Anatomical Studies on the Cranial Nerves of Fully Formed Embryonic Stage of Gambusia affinis affinis (Baird & Girard, 1853) I. The eye muscle nerves and ciliary ganglion

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Abstract: This study deals with the eye muscle nerves and the ciliary ganglion of the bony fish Gambusia affinis affinis. The eye muscle nerves include the nervi oculomotorius, trochlearis and abducens. The oculomotor nerve leaves the cranial cavity through its own foramen. It innervates the rectus superior, rectus inferior, rectus medialis and the obliquus inferior muscles. It carries pure somatic motor fibres and visceromotor (parasympathetic) ones. The ciliary ganglion is small and has no radix ciliaris brevis. There is only one ciliary nerve arising from the ciliary ganglion. The radix ciliaris longa originates from the truncus ciliaris. The nervus trochlearis passes outside the cranial cavity through its own foramen. It has no connection with the other cranial nerves. It carries pure somatic motor fibres to the obliquus inferior muscle. The nervus abducens leaves the cranial cavity through its own foramen. It enters the posterior eye muscle canal (myodome) and it has no connection with the other cranial nerves. It carries pure somatic motor fibres to the rectus lateralis muscle.

Key Words: Gambusia affinis affinis - oculomotor-trochlear-abducens-ciliary ganglion.

1. Introduction

The sensory system of fishes (receptors, their nerves as well as their centres) play a major and sometimes a decisive role in many fish behavioral patterns (feeding, defense, spawning, schooling orientation, migration, etc.).

The study of the cranial nerves is important because their distribution is correlated to the habits and habitats of animals and also because they show an evolutionary trend among the animals of the same group.

Of the very early works done on the cranial nerves of bony fishes were those of Stannius (1849) and Goronowitsch (1888); these classical studies are still useful to investigators. Similar work on the morphology and structure of the cranial nerves in the genus Pleuronectes was done by Cole and Johnston (1901). The most valuable works of these early ones were those carried out by Allis (1903, 1909 & 1922) and Herrick (1899 & 1901).


Although the previously mentioned studies of different authors may throw light on the subject of the cranial nerves of fishes, yet it cannot be stated that the cranial nerves of a poeciliid fish is similar to other fishes; and what are the differences if present? Thus it was suggested that a detailed microscopic study on the eye muscle nerves in Gambusia affinis affinis will be very useful.

The main and fine branches of these cranial nerves, their distribution, their relations with other nerves and with the other structures of the head, their analysis and the organs they innervate are studied thoroughly, hoping that they may add some knowledge on this important subject and also to the behaviour and phylogeny of this group of fishes.

2. Material and Methods

The species chosen for this study is the fully formed larvae of Gambusia affinis affinis (Mosquito fish) which is a fresh water bony fish. The larvae were fixed in aqueous bouin for 24 hours. After washing several days with 70% ethyl alcohol, the heads were stained with borax carmine method (Galigher & Kozloff, 1964). Decalcification was necessary before sectioning and staining in toto for the specimens. After staining in toto, the heads were prepared for blocking and then sectioning transversely at 10 micron by microtome. The serial sections were mounted on slides and counterstained in picroindigo carmine. The serial sections were drawn by projector. From these drawings an accurate graphic reconstructions for the eye muscle nerves and the ciliary ganglion are made in a lateral view. Also, parts of certain sections were photomicrographed to demonstrate the relation of these nerves with the other cranial structures.
3. Results
Nervus Oculomotorius

In Gambusia affinis affinis, the oculomotor nerve arises from the midlateral side of the mesencephalon by a single root (Figs 1 & 2, RO.III). Immediately after its emergence, it runs anteroventrally within the cranial cavity, passing lateral to the brain, ventral and then ventromedial to the nervus trochlearis and medial to the Gasserian ganglion of the nervus trigeminus. It continues anteroventrally running ventral to the brain and dorsal to both the pleurophenoid bone and the vena capites lateralis (anterior cardinal vein). Shortly after that, the nervus oculomotorius leaves the cranial cavity, passing lateral to the brain, ventral and dorsal to the Pleurosphenoid bone and the rectus inferior muscles. Thereafter, it shifts ventrally passing ventral to the rectus superior muscle and dorsal to the rectus medialis muscle. Finally, it enters the obliquus inferior muscle from its dorsolateral edge and terminates between its fibres (Fig.1, N.OB.IF).

Shortly, anterior to the origin of the previous branch, the ramus inferior extends more forwards running medial to the ciliary ganglion, ventrolaterally to the rectus superior muscle, medial to the rectus medialis muscle and dorsolateral to the rectus inferior muscle where it divides into two branches, one lateral and the other medial (Fig.1).

