Anatomical studies on the cranial nerves of *Tilapia zillii* II.Nervus Trigeminus

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Abstract: The nervus trigeminus arises by one root. It gives off the nervus ophthalmicus r which has an intracranial profundal ganglion and leaves the cranial cavity through its owen foramen.It divides into the radix ciliaris longa and the truncus ciliaris. The nervus trigeminus leaves the cranial cavity through the prootic foramen together with the anterodorsal lateral line nerve. It enters the Gasserian ganglion which lies extracranially. The Gasserian ganglion receives also the ramus ophthalmicus superficialis lateralis. The later ganglion gives off the rami ophthalmici superficialis trigeminus and lateralis as one ramus dorsally and the maxillomandibular trunk ventrally.The ramus ophthalmicus superficialis V carrying the lateralis fibres enters the olfactory region passing through a depression in the dorsal edge of the sphenoseptal commissure. This ramus carries general somatic sensory fibres to the skin dorsal and anterior to the eyes and to that covering the olfactory capsule and special somatic sensory ones (lateralis fibres). There is a single constrictor dorsalis nerve (carries visceromotor fibres), which innervate the levator arcus palatini and the dilator opercularis muscles. The ramus maxillaris divided into dorsal and ventral divisions and anastomoses with the ramus palatinus of the nervus facialis. The ramus maxillaris carries general somatic sensory fibres to the skin and special ones (lateralis fibres) from the anterior lateral line nerve and visrosensory ones for the taste buds (from the nervus facialis). The ramus mandibularis V divides into ramus externus and ramus internus. It carries visceromotore fibres to the adductor mandibularis and the anterior and posterior intermandibularis muscles and general (to the skin and teeth) and special(to the lateral line neuromasts) somatic sensory fibres and special visrosensory ones to the taste buds at the most anterior part of lower lip and jaw.

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1. Introduction:

The study of the cranial nerves is important because their distribution is correlated with the habits and habitats of animals and also because they show an evolutionary trend among animals of the same group (Hussein, 2010 and Mattar, 2012). The cranial nerves connect the brain with all the important centers of perception of the outer surface of the head, as well as the inner surface of the buccopharyngeal and other visceral regions, so that they seem to be important in determining the animal's behavior (Shaheen, 1987).

From the early works done on the cranial nerves of bony fishes are those that carried on the morphology and structure of the cranial nerves in the genus *Acipenser* and *Pleuronectes* were done by Johnston (1898) and Cole and Johnston (1901), respectively. Although these studies are classical, yet they are still useful to the investigators. The most valuable works from these early ones were that carried out by Allis (1897, 1903, 1909& 1922) and Herrick (1899&1901).

Several authors published their works on the cranial nerves of bony fishes. These works include the studies of Northcutt and Bemis (1993), Piotrowski and Northcutt (1996) and Dakrory (2000) on *Latimeria chalumnae*, *Polypterus senegalus* and *Ctenopharyngodon idellus,* respectively. The most recent works are those of Hussein (2010) on Mugil cephalus and Matter (2012) on *Gammbosia affinis affins.*

It is quite evident from the above historical review that there are numerous works on the cranial nerves of fishes, but few studies has been made concerning the cranial nerves of cichlid fishes which is an interesting group among teleosts. Although the previously mentioned studies of different authors may threw light on the subject of the cranial nerves of fishes, yet it cannot be stated that the cranial nerves of a cichlid is similar to other fishes; and what are the differences if present? Thus it was suggested that a detailed microscopic study on the nervus trigeminus in a cichlid species will be very useful.

The main and fine branches of this nerve, its distribution, its relation with each other and with the other structures of the head, analysis and the organs they innervate are studied thoroughly, hoping that it may add some knowledge on this important subject and also to the behaviour and phylogeny of this group of fishes.

2. Materials and Methods

Tilapia zillii is a diurnal fish inhabiting shallow areas with vegetation. It feeds on aquatic weeds and epiphytic diatoms. It is an economically important fish as a source of proteins. It is not a water breader and builds nests for egg incubation.

The fully formed larvae of this species were collected from a Nile tributary near Abu-Rawash. The heads of the fully formed larvae were fixed in aqueous Bouin for 24 hours. After washing several days with 70% alcohol, the heads were decalcified by placing the heads in EDTA solution for four weeks with changing the solution every four days. Therafter the specimens stained with Borax carmine in *toto* according to Grenacher's Borax carmine method (Galigher and Kozloff, 1964) which is highly satisfactory for nerve cells and fibres.

The heads were sectioned transversely (10 microns in thickness), after embedding in paraffin. The serial sections were counter stained in picroindigo carmine. The serial sections were drawn with the help of the projector. From these sections, an accurate graphic reconstructions for the eye muscle nerves was made in a lateral views. In order to show the position of the nerves, and their relations to the other different structures of the head, several serial sections are photomicrographed.

3. Results

In the present study, the nervus trigeminus originates from the ventrolateral side of the anterior part of the medulla oblongata by means of one stout root (Figs. 1 & 2, RO.V). This root runs forwards in a venterolateral direction, passing lateral to the brain (B) dorsal to the nervus facialis (N.VII) and the anteroventral lateral line nerve (N. AVLL), medial to the anterodorsal lateral line nerve and the inner ear (ASC) and ventral to the brain and the nervus trochlearis. Opposite to the origin of the nervus oculomotorius from the brain, the nervus trigeminus gives off a nerve from its dorsomedial side, which is the nervus profundus (Fig. 1, N. PRF). This nerve will be described shortly later.

The main nervus trigeminus continues anteriorly passing between the ganglion of the anteroventral lateral line nerve medially and the inner ear and the anterodorsal lateral line nerve laterally. Thereafter, it leaves the cranial cavity by piercing the meninx primitiva through the prootic foramen (Figs. 3 & 4, PRO. F), together with the rami buccalis and the ophthalmicus superficialis lateralis. This foramen lies just medial to the anterior end of the auditory capsule and lateral to the prootic bone (basiotic lamina). It is separated from the foramen of the nervus facialis by a bony strut. Directly outside the cranial cavity, the nervus trigeminus enters the Gasserian ganglion (Figs. 1 & 4, G. GS). This ganglion receives also a large branch of the anterodorsal lateral line nerve. The Gasserian ganglion is oval in shape and lies totally outside the cranial cavity in the postorbital region, medial to the floor of the auditory capsule, lateral to the internal jugular vein and ventral to the prootic bone and prootic foramen. Anteriorly, the Gasserian ganglion (Figs. 1, 5 & 6, G. GS) gives off the ramus ophthalmicus superficialis (Figs. 1, 5 & 6, R.OS.V) dorsally and the maxillomandibular trunk ventrally (Figs. 1, 5 & 6, MM. T). Just posterolateral to the origin of the ramus ophthalmicus, the Gasserian ganglion gives off a dorsal branch which is the ramus oticus of the anterodorsal lateral line nerve.

Nervus Profundus

The nervus profundus arises from the nervus trigeminus posterior to its enterence the Gasserian ganglion (Figs. 1 &5, N. PRF). It extends anterodorsally within the cranial cavity till it enters its owen ganglion; the profundal ganglion (Figs. 1&5, G. PRF). From the anterior end of this ganglion, it emerges again and runs forwards within the cranial cavity for a short distance. Thereafter, it leaves the cranial cavity throught its owen foramen and gives off a ventral branch which is the radix ciliaris longa (Fig. 1, RD. CL). The radix ciliaris longa extendes anteromedially to fuse with the cranial sympathetic nerve forming the common root of the ciliary ganglion.

The main nervus profundus extends anteriorly for a long distance as the main truncus ciliaris, where it enters the eyeball through a foramen in the dorsomedial side of the sclera and ends in the ciliary body within the eyeball (Fig. 1, T. CIL).

