzmann, 1896; Cords, 1904; Carpenter, 1906; Lenhossék, 1912; Webb, 1957; Ābrahām and Stammer, 1966; Abdel-Kader and Fathy, 2000). Thus it can be stated that the absence of the sympathetic root is a common character among birds so far described.

In mammals, Kurus (1956) reported that the sympathetic connection between the ciliary ganglion and the internal carotid sympathetic plexus was present in mammals. This connection was reported by Winckler (1937) in rhesus monkey, Taylor and Weber (1969) in cat and Hegazy and Mostafa (1990) in the hedgehog and the bat. On other hand, Lenhossék (1912) mentioned that the sympathetic root may be absent in humans. This connection was also absent in the ox (Schachtschabel, 1908) and in the goat, sheep and ox (Godinho and Getty, 1971). On the contrary, Cunningham (1931) and Kuntz (1933) reported that the sympathetic root of the ganglion in humans may or may not be carried by nasociliary nerve. In *M. monspessulana,* there is only one strong ciliary nerve arising from the ciliary ganglion, while in *N. tessellata* (El-Ghareeb et al., 2004) and *C. rogersi* (Mostafa et al., 2013), there are two ciliary nerves arising from the ciliary ganglion.

The number of the ciliary nerves is variable in the vertebrates. Among reptiles, the number ranges from one to three. One ciliary nerve was found in the snakes *P. sibilans* and *E. jaculus* (Hegazy, 1976), *Coluber elegantissinus, Psammophis schokari* and *S. diadema* (Mostafa, 1991). The same was present in the lizards *C. ocellatus* (Santamaria-Arnaiz, 1959; Soliman and Hegazy, 1969), *P. hasselquistii, A. boskiana* and *L. viridis* (Soliman, 1968) and *Sphenops sepsoides* (Dakrory, 2009).

Similarly, one ciliary nerve was also found in the amphisbaenian *D. zarudnyi* (Dakrory, 1994). However, there are two nerves in the viper *C. vipera* (Hegazy, 1976) and in the lizards *Varanus bivittatus* (Watkinson, 1906), *Anolis carolinensis* (Willard, 1915), *M. quinquetaeniata* and *A. mutabilis* (Soliman, 1968), *T. mauritanica* (Soliman and Mostafa, 1984), *A. pallida* (Soliman et al., 1984), in all the lizards examined by Mostafa and Hegazy (1990) and in *V. griseus griseus* (Dakrory, 2009). Also, two ciliary nerves were found in the chelonians *Chelydra serpentina* and *C. imbricata* (Soliman, 1964). Moreover, three nerves were present in the gecko *G. kotschyi* (Evans and Minckler, 1938).

Among birds, the number of the ciliary nerves varies from one species to another. Schwalbe (1879) mentioned that the number of the ciliary nerves may vary from one (e.g., hen, owl and goose) to seven (e.g. parrots). One ciliary nerve was detected in the chick (Carpenter, 1906) and also in *M. albicollis* (Abdel-Kader and Fathy, 2000). However, Seto (1931) found five ciliary nerves in the chick. Two ciliary nerves were present in *S. senegalensis* (Soliman et al., 1976) and in *Meleagris gallopavo domesticus* (Radzimirska, 2003), while three ciliary nerves were found in *P. domesticus* (Soliman et al., 1976) and in *G. chloropus* (Abdel-Kader, 1999). On the contrary, four ciliary nerves were found in the crow (Oehme, 1968) and in *U. epops* (Soliman et al., 1976) and five nerves were found in *Struthio* (Webb, 1957).

The number of the ciliary nerves arising from the ciliary ganglion is also variable among mammals. Two ciliary nerves were found in the cat by Taylor and Weber (1969) and in the baboon by Gasser and Wise (1972). However, three ciliary nerves were found in *Hemiechinus auritus* and four in *Rhosettus aegyptaicus* arising from the ciliary ganglion as mentioned by Hegazy and Mostafa (1990). In addition, four to five ciliary nerves were present in the rhesus monkey (Bast, 1933; Kuntz, 1933). However, twelve to fifteen ciliary nerves were found in man by Cunningham (1931).

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