The lateral branch (Fig.1, N.RIF) extends anteriorly in a ventromedial direction passing lateral and then ventral to the medial branch and medial to the ciliary nerve. Thereafter, it continues running anteriorly being ventrolateral to the medial branch and lateral to the rectus inferior muscle. Finally, the lateral branch enters the latter muscle from its ventrolateral side where it achieves its final distribution.

The medial branch (Fig.1, N.RM) runs forwards in a dorsomedial direction extending medial and then dorsal to the lateral branch and ventromedial to the rectus superior muscle. Shortly anterior, it passes dorsomedial to both the ciliary nerve and the rectus inferior muscle and ventromedial to the rectus superior muscle. After that, this branch shifts dorsomedially passing ventral to the rectus superior muscle and dorsal to the rectus inferior muscle. Directly after that, it reaches the lateral side of the rectus medialis muscle where it enters and ends between its fibres.

Ciliary Ganglion

In Gambusia affinis affinis, the ciliary ganglion (Figs.1, 6 &7, G.CIL) is an oval shaped structure, consisting of a collection of ganglionic cells. It lies in the posterior part of the orbital region. The ganglion (Figs. 6 & 7, G.CIL) is surrounded by the rectus lateralis muscle laterally (M.RL), the ramus inferior of the nervus oculomotorius (R.IF) medially, the ramus superior of the nervus oculomotorius (R.SP) dorsally and the adductor hyomandibularis muscle (M.ADHY) ventrally. It measures about 40 mm in length. The light microscopic examination indicated that the latter ganglion consists of peripheral large neurons and central small ones (Fig. 7).

The ciliary ganglion is commonly described as possessing three roots; a motor (parasympathetic), a sensory and a sympathetic. The first root carries
preganglionic parasympathetic (rimiti-motor) fibres which arise in the midbrain. These fibres, as it has long been known, constitute the tectal portion of the cranial outflow of the parasympathetic system. The preganglionic parasympathetic fibres are transmitted to the ciliary ganglion by way of the nervus oculomotorius, with or without a special root; the radix ciliaris brevis. They terminate in the ganglion in a synaptic relationship with the postganglionic cell bodies. The sensory root of the ganglion consists of sensory components of the ramus profundus of the nervus trigeminus. These fibres enter the ganglion by means of a long branch; the radix ciliaris longa. The sympathetic root is composed of the postganglionic sympathetic fibres which originate in the the most anterior head (trigeminal or facial) sympathetic ganglion. Such fibres are carried to the ciliary ganglion by a fine branch; the sympathetic root. Both the sensory and postganglionic sympathetic fibres usually pass through the ganglion without interruption and become incorporated in the ciliary nerves arising from it.

In the present study, the ciliary ganglion and the ramus inferior of the nervus oculomotorius are in immediate connection; the radix ciliaris brevis is lacking (Figs.1 & 7). The microscopic investigation reveals that the preganglionic parasympathetic fibres leave the ramus inferior and directly enters the ganglion at the point of attachment between them. Such fibres constitute the parasympathetic (general motor) root of the ganglion.

In this study, the ciliary ganglion receives a long radix ciliaris longa (Figs. 1 & 7, RCL). This branch arises from the profundal ganglion of the nervus profundus and extends anteriorly in the ventromedial direction along the ventrolateral wall of the vena capitis lateralis and enters the ganglion from its dorsolateral corner (Fig. 7). The radix ciliaris longa receives the most anterior sympathetic fibres arising from the trigeminal sympathetic ganglion to carry them to the ciliary ganglion.

In this work, there is a single ciliary nerve (Figs.1 & 9, N.CIL) arising from the anterior end of the ciliary ganglion. This nerve extends forwards in a lateral direction, being ventral to the rectus superior muscle, medial to the ramus inferior of the nervus oculomotorius and then lateral to the rectus inferior muscle and medial to the eyeball. Shortly anterior, it shifts and becomes dorsal to the latter muscle, ventrolateral to both the rectus medialis muscle and the optic nerve and medial to the eyeball (Fig. 9, N.CIL). Finally, it enters the eyeball just posteroventral to the optic nerve.

**Nervus Trochlearis**

In *Gambusia affinis affinis*, the nervus trochlearis arises from the lateral side of the midbrain just anterior and dorsal to the origin of the nervus trigeminus, by a single small root (Figs.1 & 8, RO.IV). This root extends anteriorly within the cranial cavity in a ventrolateral direction passing ventral then lateral to the brain and dorsal to the trigeminal nerve (Fig. 2, N.IV). Shortly forwards, it becomes ventral to the ganglion of the anterodorsal lateral line nerve and medial to the membranous labyrinth (anterior semicircular canal). Thereafter, the nervus trochlearis continues forwards running ventrolateral to the brain and ventromedial to the auditory capsule (Fig.4, N.IV). On reaching the postorbital region, it stills intracranially extending medial to the supraorbital cartilage and lateral to the brain. After a considerable anterior course in the orbital region, it leaves the cranial cavity by penetrating the meninx rimitiva through its own foramen (Fig.9, F.TR).