The Constrictor Dorsalis Nerve (NV$_4$)

This nerve (Fig. 1, N. CD) is a purely motor nerve which arises from the most posterolateral side of the Gasserian ganglion. Immediately after its origin, it runs posterolaterally passing ventral to the hyomandibular cartilage. After a short distance, this nerve divides into dorsal and ventral branches. The dorsal branch continues posteriorly running lateral to the hyomandibular cartilage and medial to the levator arcus palatini muscle. After a short course, it enters the latter muscle from its medial side where it ends between its fibres (Fig. 1, N. LAP). The ventral branch enters directly the dilator opercularis muscle to innervate its fibres (Fig. 1, N. DO).

Ramus Ophthalmicus Superficialis Trigeminus

It arises from the anterior extremity of the Gasserian ganglion (Figs. 1, 5 & 6, R.OS.V) together with the ramus ophthalmicus superficialis lateralis and runs forwards in a dorsal direction passing dorsal to the eyeball and ventral to supraorbital cartilage (Fig. 1, R. OS.V + OS. L). Here, it gives off a lateral branch, which divids into two successive nerves; one ramifies in the skin around the supraorbital lateral line canal (Fig. 1, N.CU) and the other ends in the eighth neuromast of the supraorbital lateral line canal (Fig. 1, N. NSOC. 8). Thereafter, the main ramus runs forward giving off a lateral branch which ends in the seventh neuromast of the same canal (Fig. 1, N. NSOC. 7). The main ramus ophthalmicus superficialis continues forwards giving rise to fine branches to the skin in this region (Fig. 1, Nn. CU). In the mid-orbital region it gives off two successive fine branches to the sixth and fifth neuromasts of the supraorbital canal (Fig. 1, N. NSOC. 6 & N. NSOC. 5). Thereafter, it continues forwards in this region and gives off a branch for the fourth neuromast (Fig. 1, N. NSOC. 4) then it gives many fine nerves for the skin (Nn. CU). Reaching the antorbital region, the main ramus runs forwards passing dorsal to the oblique superior muscle, lateral to the taenia marginalis posterior and ventral to supraorbital lateral line canal. Thereafter, it extends more forwards running lateral to the sphenoseptal commissure, then dorsal to it till it enters the olfactory region.In this region, it passes through a small depression in the dorsal edge of sphenoseptal commissure which connects the taenia marginalis anterior and internasal septum. Through this course it gives off fine nerves to the skin (Fig. 1, Nn. CU).

In the olfactory region, the main ramus runs medial to taenia marginalis anterior and ventral to supraorbital lateral line canal (Fig. 8, R.OS.V+ OS. L), where it gives rise to a small branch which innervates the skin covering the taenia marginalis anterior dorsally (Fig. 1, N. CU). Anterior to this branch, the ramus continues forward passing dorsomedial to the olfactory organ and ventral to the supraorbital lateral line canal were it gives off a branch for the third neuromast of the same canal (Fig. 1, N. NSOC. 3). More forwards, the ramus ophthalmicus superficialis trigeminus extends ventral to both the nasal bone and supraorbital lateral line canal and dorsal to the olfactory epithelium. At this position, it gives rise to a fine branch to the skin covering the head dorsally (Fig. 1, N. CU) and also gives of fine branches to the first and second neuromasts (Fig. 1, N. NSOC. 2 & N. NSOC.1). Finally, the ramus ophthalmicus superficialis ends as many fine nerves in the skin covering the snout and the upper lip dorsally and laterally (Fig. 1).

Ramus Maxillaris

The ramus maxillaris arises from the ventral side of Gasserian ganglion together with the ramus mandibularis, as one trunk (the maxillo-mandibular trunk) (Figs. 1, 3 & 4, MM.T). This trunk runs anteriorly in a ventral direction (Figs. 5 & 6, MM.T) passing between the eyeball laterally and the adductor hyomandibularis muscle medially. After short distance, the maxillo-mandibular trunk separates into its rami, maxillaris and mandibularis (Figs. 1 & 9, R.MX & R.MD.V). Directly after its separation from the ramus mandibularis, the ramus maxillaris (Fig. 1, R.MX) extends forwards passing dorsal to the ramus mandibularis and dorsolateral to the adductor hyomandibularis muscle. Thereafter, it becomes dorsal to the adductor arcus palatini muscle and dorsomedial to the ramus mandibularis. Then, it continues anteriorly for a long distance passing ventral to the eyeball, lateral to the ramus mandibularis, dorsolateral to the adductor arcus palatini muscle and ventrolateral to the rectus inferior muscle. Here, it anastomoses with a branch of the ramus buccalis (Fig. 1, R.CM.BU + MX). Reaching the mid way of the orbital region, the ramus maxillaris gives off a lateral branch which immediately divides into dorsal and ventral nerves (Fig. 1). Shortly anterior, the ventral nerve ramifies and ends in the skin lateral to the adductor mandibularis muscle (Fig. 1, N.CU). The dorsal nerve runs for a long distance passing lateral to the main ramus maxillaris and ventral to the eyeball and the obliquus inferior muscle. Thereafter, the dorsal nerve divides into two fine nerves one lateral to the other. These two fine nerves fuse again with the two divisions of the ramus maxillaris (Fig. 1). Anterior to the origin of the previously described branch, the main ramus maxillaris gives off a venterolateral branch. This branch runs in a ventral direction passing dorsomedial to the adductor mandibularis muscle and dorsolateral to the palatoquadrate cartilage. Shortly anterior, the branch gives off two fine nerves one from its dorsal and the other from its ventral side. Thereafter, these nerves (the main branch and its dorsal and ventral fine nerves) run together in a ventral direction passing lateral to the palatoquadrate cartilage and dorsomedial to the adductor mandibularis muscle. Reaching the anterior orbital region, the dorsal fine nerve runs dorsally and fuses with the main ramus maxillaris. The ventral fine nerve extends anteriorly passing lateral to the main branch and becomes ventral to the lacrimal sac. Finally, it ramifies and innervates the connective tissue and the epithelial lining the roof of the mouth and the taste buds in the mouth roof angles (Fig. 1, N. TB). In the anterior orbital region, the main branch runs laterally passing ventral to the lacrimal sac. Entering the olfactory region (Fig. 1), this branch runs forward passing ventral to the lacrimal sac and dorsolateral to the buccal cavity. After a long anterior course, this branch reaches the ethmoidal region where it divides into three nerves. One of these nerves anastomoses with the ramus palatinus of the nervus facialis (Figs.1 & 13, R.CM.MX+P) and then ends in the palatalepithelium of the roof of the mouth in the ethmoidal region (Fig. 1, N. PE). The other two nerves end in the mucous epithelium of the roof of the mouth, where they ramify and innervate the epithelium and taste buds of the lateral and anterior parts of the palate (Fig. 1, N. PE). Anterior to the origin of the previously described branch the main ramus maxillaris divides into dorsal and ventral divisions. Shortly forwards, the ventral division of the main ramus maxillaris fuses with the median fine nerve as previously mentioned while the dorsal division of ramus maxillaris fuses with the lateral fine nerve. In the antorbital region, the dorsal division runs venterolaterally passing dorsal to the caudal portion of the lacrimal sac and ventral to the eyeball. Here, it gives rise to three fine nerves that continue together venterolaterally passing dorsolateral to the lacrimal sac and dorsomedial to the infraorbital lateral line canal. These nerves extend dorsal to the infraorbital lateral line canal and ramify to innervate the tissues surrounding this canal and the skin (Fig. 1, Nn. CU).