Extracranially, the nervus Trochlearis runs forwards dorsal to the eyeball, ventromedial to the supraorbital cartilage and lateral to the cranial wall. Thereafter, it continues its course dorsomedial to the rectus superior muscle and dorsolateral to the cranial wall. Then, it becomes dorsal and then medial to the latter muscle. On reaching the mid-way of the orbital region, it continues running in a dorsolateral direction being dorsal to the obliquus superior muscle and ventromedial to the supraorbital lateral line pit. More forwards, it continues its course passing dorsomedial to the obliquus superior muscle and ventromedial to the supraorbital cartilage. Finally, it enters and ends between the fibres of the latter muscle (Fig.1).

**Nervus Abducentis**

In *Gambusia affinis affinis*, the nervus abducentis originates from the ventrolateral corner of the medulla oblongata by a single fine root just medial to the origin of the anterior octaval root (Figs.1 & 10, RO.VI). Directly after its origin, it starts its intracranial forward course passing ventrolaterally being medial to the nervus octavus. Shortly forwards, this nerve continues passing medial to the lagena and dorsal to the lateral margin of the prootic bridge which forms the roof of the posterior myodome (posterior eye muscle chamber).

After a considerable anterior course, the nervus abducentis leaves the cranial cavity by piercing the meninx rimitiva through a foramen in the lateral margin of the prootic bridge (Fig. 3) passing ventral to the geniculate ganglion and dorsomedial to the truncus hyomandibularis then enters the posterior myodome (Fig. 4, PM), which lodges the rectus lateralis muscle. Within the myodome, it ramifies and enters the rectus lateralis muscle where it terminates (Fig. 4).
Fig. 1: Lateral view of a graphic reconstruction of the nervi oculomotorius, trochlearis, abducens and the ciliary ganglion of *Gambusia affinis affinis*.

Fig.2: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the otic region, showing the root of the nervus oculomotorius and the nervi profundus, trochlearis and abducens. It also demonstrates Gasserian ganglion, geniculate ganglion, ramus ampullaris anterior of the octavus nerve.

Fig.3: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the otic region, illustrating the nervi oculomotorius, anterior lateral line, trochlearis and abducens.

Fig.4: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the otic region, demonstrating the oculomotor foramen, nervi profundus and trochlearis, the nervus abducens within the posterior myodome.

Fig.5: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the postorbital region, showing the division of the nervus oculomotorius into rami superior and inferior, nervus trochlearis and profundal ganglion.

Fig.6: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the postorbital region, nervus trochlearis, profundal ganglion, illustrating the position of the ciliary ganglion.

Fig.7: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the postorbital region, demonstrating the structure of the ciliary ganglion and the radix ciliaris longa entering the ganglion.
Fig. 8: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the otic region, the root of the nervus trochlearis arising from the brain.

Fig. 9: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the orbital region showing the trochlear foramen and the ciliary nerve.

Fig. 10: A photomicrograph of part of transverse section of *Gambusia affinis affinis* passing through the otic region, illustrating the origin of the root of the nervus abducens from the medulla oblongata.

**LIST OF ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>Auditory capsule;</td>
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<tr>
<td>BSP</td>
<td>Basisphenoid bone;</td>
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<tr>
<td>CE</td>
<td>Cerebral hemisphere;</td>
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<tr>
<td>F.FA</td>
<td>Facial foramen;</td>
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<td>F.OP</td>
<td>Optic foramen;</td>
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<tr>
<td>G.ADL</td>
<td>Anterodorsal lateral line ganglion;</td>
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<td>G.GN</td>
<td>Geniculate ganglion;</td>
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<tr>
<td>G.PI</td>
<td>Pituitary gland;</td>
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<tr>
<td>INF</td>
<td>Infundibulum;</td>
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<tr>
<td>M.MM</td>
<td>Adductor mandibularis medius muscle;</td>
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<tr>
<td>M.LABE.II</td>
<td>Second levator arcualis branchialis externus muscle;</td>
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<tr>
<td>M.LIF</td>
<td>Rectus inferior muscle;</td>
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<tr>
<td>M.RM</td>
<td>Rectus medialis muscle;</td>
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<tr>
<td>M.TD</td>
<td>Transversus dorsalis muscle;</td>
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<tr>
<td>N.AVL</td>
<td>Anteroventral lateral line nerve;</td>
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<tr>
<td>N.CSY</td>
<td>Cranial sympathetic nerve;</td>
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<td>N.II</td>
<td>Nervus opticus;</td>
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<td>N.IV</td>
<td>Nervus trochlearis;</td>
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<tr>
<td>N.OB.IF</td>
<td>Nerve to the obliquus inferior muscle;</td>
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<td>N.PR.F</td>
<td>Nervus profundus;</td>
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<td>N.RF</td>
<td>Nerve to the rectus lateralis muscle;</td>
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<td>N.RSP</td>
<td>Nerve to the rectus superior muscle;</td>
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<td>N.VI</td>
<td>Nervus abducens;</td>
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<tr>
<td>OL.BU</td>
<td>Olfactory bulb;</td>
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<td>OP.LO</td>
<td>Optic lobe;</td>
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<td>PRC</td>
<td>Prootic cartilage;</td>
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<tr>
<td>RCL</td>
<td>Radix ciliaris longa;</td>
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<tr>
<td>R.BU</td>
<td>Ramus buccalis;</td>
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<td>R.SP</td>
<td>Ramus superior;</td>
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<tr>
<td>R.OSL</td>
<td>Ramus ophthalmicus superficialis lateralis;</td>
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<td>R.PA</td>
<td>Ramus palatinus;</td>
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<td>R.OF</td>
<td>Root of the nervus oculomotorius;</td>
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<tr>
<td>R.OI</td>
<td>Root of the nervus oculomotorius;</td>
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<tr>
<td>R.RF</td>
<td>Rami ophthalmicus superficialis trigeminus and lateralis;</td>
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<td>R.MM</td>
<td>Rectus medialis muscle;</td>
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<tr>
<td>R.MM</td>
<td>Taenia marginalis;</td>
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<td>V.CL</td>
<td>Vena capitis lateralis;</td>
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**4. Discussion**

In the present study, the nervus oculomotorius shows no decussation near its origin in the brain. A complete decussation for the nervus oculomotorius within the brain was observed by Dakrory (2000) in *Ctenopharyngodon idellus*, Ali (2005) in *Tilapia zillii*, Hussein (2010) in *Mugil cephalus* and Taha (2010) in *Hypophthalmichthys molitrix*. The nervus oculomotorius gets its exit from the cranial cavity through its own foramen, the foramen oculomotorius. This condition was found also in many cartilaginous fishes (Chandy, 1955; Hamdy, 1959; El-Toubi and

Among bony fishes, the nervus oculomotorius was found to issue from the cranial cavity through its own foramen as in Ailia (Srinivasachar, 1956), Amphipnous cuchia (Saxena, 1967), Trichiusurus lepturus (Harrison, 1981), Ctenopharyngodon idellus (Dakrory, 2000), Tilapia zillli (Ali, 2005) and Hypophthalmichthys molitrix (Taha, 2010). However, the nervus oculomotorius was found to leave the cranial cavity together with the nervi Opticus, trigeminus, abducens and facialis through a large sphenoid fissure in 29 mm Arius jella and 16 mm Plotosus canius (Srinivasachar, 1959). In Clarias batrachus (Dalela and Jain, 1968), the nervus oculomotorius was found to emerge from the cavum cranii together with the nervus oculomotorius and the nervus trigeminus through a separate foramen. This finding may be related to the absence of the true pila prootica (El-Toubi and Abdel-Aziz, 1955; Piotrowski and Northcutt, 1996). On the other hand, in Gnathonemus petersii (Szabo et al., 1987), the oculomotor nerve is divided within the cranial cavity into two branches, which enter the orbit separately, i.e., there are two foramina for the nervus oculomotorius.

In the present work, the oculomotor foramen is located between the lateral edge of the prootic bone medially and the pleurosphenoid bone laterally. This result is similar to the finding of Ali (2005) in Tilapia zillli. Different localities for the oculomotor foramen were described in other fishes by some authors. This foramen was found in the lateral ethmoid bone in Amphipnous cuchia (Saxena, 1967), in the basisphenoid bone in Trichiurus lepturus (Harrison, 1981), in the orbitosphenoid bone in Polypterus senegalus (Piotrowski and Northcutt, 1996) or surrounded by the pleurosphenoid bone in Ctenopharyngodon idellus (Dakrory, 2000) and in Hypophthalmichthys molitrix (Taha, 2010). However, Ray (1950) described a special oculomotor foramen in the membranous cranial wall of the orbitotemporal region in Lampanyctus leucopsarus, while Srinivasachar (1956) described this foramen in the preoptic root of the orbital cartilage in Ailia.