The ventral division (Fig. 1, R. MX) runs dorsally extending dorsal to both the lacrimal sac (LC. S) and olfactory organ, lateral to the olfactory epithelium and medial to the lamina orbitonasalis. In this region, it continues dorsally passing between the supraorbital lateral line canal laterally and internasal septum medially. Finally, it ends as many fine branches in the skin of the dorsal extremity of the snout (Fig.1, Nn. CU)

Ramus Mandibularis

After its separation from the maxillo-mandibular trunk, the ramus mandibularis (Figs. 1 & 9, R.MD.V) extends anteriorly passing ventrolateral to the ramus maxillaris, dorsolateral to the adductor hyomandibularis muscle, dorsomedial to the adductor mandibularis muscle and ventromedial to the eyeball. It continues its forwards course passing dorsal and then dorsolateral to the adductor arcus palatine muscle, venterolateral to the ramus maxillaris, ventromedial to the eyeball and dorsomedial to the adductor mandibularis muscle. Thereafter, it passes ventral to the eyeball, venterolateral to the ramus maxillaris and dorsal to the adductor arcus palatine muscle. Here, it gives off two successive branches. The first branch enters the external division of adductor mandibularis muscles and ends between its fibres and the second innervates the internal division of the adductor mandibularis muscle (Fig. 1, Nn.AMM). Anterior to the origin of the previously mentioned branches the ramus mandibularis continues forwards passing dorsomedial to the adductor mandibularis muscle, dorsolateral to the adductor arcus platini muscle, lateral to the ramus maxillaris and ventral to the eyeball. After a long forward course, the ramus mandibularis shifts ventrally passing between the external division of the adductor mandibularis muscle laterally, the internal division of the same muscle ventrally and both the palatoquadrate cartilage and the adductor arcus palatini muscle medially. The ramus mandibularis continues ventrally in a forward direction till it reaches the anterior orbital region.

In the anterior orbital region, the ramus mandibularis extends ventromedial to the external division of the adductor mandibulais muscle and lateral to the palatoquadrate cartilage. Here, the ramus mansibularis gives off a sensory branch for the skin covering the latter muscle laterally and ventrally (Fig.1, N. CU). Shortly anterior, the ramus mandibularis gives off a small nerve which enters directly the external division of the adductor mandibularis muscle (Fig. 1, N. AMM). Anterior to the origin of the latter motor branch, the ramus mandibularis extends ventral to the adductor mandibularis muscle (external division) and lateral to the pharyngeal cavity. Reaching the orbitonasal region, the ramus mandibularis divides into two rami; ramus mandibularis trigeminus internus dorsally and ramus mandibularis trigeminus externus ventrally (Figs. 1&14, R. MDI.V &R. MDE. V).

Ramus Mandibularis Internus

The ramus mandibularis internus (Figs. 1 & 14, R. MDI.V) runs forwards for considerable distance passing lateral to the external division of the adductor mandibularis muscle and the pharyngeal cavity and medial to the preopercular bone. Thereafter, it continues extending dorsal to Meckel's cartilage and ventral to suprangular bone. Reaching the level of the ethmoidal region, this ramus gives off three successive branches (Fig, 1). Shortly forwards, these branches run lateral to intermandibularis anterior muscle and dorsal to the dentary bone. Here, one of these branches ramifies to innervate the teeth and the surrounding connective tissues (Fig. 1, N. TE). The second branch runs ventrally and ends in the mandibular lateral line canal. More forwards, the third branch ramifies in the anterior tip of the lower jaw and innervates the teeth and the connectie tissues of the lower jaw (Fig. 1, N. TE). The main ramus runs for a considerable distance passing lateral to the dentary bone and medial to the labial cartilage. After a short course in this position, it ramifies into several fine nerves which innervate the skin, epithelial tissues and taste buds of the lateral tip of lower jaw (Fig. 1, N.CU+TB).

Ramus Mandibularis Externus

The ramus mandibularis externus (Figs. 1 & 14, R.MDE.V) extends forwards running ventral to the ramus manibularis internus, lateral to the external division of the adductor mandibularis muscle and medial to the opercular bone. After a long course in this position, it becomes lateral, ventrolateral and then ventral to Meckel's cartilage. Here, it is connected with the ramus mandibularis facialis by a fine communicating branch (Figs. 1 & 16, R.CM.MD.VII + MDE.V). Thereafter, this ramus fuses with the ramus mandibularis of the nervus facialis forming a common nerve (Fig. 1, CO.N). Anterior to this fusion, the common nerve divides into medial and lateral branches. The median branch runs ventromedially giving off a posterior nerve (Figs. 1 & 15, N.IMP) to the intermandibularis posterior muscle. Then, it passes dorsomedially giving rise to a ventral fine nerve that ramifies in the skin and tissues in the ventral side of the lower jaw. The remainder of the medial branch ramifies and ends in the intermandibularis anterior muscle (Fig. 1, N.IMA). The lateral branch runs anteriorly passing dorsal to the adductor mandibularis muscle, medial to the dentary bone and ventral to the intermandibularis anterior muscle. Shortly after that, it ramifies into several fine branches and innervates the skin (Fig.1, N. CU) and the taste buds at the most anterior part of lower lip, and the skin and tissues lateral to the dentary bone.

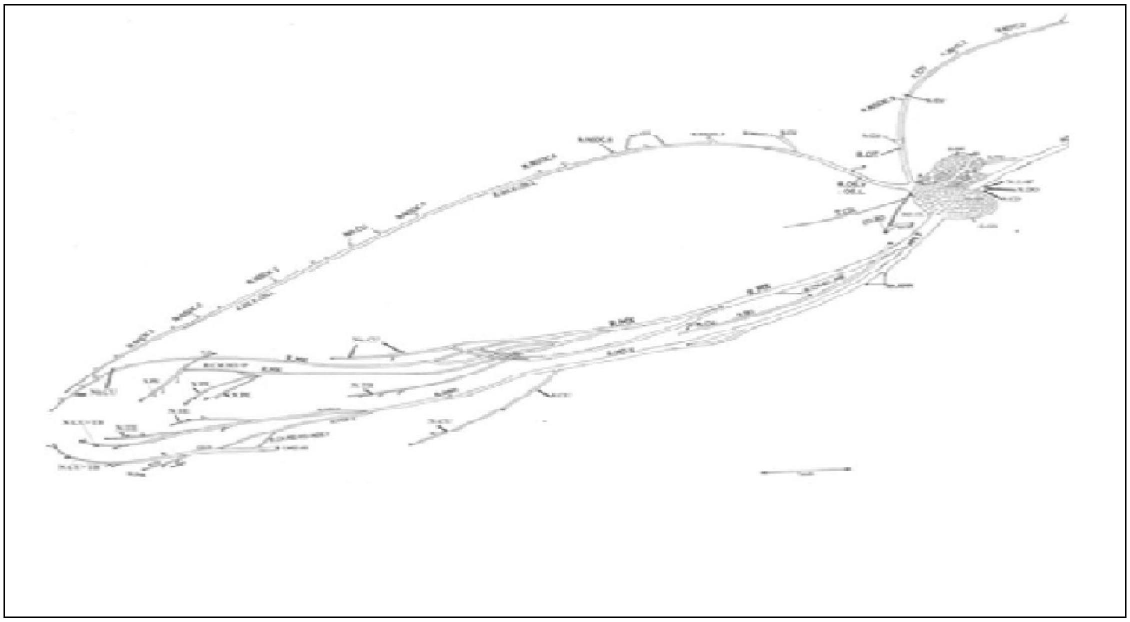
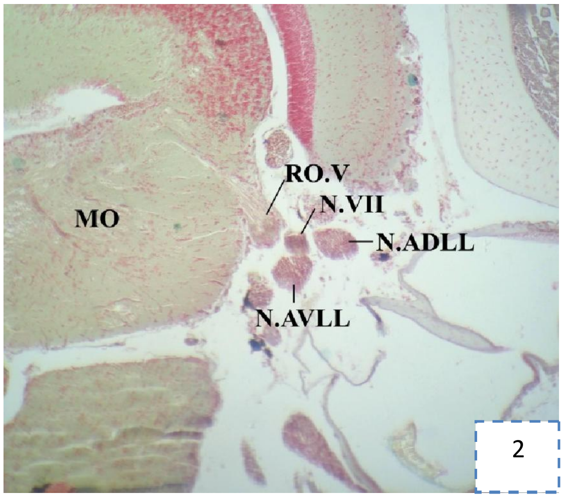


Fig. 1: Graphic reconstruction of the nervus trigeminus of *Tilapia zillii* in a lateral view.