In the jawless fishes, Johnels (1948) described an optic fenestra through which emerge the optic and the three eye muscle nerves from the cranial cavity in Petromyzon. However, Jollie (1968) described a separate oculomotor foramen in lampreys. The author added that this may confluent with a large optic foramen located anterior to it. On the other hand, the three eye muscle nerves along with their muscles are lacking in the hagfishes (Jollie, 1968; Northcutt, 1985; Wicht, 1996). Fernholm and Holmberg (1975) stated that the hagfishes have relatively small eyes, and there was tendency toward eye reduction. Parallel with these results, Wicht (1996) recorded that the external eye muscles as well as the accompanying nerves are entirely lacking in all species of hagfishes even in that retained relatively large and differentiated eyes as in Eptatretidae.

In Amphibia, the oculomotor nerve has its own foramen as described by many authors (Sokol, 1977 & 1981; Mostafa and Soliman, 1984; Shaheen, 1987). However, in Rhyacotriton olympicus (Srinivasachar, 1962), the optic and the oculomotor nerves pass through a common foramen.

In the present investigation, the nervus oculomotorius is divided extracranially into two rami, the ramus superior and the ramus inferior. This case was agreed with what was generally found in most fishes such as Ctenopharyngodon idellus (Dakrory, 2000), Tilapia zillii (Ali, 2005) and Hypophthalmichthys molitrix (Taha, 2010). However, in the teleosts Gnathonemus petersii (Szabo et al., 1987) and Alticus kirkii magnosisi (Ali and Dakrory, 2008) the nervus oculomotorius is divided intracranially into a posterior branch to the rectus superior muscle and an anterior branch to the other three muscles. In Lampanyctus leucopsarus (Ray, 1950), the division of the nervus oculomotorius into its two rami is in the oculomotor foramen.

The studied species showed no connection between the nervus oculomotorius and other cranial nerves. This observation was similar to that found in Tilapia zillii (Ali, 2005), Alticus kirkii magnosisi (Ali and Dakrory, 2008), Mugil cephalus (Hussein, 2010) and Hypophthalmichthys molitrix (Taha, 2010). However, the connection between the nervus oculomotorius and the nervus trigeminus was recorded among bony fishes. In Polypterus senegalus, this nerve joins the profundus nerve (El Toubi and Abdel-Aziz, 1955). In the same species, however, two connections between these two nerves were found by Piotrowski and Northcutt (1996). In Ctenopharyngodon idellus (Dakrory, 2000) the nervus oculomotorius is connected to the trigeminal ganglion through a fine anastomosing branch. In Gnathonemus petersii (Szabo et al., 1987), the oculomotor nerve anastomoses with the ophthalmic branch of the trigeminolateral line complex. Earlier, an anastomosis between the nervus oculomotorius and the nervus trochlearis was found in Pleuronectes (Cole and Johnstone, 1901) and between this nerve and the nervus abducens in Cyclothone accliniens (Giere, 1904). However, Marathe (1955), Dakrory (2000), Ali (2005) and Taha (2010) revealed no connections between the nervus oculomotorius and both the nervi trochlearis and
abducens in Pseudorhombus arsius, Ctenopharyngodon idellus, Tilapia zillii and Hypophthalmichthys molitrix, respectively.

An anastomosis between the nervus oculomotorius and other cranial nerves seems to be widely spread among Amphibia, Reptilia, Aves and Mammalia. With respect to amphibians, the nervus oculomotorius is connected with both Gasserian ganglion and the ramus ophthalmicus profundus as in Bufo viridis and Bufo regularis (Paterson, 1939; Soliman and Mostafa, 1984; Shaheen, 1987).

The ciliary ganglion of the fish Gambusia affinis affinis is found in the postorbital region of the head, this finding was also reported by Dakrory (2000) in both Ctenopharyngodon idel dus and Rhinobatus halavi and in Gambusia affinis affinis, Tilapia and Mugil cephalus (Dakrory, 2003), Tilapia zillii (Ali, 2005), Alticus kirkii magnosi (Ali and Dakrory, 2008), Mugil cephalus (Hussein, 2010) and Hypophthalmichthys molitrix (Taha, 2010). Among bony fishes, a distinct ciliary ganglion was also described in the perciform Pseudorhombus arsius (Marathe, 1955), polycentrus schomburgkii (Freihofer, 1978), Trichiurus lepturus (Harrison, 1981) and in the cladistian, Polypterus senegalus (Piotrowski and Northcutt, 1996), in Ctenopharyngodon idellus (Dakrory, 2000) and in Tilapia and Mugil (Dakrory, 2003).

In cartilaginous fishes, the ciliary ganglion was observed by Young (1988) in dog fish Mustelus and in skates and rays. However, the ciliary ganglion was completely lacking in Salmo and Cyclothone acclinidens (Gierse, 1904), in Dipnoi (Jenkin, 1928) and in the ray fish Dasyatis rafinesque (Chandy, 1955). Again, Burr (1933) denied the presence of the ciliary complex in Opistrophoetus soleatus, but he found a ganglion on the third cranial nerve.

In Amphibia, the ciliary ganglion seems to be absent or transitory. It was found to be absent in Amblystoma punctatum (Herrick, 1894), Amphiuma means (Norris, 1908) while it was only transitional and non-functional in Amblystoma tigrinum (Coghill, 1902; Kuntz, 1914). In Rana bedriagae, the ciliary ganglion is poorly developed (Dakrory, 2002). However, Mostafa and Soliman (1984) described a ciliary ganglion of two parts in Bufo viridis.

In the present work, there is no sympathetic connection between the ciliary ganglion and the anterior sympathetic head ganglion. Similar condition was found in Pseudorhombus arsius (Marathe, 1955), Polypterus senegalus (Piotrowski and Northcutt, 1996), Alticus kirkii magnosi (Ali and Dakrory, 2008) and in Hypophthalmichthys molitrix (Taha, 2010). Similarly, Cyclostomata lack such system (Walker, 1987). In Amphibia, this connection was not cited in the literature (Mostafa and Soliman, 1984; Shaheen, 1987; Dakrory, 2002). Also, the cartilaginous fishes lack the head sympathetic system (Chandy, 1955; Walker, 1987; Young, 1988; Dakrory, 2000).

Among bony fishes, the sympathetic root originates from the facial sympathetic ganglion. Such condition was reported in Lampamctus leucopsarus.
In the current study, the poeciliid fish Gambusia affinis affinis shows that in addition to the ciliary nerve, a truncus ciliaris profundus enters the eyeball through a foramen excavated in the dorsal side of the sclera just ventral to the obliquus superior muscle. This finding shows that the eye is accommodated by both the ciliary nerve and the truncus ciliaris. Therefore, this reflects the fact that the eye is well developed in the studied fish and this fish depends on vision during its feeding. So, it may be considered as a diurnal animal. A similar observation was found also by Young (1988), Ali (2005) in Tilapia zillii and Taha (2010) in Hypophthalmichthys molitrix. In Polypterus senegalus, Piotrowski and Northcott (1996) described two ciliary nerves.

In cartilaginous fishes, Kent (1978) stated that the postganglionic fibres penetrate the sclera and pass to the sphincter pupillae and the ciliary muscle of the iris diaphragm. The author added that the bony fish lack the ciliary muscles but there is a special compound, Campanula Halleri, was found which draw the lens backwards for accommodation. Young (1988) concluded that the Campanula Halleri or retractor lentis muscle is innervated through the oculomotor nerve and the ciliary ganglion.

Among Amphibia, there are two ciliary nerves in Bufo viridis (Mostafa and Soliman, 1984) and Rana bedriagie (Dakrory, 2002). On the other hand, there is no ciliary ganglion and consequently, no ciliary nerve was present in some other amphibians (Norris, 1908; McKibbon, 1913; Paterson, 1939; Shaheen, 1987).

In the present study, the nervus trochlearis emerges from the cranial cavity through a special foramen, the trochlear foramen that located in the pleurophenoid bone. This is the case found in some fishes such as Parasilurus asotos (Atoda, 1936), Lampanyctus leucopsarus (Ray, 1950), Polypterus senegalus (Piotrowski and Northcutt, 1996) and in Tilapia zillii (Ali, 2005).

Among Chondrichthyes, Young (1988) and Dakrory (2000) reported that the motor root from the oculomotor nerve joins a sensory one from the trigeminal nerve then it enters the ganglion. A radix ciliaris brevis was found in some reptiles (Soliman and Hegazy, 1969; Abdel-Kader, 1990; Omar, 2009), in some birds (Soliman et al., 1976) and in some mammals (Godinho, 1972; Hegazy and Mostafa, 1990). From the above mentioned observation, it appears that the parasym pathetic fibres (the motor root) of the nervus oculomotorius may or may not form a separate branch, radix ciliaris brevis, which enters the ganglion or it is found on the ramus inferior without any communicating branch.

In the present study, one ciliary nerve arises from the ciliary ganglion. The number of ciliary nerves is variable in vertebrates. The presence of one ciliary nerve appear to be a common character among bony fishes as in Trichiurus lepturus (Harrison, 1981), in Polypterus senegalus in (Piotrowski and Northcutt, 1996), in the cyprinid Ctenopharyngodon idellus (Dakrory, 2000), in Mugil cephalus (Dakrory, 2003), in Alticus kirki magnosi (Ali and Dakrory, 2008) and in Hypophthalmichthys molitrix (Taha, 2010). On the other hand, there is one ciliary nerve arising from the ophthalmicus profundus nerve and not from the ciliary ganglion as in the ray Dasyatis refrinesque (Chandy, 1955).
(Puzdrowski, 1987). Nakae and Sasaki (2006) reported that the trochlear nerve in *Mola mola* emerges from the cranium through the anterior part of the suture between the pterosphenoid and basi sphenooid.