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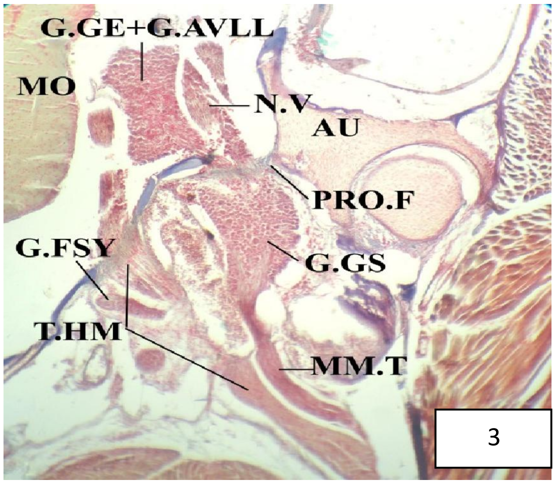

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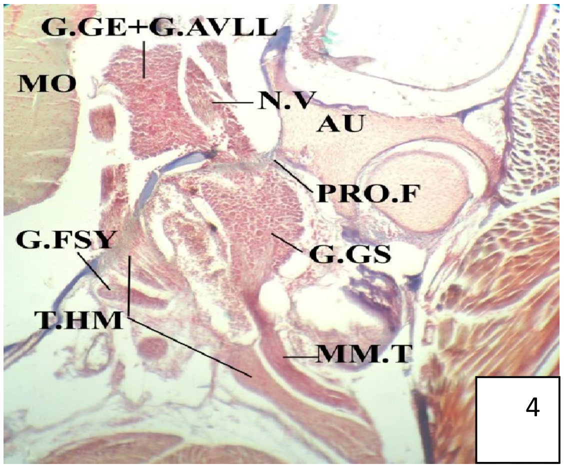
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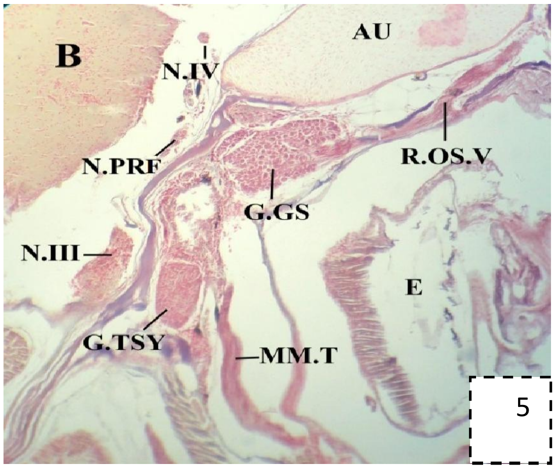
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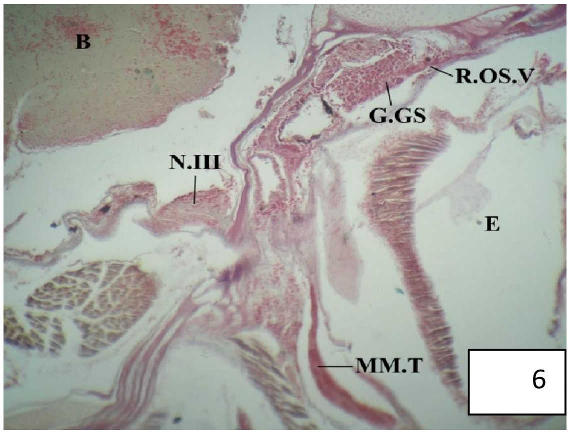
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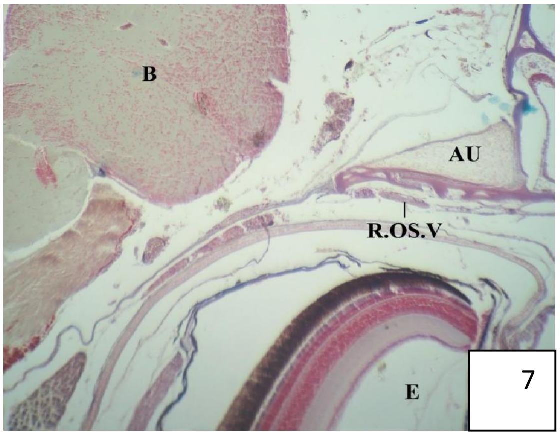
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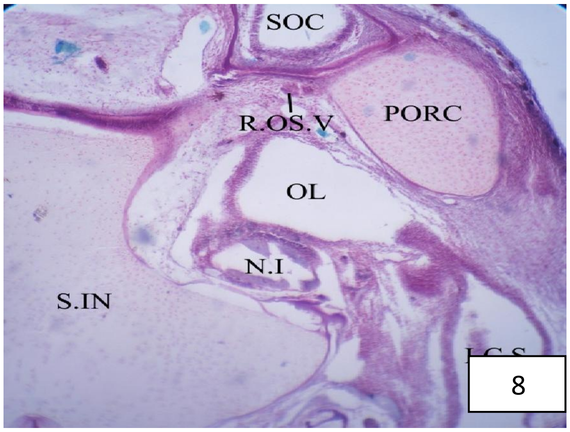
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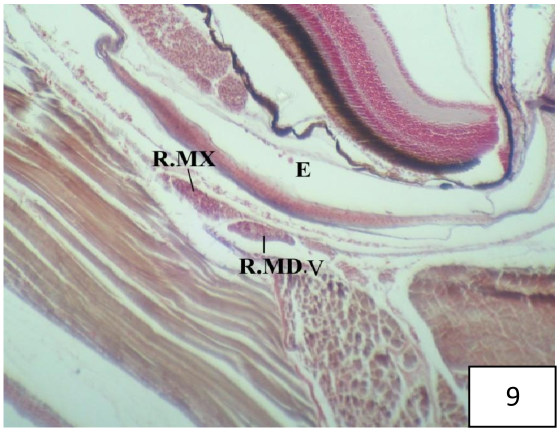
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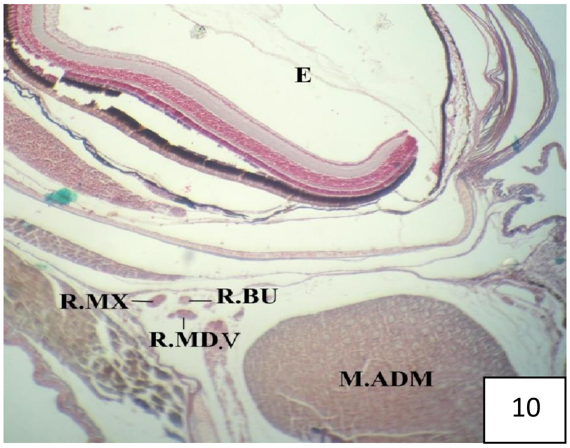

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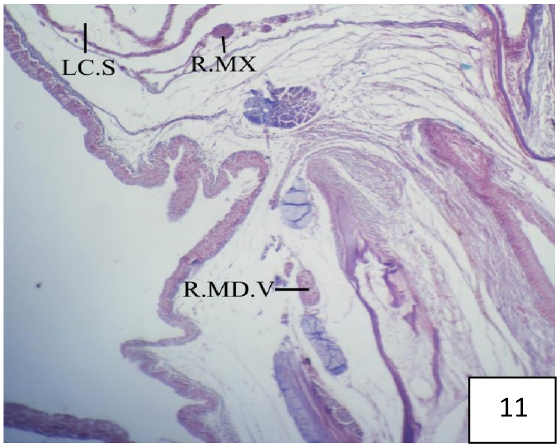