Among cartilaginous fishes, the nervus trochlearis leaves the cerebral cavity through its own foramen, the trochlear foramen (Chandy, 1955; El-Toubi and Hamdy, 1959 & 1968; Hamdy and Hassan, 1973; Mazhar, 1979; El- Satti, 1982; Dakrory, 2000). In the cyclostomates *Petromyzon*, the nervus trochlearis leaves the cranial cavity together with the optic, oculomotor and abducens nerves through the optic fenestra (Johnels, 1948). On the other hand, Jollie (1968) reported a special foramen for the trochlear nerve in lampreys.

In most amphibians, the trochlear nerve exits the cerebral cavity through a special foramen (Herrick, 1894; Norris, 1908; Stadtmuller, 1925; Aoyama, 1930; de Beer, 1937; Paterson, 1939; Sokol, 1977 & 1981; Mostafa and Soliman, 1984; Shaheen, 1987; Trueb and Hanken, 1992; Haas, 1995; Dakrory, 2002). In most cases, this foramen is found in the orbital cartilage. However, Van Eeden (1951) mentioned that the trochlear foramen, in *Ascalaphus truei*, does not pierce the orbital cartilage at all; but the nervus trochlearis passes over its margin. This author added that *Ascalaphus truei* shares this feature with some Urodela. Sokol (1977) reported that the trochlear foramen in the anuran *Pipa cadvalhoi* is very small and presumably lies above the oculomotor foramen as in other tadpoles. In this respect, the trochlear foramen *Amblystoma punctatum* (Herrick, 1894) and *Necturus* (McKibben, 1913) was found to be located in the parietal bone. Sheil (1999), dealing with *Pyxicephalus adspersus*, stated that the trochlear foramen is located ventral to the lamina perpendicular to the frontoparietal bone or pierces it. On the other hand, a large optic-proptic foramen, for the exit of the nervi II-VII was described by Trueb and Cannatella (1982) in *Rhinophrynus dorsalis* and *Pipa pipa*. Haas and Richard (1998) revealed that the nervi opticus and trochlearis leave the cranial cavity together through a large foramen opticum in Boophis.

In the present study, there is no decussation of the left and right trochlear nerves inside the brain. This finding was in agreement with that reported by Ali (2005) in *Tilapia zillii* and by Ali and Dakrory (2008) in *Alticus kirkii magnosi*. However, there is a complete trochlear decussation of the left and right trochlear nerves inside the brain as reported in *Gnathonemus petersii* (Szabo et al., 1987). *Polypterus senegalus* (Piortrowski and Northcutt, 1996), in both the batoid *Rhinobatus halavi* and in the cyprinid *Ctenopharyngodon idellus* (Dakrory, 2000), in *Mugil cephalus* (Hussein, 2010) and in *Hypophthalmichthys molitrix* (Taha, 2010).

The present investigation shows no connection between the nervus trochlearis and the other cranial nerves. This observation was in agreement with the result recorded in *Rhinobatus halavi* and *Ctenopharyngodon idellus* (Dakrory, 2000), *Tilapia zillii* (Ali, 2005, *Alticus kirkii magnosi* (Ali and Dakrory, 2008) and *Hypophthalmichthys molitrix* (Taha, 2010). An anastomosis between the nervus trochlearis and the nervus trigeminus is widely found among fishes. Such anastomosis was mentioned with the mandibular branch of the trigeminal-lateral line complex in *Gnathonemus petersii* (Szabo et al., 1987) and with the profundus nerve in *Polypterus senegalus* (Piortrowski and Northcutt, 1996). The connection between the trochlear nerve and the trigemino-facial ganglion was previously observed by Atoda (1936) in *Parasilurus asotus*. A connection between the nervus trochlearis and the ramus lateralis accessorius was recorded by Herrick (1899) in *Menidia*.

Among amphibians, the nervus trochlearis was found to anastomose with the ramus ophthalmicus profundus of the nervus trigeminus in *Amblystoma punctatum* (Herrick, 1894), *Xenopus laevis* (Paterson, 1939) and in *Bufo regularis* (Shaheen, 1987). However, such a connection is not found in *Amblystoma tigrinum* (Coughill, 1902) and in *Bufo viridis* (Mostafa and Soliman, 1984).

Generally and as presented in the current study, the nervus trochlearis innervates the obliquus superior muscle; a finding which was reported also by many authors (Kassem et al., 1988; Bauchot et al., 1989; Dakrory, 2000, Ali, 2005; Nakae and Sasaki, 2006; Taha, 2010).

It is clear from the detailed anatomical study of the serial sections of the head of the fish *Gambusia affinis affinis* that the nervus trochlearis carries special somatic motor fibres.

In this work, the nervus abducens of the studied poeciliid fish arises from the medulla oblongata by a single root. This is the same condition observed in *Argyropelecus hemigymnus* (Handrick, 1901), *Scomber scomber* and *Scorpaena scrofa* (Allis, 1903 & 1909), *Cycloptone acclinidens* (Giese, 1904), *Tetradon oblongus* (Bal, 1937) *Lampanyctus leucopars* (Ray, 1950), *Dasyatis rafinesque* (Chandy, 1955), *Polypterus senegalus* (El-Toubi and Abdel-Aziz, 1955), in *Parasilurus asotus* (Saxena, 1969), *Ctenopharyngodon idellus* (Dakrory, 2000), *Tilapia zillii* (Ali, 2005) and *Alticus kirkii magnosi* (Ali and Dakrory, 2008). On the other hand, the nervus abducens arises by two roots, as it was found by Stannius (1849) in *Cottis* and *Trigla*, Herrick (1899 & 1901) in *Menidia* and *Amieturus melas*, respectively, Allis (1909) in both *Lepidotrigla* and adult *Scorpaena scrofa*, Pancratz (1930) in *Opunus tau*, Atoda (1936) in *Parasilurus asotus*, Harrison (1981) in *Trichiurus lepturus* and by Bauchot et al.
In jawless fishes, the nervus abducens emerges from the cerebral cavity together with the optic, oculomotor and trochlear nerves, through the optic fenestra (Johnels, 1948). On the other hand, Jollie (1968) reported that in lampreys the nervus abducens passes out the cranium together with the trochlear and trigeminal nerves through a large opening in the lateral side of the skull. However, Kent (1978) stated that lampreys seem to lack an abducens nerve or may be represented by small bundle emerging from the hind brain on the anterior surface of the trigeminal nerve.

Regarding the emergence of the nervus abducens from the cerebral cavity in Amphibia, it was found that this nerve passes with the nervus trigeminus, through the foramen prooticum (Sokol, 1977 & 1981; Mostafa and Soliman, 1984; Shaheen, 1987; Reiss, 1997; Dakrory, 2002). However, Haas (1995) showed that the nervus abducens in Colostethus nubicola, Colostethus subpunctatus, Epipedobates tricolor and Phyllobates bicolor, leaves the cranial cavity through a fissure prootica. On the other hand, Trueb and Cannatella (1982) described a single foramen "optic-prootic foramen" for the exit of the optic, oculomotor, trochlear, trigeminal, abducens and facial nerves in Rhinophrynus dorsalis and Pipa pipa.

In this study, the nervus abducens shows no connection with other cranial nerves. This is the case, which was mentioned in many fishes (Alis, 1903; Bal, 1937; Ray, 1950; El-Toubi and Abdel-Aziz, 1955; Chandy, 1955; Saxena, 1967 & 1969; Harrison, 1981; Dakrory, 2000; Ali, 2005; Ali and Dakrory, 2008). However, two connections between the nervus abducens and the profundus nerve were recorded by Piotrowski and Northcutt (1996) in Polypterus senegalus.

In Amphibia, the nervus abducens passes through the Gasserian ganglion without any interchange of fibres. It leaves this ganglion with the ramus ophthalmicus profundus with which it is merged (Herrick, 1894; Coghill, 1902; Norris, 1908; Wiedersheim, 1909; Paterson, 1939; Mostafa and Soliman, 1984; Shaheen, 1987).

Generally and in the present work, the nervus abducens, as in all vertebrates, innervates the rectus lateralis (externus) muscle. This condition was reported by many authors in some fishes (Bauchot et al., 1989; Dakrory, 2000; Ali, 2005; Nakae and Sasaki, 2006; Ali and Dakrory, 2008; Taha, 2010). In Tridentiger trigonocephalus, Kassem et al. (1988) stated that the rectus externus muscle consists of two kinds of fibres and is innervated by two distinct nerve bundles. However, in Latimeria chalumnae (Northcutt and Bemis, 1993) and in many tetrapoda, it innervates the rectus externus and the retractor oculi muscles. In Cyclostomata, Edgeworth (1935) stated that the nervus abducens innervates the rectus externus and the rectus
nervus abducens in externus inferior muscles. Fritzsch et al. (1990) found that two of the six ocular muscles are innervated by the nervus abduces in Petromyzon marinus. Pombal et al. (1994) confirmed this finding.

The rectus lateralis muscle is located within the posterior myodome (the eye muscle chamber). Some authors recorded the presence of this myodome in Ctenopharyngodon idellus (Dakrory, 2000) and Tilapia zilli (Ali, 2005).

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