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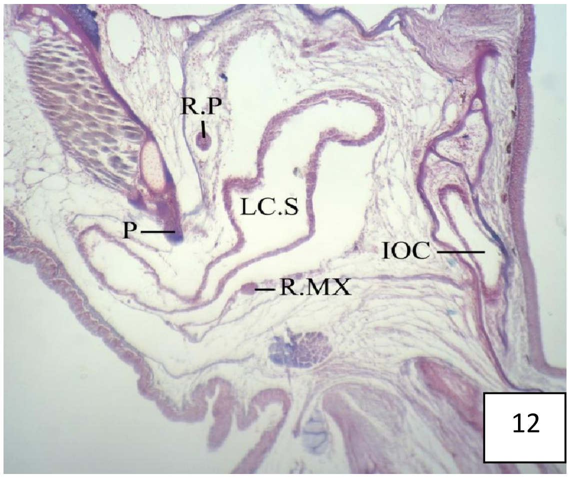

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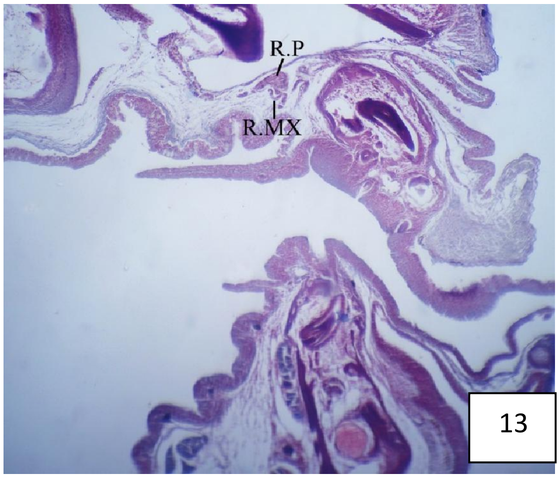

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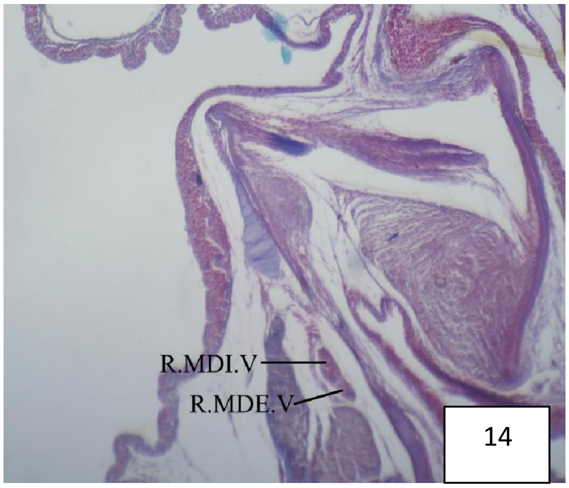

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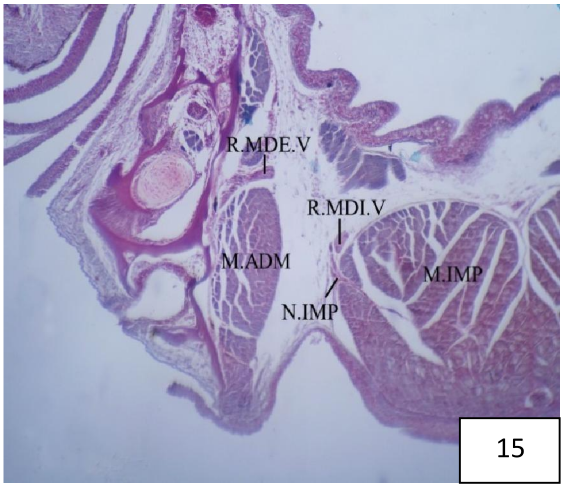

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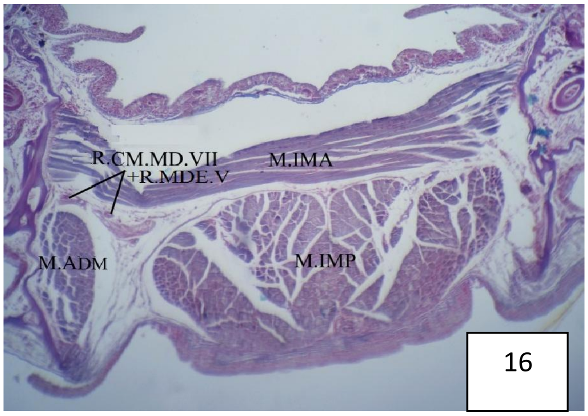

Fig. 2: Part of transverse section passing through the otic region showing the origin of the nervus trigeminus.

Fig. 3: Part of transverse section passing through the otic region illustrating the prootic foramen, gasserian ganglion and the maxillomandibular trunk.

Fig. 4: Part of transverse section passing through the otic region demonstrating the prootic foramen, gasserian ganglion, the maxillomandibular trunk and the profundal nerve.

Fig. 5: Part of transverse section passing through the postorbital region elucidating the profundal nerve, the ramus ophthalmicus superfacialis trigeminus.

Fig. 6: Part of transverse section passing through the postorbital region demonstrating the ramus ophthalmicus superfacialis trigeminus, gasserian ganglion and the maxillmandibular trunk.

Fig. 7: Part of transverse section passing through the orbital region showing the ramus ophthalmicus superfacialis trigeminus

Fig. 8: Part of transverse section passing through the olfactory region showing the ramus ophthalmicus superfacialis trigeminus.

Fig. 9: Part of transverse section passing through the orbital region illustrating the rami maxillaris and mandibularis.

Fig. 10: Part of transverse section passing through the orbital region elucidating the ramus maxillaris.

Fig. 11: Part of transverse section passing through the olfactory region demonstrating the position of the rami maxillaris and mandibularis of the nervus trigeminus.

Fig. 12: Part of transverse section passing through the olfactory region showing the ramus maxillaris of the nervus trigeminus.

Fig. 13: Part of transverse section passing through the olfactory region illustrating the anastomosis between the ramus maxillaris of the nervus trigeminus and the ramus palatinus of the nervus facialis.

Fig. 14: Part of transverse section passing through the orbital region elucidating the division of the ramus mandibularis of the nervus trigeminus into its interal and external rami.

Fig. 15: Part of transverse section passing through the olfactory region demonstrating the position of the rami mandibulares internal and external of the nervus trigeminus.

Fig. 16: Part of transverse section passing through the olfactory region showing the postion of the ramus mandibularis externus of the nervus trigeminus and the ramus mandibularis of the nervus facialis just before fusion.

4. Discussion

In the species under investigation, the nervus trigeminus issues from the medulla oblongata by only one root. This is the case found in *Menidia* (Herrick, 1899), *Pleuronectes* (Cole and Johnstone, 1901), *Scomber scomber* and *Scorpaena scrofa* (Allis, 1903&1909, respectively), *Cyclothone acclinidens* (Gierse, 1904), *Lampanyctus leucopsarus* (Ray, 1950), *Mastacembelus armatus* (Bhargava, 1959), *Carassius auratus* (Puzdrowski, 1988), *Ctenopharyngodon idellus* (Dakrory, 2000), *Mugil cephalus* (Hussien, 2010) and in *Gambusia affinis affinis* (Mattar, 2012).

A single trigeminal root, is separated from the profundus one, was recorded in *Polypterus senegalus* (Allis, 1922; El-Toubi and Abdel-Aziz, 1955) and in *Latimeria chalumnae* (Northcutt *et al*., 1978). In *Polycentrus schomburgkii*, Freihofer (1978) stated that the trigeminal and profundus roots are closely associated, but they are separate at the brain. The nervus trigeminus arises by two separate roots in *Tetrodon oblongus* (Bal, 1937), *Acipenser oxyrhynchus* and *Scaphirhynchus platorynchus* (New and Northcutt, 1984). In *Polypterus senegalus*, Piotrowski and Northcutt (1996) described a sensory root and a motor one entering the brain separately for the nervus trigeminus.

The nervi trigeminus and facialis in many fishes arise in close association, and their ganglia are so close that they form together a structure called trigemino-facial complex. The number of roots for this complex is variable among fishes. A single root for the trigemino-facial complex was mentioned in *Silurus glanis* (Juge, 1899), *Parasilurus asotus* (Atoda, 1936), *Mystus seenghala* (Mithel, 1964a) and in *Clarias batrachus* (Dalela and Jain, 1968). There are two roots for the complex in *Amia calva* (Allis, 1897) and *Scomber scomber* (Allis, 1903), *Lampanyctus leucopsarus* (Ray, 1950), *Wallago attu* (Sinha, 1964), *Mastacembelus armatus* (Maheswari, 1965), *Amphipnous cuchia* (Saxena, 1967) and in *Trichiurus lepturus* (Harrison, 1981). In *Cyclothone acclinidens,* however, Gierse (1904) described two roots for the complex, the posterior one of which represents the facial and octaval root. In *Bagarius bagarius*, Mithel (1964b) stated that the trigeminal and facial nerves have four roots; two ventral for the hyomandibular trunk and two dorsal for the intracranial trigemino-facial complex. The same arrangement was observed in *Tetrodon oblongus* (Bal, 1937). Five roots, the most anterior of which being the trigeminal root while the remaining four are all assigned to be facialis, are described for the trigemino-facial complex in *Scorpaena scrofa* (Allis, 1909). This agrees with the finding of Herrick (1899) in *Menidia*. Freihofer (1978) described six roots; two trigeminal and four facial-lateralis in *Polycentrus schomburgkii*.

In *Argyropelecus hemigymnus*, on the other hand, Handrick (1901) found that all the roots of the trigemino-facial-acoustic complex were completely fused.

Among cartilaginous fishes, a single trigeminal root was observed in *Pteroplatea altavela* (Mazhar, 1979). Two trigeminal roots were recorded in *Squalus acanthias* (Norris and Hughes, 1920). However, the nervus trigeminus originates from the medulla oblongata by means of a large root and three small rootlets in *Chimaera monstrosa* (Cole, 1896), *Squalus acanthias* (Landacre, 1916), *Mustelus californicus* (Norris and Hughes, 1920), and in *Rhinobatus halavi* (Dakrory, 2000).

In Agnatha, Kuratani *et al.* (1997) described separate profundus and maxillo-mandibular nerves arising from the hindbrain by means of separate roots in the larval stages of *Lampetra japonica*. In the hagfishes, *Eptatretus stoutii* and *Myxine glutinosa* (Braun, 1998), there is a single preotic nerve complex composed of five ganglia and rami for the trigeminal nerve. Braun and Northcutt (1997) found that, in *Eptatretus stoutii* and *Myxine glutinosa*, the nervus trigeminus is closely associated with the nervus lateralis and its ganglion.

Among Amphibia, the nervus trigeminus arises by a single root in *Bufo viridis* (Soliman and Mostafa, 1984 a & b) and in *Bufo regularis* (Shaheen, 1987). In some amphibians, the nervus trigeminus arises by more than one root as stated by Herrick (1894) in *Amblystoma punctatum* and Norris (1908) in *Amphiuma means*.

In *Tilapia zillii*, the nervus trigeminus passes outside the cranial cavity through the prootic foramen together with the anterodorsal lateral line nerve.The relation of the rami of the nervus trigeminus and the other cranial nerves and their exits from the cranial cavity shows a great variation in bony fishes. A separate trigeminal foramen was recorded in *Lampanyctus leucopsarus* (Ray, 1950), *Hepsetus odöe* (Bertmar, 1959) and in *Polypterus senegalus* (Piotrowski and Northcutt, 1996). In the latter species, the foramen is located in the orbitosphenoid bone. A common trigemino-facial foramen, which is situated in the prootic bone, was found in *Anchoa compressa* and *Aplochiton zebra* (Chapman, 1944 a & b). On the other hand, Nawar (1954) described a gap found anterior to the prootic bone for the emergence of the oculomotor, trochlear and abducens nerves, together with the trigemino-facial complex.

In some teleosts, like *Syngnathus* (Kindred, 1921 & 1924), *Anguilla vulgaris* (Norman, 1926), *Salmo trutta* and *Amia calva* (de Beer, 1926 & 1937), *Gambusia* (Ramaswami, 1945) and *Tilapia nilotica* (Abdel-Aziz, 1959) a trigemino-facial chamber with a ventrolateral boundary formed by the lateral commissure, is found giving exit for the nervi trigeminus and facialis.

Among Amphibia, the nervus trigeminus leaves the cranial cavity together with the nervus facialis through the prootic foramen in *Bufo viridis* (Soliman and Mostafa, 1984a & b), *Bufo regularis* (Shaheen, 1987), *Xenopus laevis* (Trueb and Hanken, 1992) and in *Leptodactylus larva* (Larson and De Sá, 1998). These findings agree with those of Haller von Hallerstein (1934), Hall and Larson (1998) and Sheil (1999). A prootic foramen for the emergence of the nervi trigeminus, abducens and facialis, as well as anuran equivalent long ciliary nerve was described by Sokol (1975, 1977 & 1981) in *Bombina orientaus, Pipa cavalhoi* and *Pelodytes punctatus*, respectively. This is also the case found in *Dendrobates tinctorius* and *Epipedobatus anthonyi* by Haas (1995). However, in *Ascaphus truei*, Reiss (1997), described a prootic foramen for the exit of the nervi trigeminus and abducens as well as the anterodorsal lateral line nerve.

In this study, the trigeminal ganglion is represented by a separate profundal and Gasserian (maxillo-mandibular) ganglia. Similar conditions were observed in the bony fishes studied by Allis (1897, 1903, 1909 & 1922), in *Acipenser, Amia* and *Lepidosteus* (Norris, 1925), *Synodus lucioceps* and *Lampanyctus leucopsarus* (Ray, 1950), *Polypterus senegalus* (El-Toubi and Abdel-Aziz, 1955; Piotrowski and Northcutt, 1996), *Polycentrus schomburgkii* (Freihofer, 1978) *Acipenser oxyhynchus* and *Scaphirhynchus platorynchus* (New and Northcutt, 1984) and in *Latineria chalumnae* (Northcutt and Bemis, 1993). On the other hand, the trigeminal ganglion is represented by one mass; the Gasserian ganglion, there is no separate profundal ganglion were observed in *Protopterus annectens* (Pinkus, 1895), *Ameiurus* (Workman, 1900), *Parasilurus asotus* (Atoda, 1936), *Clarias batrachus* (Dalela and Jain, 1968) and in *Trichiurus lepturus* (Harrison, 1981).

In the jawless fishes, the trigeminal and profundal root and ganglia are fused, *i.e.*, there is a single trigminal "Gasserian ganglion". This was mentioned in *Petromyzon* (Johnston, 1905), *Eptatretus stoutii* and *Bedellostoma domberyi* (Worthington, 1906) and in the adult *Lampetra japonica* (Koyama *et al*., 1987; Kuratani *et al*., 1997).

In Amphibia, the prootic or trigeminal ganglion is divided into two portions: a dorsal maxillo-mandibular part and a ventral ophthalmic one in *Bufo regularis* (Shaheen, 1987). On the other hand, there is one Gasserian ganglion in *Amblystoma tigrinum* (Coghill, 1902) and in *Bufo viridis* (Soliman and Mostafa, 1984a).

In *Tilapia zillii*, the Gasserian ganglion is located extracranially, whereas the profundal one lays intracranialy. This case appears to be common feature among bony fishes as mentioned by several authors (Allis, 1897; 1903 & 1909; Young, 1931; Ray, 1950; Freihofer, 1978). However, an extracranial Gasserian (maxillo-mandibular) ganglion as mentioned by many authors (Handrick, 1901; Sewertzoff, 1928; El-Toubi and Abdel-Aziz, 1955; Bhargava, 1959; Dalela and Jain, 1968; Dakrory, 2000). Both the Gasserian and the profundal ganglia were found to be extracranial in *Acipenser oxyrhynchus* and *Scaphirhynchus platorynchus* (New and Northcutt, 1984), *Polypterus senegalus* (Piotrowski and Northcutt, 1996) and in *Gambusia affinis affinis* (Mattar, 2012). The same was mentioned in the cartilaginoug species *Laemargus "Somniosus"* (Ewart, 1889) and *Squalus acanthias* (Norris and Hughes, 1920). In this respect, de Beer (1937) stated that the trigeminal ganglion is situated extracranially in Dipnoi, Amphibia and Reptilia. However, Soliman and Mostafa (1984a) described a Gasserian ganglion which is located in the prootic foramen with its large bulk situated within the cranial cavity in *Bufo viridis*. This is also the case found in *Bufo regularis* (Shaheen, 1987).

In this study, the ramus ophthalmicus superficialis trigeminus fuses completely with the ramus ophthalmicus superfacialis of the anterodorsal lateral line nerve. This was the case mentioned in *Carassius auratus* (Puzdrowski, 1988). However, the ramus ophthalmicus superficialis trigeminus and that of the nervus facialis fuse into a single trunk known as supraorbital trunk in *Menidia* (Herrick, 1899), *Scomber scomber* (Allis, 1903), *Parasilurus asotus* (Atoda, 1936), *Lampanyctus leucopsarus* (Ray, 1950) and *Amphipnous cuchia* (Saxena, 1967).

In *Tilapia zillii*, the rami maxillaris and mandibularis arise as a single trunk; the maxillo-mandibulr trunk. This is common among bony fishes (Herrick, 1899; El-Toubi and Abdel-Aziz, 1955; Sinha, 1964; Mithel, 1964 a, b; Maheswari, 1965; Saxena, 1967; Freihofer, 1978; Harrison, 1981; Puzdrowski, 1988; Piotrowski and Northcutt, 1996; Dakrory, 2000; Hussien, 2010; Mattar, 2012).

However, among cartilaginous fishes the rami maxillaris and mandibularis arise separately from the Gasserian ganglion in *Acipenser oxyrhynchus* and *Scaphirhynchus platorynchus* by New and Northcutt (1984) and in *Rhinobatus halavi* by Dakrory (2000).

In the present study, there is a connection between the ramus maxillaris of the nervus trigeminus and the ramus buccalis of the anterodorsal lateral line nerve. The condition is nearly similar to that observed in *Scomber scomber* and *Scorpaena scrofa* (Allis, 1903 & 1909), *Polycentrus schomburgkii* (Freihofer, 1978), *Polypterus senegalus* (Piotrowski and Northcutt, 1996), *Mugil cephalus* (Hussien, 2010) and in *Gambusia affinis affinis* (Mattar, 2012).

However, in *Ctenopharyngodon idellus* (Dakrory, 2000) the fibres of both rami, maxillaris and buccalis, arise together as a single common nerve from the infraorbital trunk. In *Lampanyctus leucopsarus* (Ray, 1950) and *Trichiurus lepturus* (Harrison, 1981), these rami run close together in the orbital region, then, they separate and run independently at the anteroventral end of the orbit. Among cartilaginous fishes, there are several connections between the rami maxillaris and buccalis in *Rhinobatus halavi* (Dakrory, 2000).

In the present study, the ramus maxillaris fuses with the ramus palatinus facialis in the ethmoidal region, the connection between the two rami appears to be common in bony fishes. It was described by Allis (1897) in *Amia*, Ray (1950) in *lampanyctus leucopsarus*, Freihofer (1978) in *Polycentrus schomburgkii*, Piotrowski and Northcutt (1996) in *Polypterus senegalus*, Dakrory (2000) in *Ctenopharyngodon idellus,* Hussien (2010) in *Mugil cephalus* and by Mattar (2012) in *Gambusia affinis affinis*. On the other hand, such connection is absent in *Menidia* (Herrick, 1899), *Argyropelecus hemigymnus* (Handrick, 1901), *Scomber scomber* and *Scorpaena scrofa* (Allis, 1903&1909 respectively) and in *Cyclothone acclinidens* (Gierse, 1904).

Among Amphibia, the connection between the ramus maxillaris of the nervus trigeminus and the ramus palatinus of the nervus facialis appears to be of wide occurrence (Swanepoel, 1970; Jurgens, 1971;

Soliman and Mostafa, 1984a& b; Shaheen, 1987; Roćek, 1993). However, such connection is absent in *Amblystoma punctatum* (Herrick, 1894).

In *Tilapia zillii*, the ramus maxillaris is not divided. The same case found in *Ctenopharyngodon idellus* (Dakrory, 2000). However, the ramus maxillaris is divided into two branches, maxillaris superior and maxillaris inferior in *Polycentrus schomburgkii* (Freihofer, 1978). In addition to the main ramus maxillaris, an accessory maxillary branch was mentioned by Herrick (1901) and Atoda (1936) in *Amiurus* and *Parasilurus asotus*, respectively. In *Polypterus senegalus*, Piotrowski and Northcutt (1996) described, in addition to the maxillary branches to the teeth, a nerve arising from the Gasserian ganglion to the teeth also.

In the present work, the ramus maxillaris carries somatic sensory fibres only, like in most bony fishes. On the other hand, in few bony species, in addition to the somatic sensory fibres for the teeth and skin, the ramus maxillaris carries visceral motor fibres for the adductor mandibularis muscles. Although such condition is very rare, it has been recorded in *Menidia* by Herrick (1899), in *Polypterus senegalus* by Piotrowski and Northcutt (1996) and in *Ctenopharyngodon idellus* by Dakrory (2000).

In the present study, there is a single constrictor dorsalis nerve arising from the Gasserian ganglion and innervates the levator arcus palatini and the dilator opercularis muscles. The same result is recorded in *Mugil cephalus* (Hussien, 2010) and in *Gambusia affinis affinis* (Mattar, 2012). Edgeworth (1935) stated that, the branch (constrictor dorsalis nerve) which innervates the levator arcus palatini and the dilator opercularis muscles arises from the Gasserian ganglion or from the maxillo-mandibular trunk. Such nerve was referred to as the ramus opercularis trigemini by Ray (1950) and Freihofer (1978). In this respect, the constrictor dorsalis nerve arises from the infraorbital trunk in *Parasilurus asotus* (Atoda, 1936), *Lampanyctus leucopsarus* (Ray, 1950), *Trichiurus lepturus* (Harrison, 1981) and in *Ctenopharyngodon idellus* (Dakrory, 2000). However, this nerve arises from the ramus mandibularis in *Polycentrus schomburgkii* (Freihofer, 1978). On the other hand, Piotrowski and Northcutt (1996) stated that the fibres innervating the levator arcualis palatinus muscle in *Polypterus senegalus* arise directly from the Gasserian ganglion, but they mentioned nothing about the innervation of the dilator opercularis and the spiracularis muscles.

In *Tilapia zillii*, the adductor mandibularis muscles receive their innervation from the ramus mandibularis trigeminus only. In *Lampanyctus leucopsarus* (Ray, 1950) and *Polycentrus schomburgkii* (Freihofer, 1978), there are three nerves arising from the ramus mandibularis, a case recommended by Harrison (1981) in *Trichurus lepturus*. On the other hand, Piotrowski and Northcutt (1996) mentioned that, the adductor mandibularis muscles in *Polypterus senegalus* receive their innervation through branches arising from the Gasserian ganglion, ramus maxillaris and ramus mandibularis trigeminus. However, in *Ctenopharyngodon idellus* (Dakrory, 2000), the adductor mandibularis muscles receive their innervation from the rami maxillaris and mandibularis trigemini.

In this study, the intermandibularis muscle is divided into anterior and posterior muscles. Both muscles are innervated by the ramus mandibularis trigeminus after its connection with the ramus mandibularis externus of the nervus facialis. The posterior intermandibularis muscle is also innervated from the ramus hyoideus of the nervus facialis. This was also the case observed in *Menidia* (Herrick, 1899), *Polycentrus schomburgkii* (Freihofer, 1978) and in *Polypterus senegalus* (Piotrowski and Northcutt, 1996). In *Lampanyctus leucopsarus* (Ray, 1950), however, the intermandibularis muscle is single and is innervated by the nervus facialis. In Dipnoi, on the other hand, Edgeworth (1935) stated that the intermandibularis muscle is innervated from an anastomosis between the nervi trigeminus and facialis.

Among cartilaginous fishes, in *Rhinobatidae* and *Rajiidae*, Edgeworth (1935) stated that the anterior intermandibularis muscle is innervated by the ramus mandibularis trigeminus whereas the posterior one receives double innervation from both the ramus mandibularis trigemini and the nervus facialis. This latter author added that this muscle is single in *Trygon* and is either single or double in Holocephali and is/are innervated by the ramus mandibularis of the nervus trigeminus. He also recorded that, in sharks, there is a single intermandibularis muscle, which is innervated by the nervus trigeminus, but in *Hexanchus* and *Chlamydoselachus*, if present, it is innervated by the nervus facialis. In *Mustelus canis*, Song and Boord (1993) recorded a distal branch from the nervus trigeminus for this muscle.

Among Amphibia, the intermandibularis muscle is innervated by the ramus mandibularis of the nervus trigeminus in the larva and adult of *Amblystoma punctatum* (Piatt, 1938). The same was found by Strong (1895), Norris (1913), Norris and Hughes (1918) and by Francis (1934) in Apoda and by Soliman and Mostafa (1984 b) and Shaheen (1987) in Anura. On the other hand, Paterson (1939), dealing with *Xenopus laevis*, mentioned that the intermandibularis muscle is innervated by the ramus hyomandibularis of the nervus facialis.

The innervation of the geniohyoideus muscle by the ramus mandibularis of the nervus trigeminus, a case which is not observed in *Tilapia zillii*, was noted by Allis (1897& 1903) in *Amia calva* and *Scomber scomber*, respectively.

In the present study, there is a connection between the rami mandibularis trigeminus and facialis. Such connection was noted in Menidia (Herrick, 1899), *Lampanyctus leucopsarus* (Ray, 1950), *Mastacembelus armatus* (Maheswari, 1965), *Amphipnous cuchia* (Saxena, 1967), *Polycentrus schomburgkii* (Freihofer, 1978), *Ctenopharyngodon idellus* (Dakrory, 2000), *Mugil cephalus* (Hussien, 2010) and in *Gambusia affinis affinis* (Mattar, 2012). In *Polypterus senegalus* (Piotrowski and Northcutt, 1996), the former connection is present, in addition to another one between the ramus mandibularis and the anteroventral lateral line nerve.

It is clear from the detailed anatomical study of the serial sections of *Tilapia zillii* that the nervus trigeminus carries somatic sensory fibres of the general type to the skin, visceral motor fibres to the muscles of mastication, special somatic sensory (lateralis) fibres to the sensory structure of the lateral line system and also visceral sensory fibres of both the special (to taste buds) and the general (oropharyngeal epithelium) types. The special somatic sensory and both types (general and special) of the visceral sensory fibres that are carried by the nervus trigeminus are introduced through the connections of its branches with those of both the nervus facialis and the nerves of the lateral line system.

List of Abbreviation

AU : Auditory capsule.
B : Brain.
CO.N : Common nerve.
CO.RO : Common root.
E : Eye.
G.CIL : Ciliary ganglion.
G.FSY : Facial sympathetic ganglion.
G.GE : Geniculate ganglion.
G.GE+G.AVLL : Geniculate and anteroventral lateral line ganglia.
G.GS : Gasserian ganglion.
G.PRF : Profundal ganglion.
G.TSY : Trigeminal sympathetic ganglion.
IOC : Infraorbital lateral line canal.
LC.S : Lacrimal sac.
LC.S : Lacrimal sac.
M.ADM : Adductor mandibularis muscle.
M.IMA : Anterior intermandibularis muscle.
M.IMP : Posterior intermandibularis muscle.
MM.T : Maxillo-mandibular trunk.
MO : Medulla oblongata.
N. IMA : Nerve to the anterior intermandibularis muscle.
N.ADLL: Anterodorsal lateral line nerve.
N.AVLL: Anteroventral lateral line nerve.
N.CD : Constrictor dorsalis nerve.
N.CU : Nerve to the skin.
N.DO : Nerve to the dilator opercularis muscle.
N.IMP : Nerve to the posterior intermandibularis muscle.
N.IV : Nervus trochlearis.
N.LAP : Nerve to the levator arcus platini muscle.
N.NOTC.1 : Nerve to the first neuromast of the otic canal.
N.NOTC.2 : Nerve to the second neuromast of the otic canal.
N.NSOC.1 : Nerve to the first neuromast of the supraorbital lateral line canal.
N.NSOC.2 : Nerve to the second neuromast of the supraorbital lateral line canal.
N.NSOC.3 : Nerve to the third neuromast of the supraorbital lateral line canal.
N.NSOC.4 : Nerve to the fourth neuromast of the supraorbital lateral line canal.
N.NSOC.5: Nerve to the fifth neuromast of the supraorbital lateral line canal.
N.NSOC.6 : Nerve to the sixth neuromast of the supraorbital lateral line canal.
N.NSOC.7: Nerve to the seventh neuromast of the supraorbital lateral line canal.
N.NSOC.8 : Nerve to the eighth neuromast of the supraorbital lateral line canal.
N.PE : Nerve to the palatal epithelium
N.PR : Profundal nerve.
N.PRF : Nervus profundus.
N.TB : Nerve to the taste buds
N.I : Nervus olfactorius.
N.III : Nervus oculomotorius.
N.V : Nervustrigeminus.
N.VII : Nervus facialis.
Nn. AMM : Nerves to the anterior mandibularis muscle.
Nn. CU : Nerves to the skin.
OL : Olfactory organ.
OS.L : Ophthalmic superfacialis lateralis.
P : Palatine bone.
PORC : Preoptic root cartilage.
PRO.F : Prootic foramen.
R.BU : Ramus buccalis of the anterodorsal lateral line nerve.
R.CM.BU+MX : Ramus communicans between the the ramus buccalis lateralis and the ramus maxillarisV.
R.CM.MD.VII+MDE.V: Ramus communicans between the the ramus mandibularis of the nervus facialis and the ramus mandibularis externus of the nervus trigeminus.
R.CM.MX+P: Ramus communicans between the the ramus maxillaris and the ramus palatinus facialis.
R.MD.V : Ramus mandibularis of the nervus trigeminus.
R.MDE.V : Ramus mandibularis externus of the nervus trigeminus.
R.MDI.V: Ramus mandibularis internus of the nervus trigeminus.
R.MX : Ramus maxillaris of the nervus trigeminus.
R.OS.V : Ramus ophthalmicus superficialis trigeminus.
R.OT : Ramus oticus.
R.P : Ramus palatinus of the nervus facialis.
RD.CL : Radix ciliaris longa.
RO.V : Root of the nervus trigeminus.
Rr.OS.V+OS.L : Rami ophthalmici superfacialis trigeminus and lateralis.
S.IN : Internasal septum.
SOC : Supra orbital lateral line canal.
SY. RO : Sympathetic root.
T.CIL : Truncus ciliaris profundus.
T.HM : Truncus hyomandibularis.

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