The Trigeminal Nerve. Part I: An Over-View

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ABSTRACT: The trigeminal nerve is the largest and most complex of twelve cranial nerves. Its vas size and influence are greatly appreciated when one attempts to diagnose and treat patients suffering from orofacial pain and temporomandibular joint disorders. Without a thorough knowledge of the trigeminal nerve, the efficacy of diagnostic and therapeutic procedures will be very disappointing. This is the first of a four-part series of articles about the trigeminal nerve, a basic over-view of both the gross and neuroanatomical structures is presented.

As practitioners from various backgrounds and specialties, we are all charged with evaluation patients suffering with orofacial, temporomandibular joint, head and neck pain. The finest service we can offer our patients is to discover an accurate diagnosis or diagnoses, as the case may be. Due to the great anatomical complexity of the head and neck regions, diagnostic procedures are often difficult at best.

Through knowledge of the trigeminal nerve is a must if one expects to gain any degree of success with these types of patients. In anatomy lectures and laboratories, each of us learned the basic anatomy of this largest of the cranial nerves; however, trigeminal anatomy was soon forgotten once we passed the National Board Examination.

As doctors and therapists who diagnose and treat orofacial pain and temporomandibular joint disorders, we have no choice but to be experts of the trigeminal system. This statement is not s suggestion, but rather, a commandment.

This four-part series of articles will serve as in-depth study guides and sources of information concerning the trigeminal nerve. The first article is an over-view; each of the additional three articles describes and discusses the individual divisions of the trigeminal nerve.

Cranial Origin of the Trigeminal Nerve

The trigeminal, or fifth cranial nerve, is comprised of three major divisions: the ophthalmic, the maxillary, and the mandibular. The largest cranial nerve is the great afferent nerve of the face, of the mucous membranes of the head, the afferent nerve (The term afferent, “to bring to,” is interchanged with the term sensory in this article.) of internal cranial structures, the afferent nerve of the teeth and temporomandibular joints, and efferent (motor) nerve of the first branchial arch (**Table 1**).

The trigeminal nerve has its origin at the lateral border of the pons through two roots, the sensory (portio major), which is much larger than the motor root (portio minor). The afferent fibers, except for those associated with pressure and stretch receptors and proprioception[1], have their cell bodies of origin located in the trigeminal (Gasserian or semilunar) ganglion. They enter the pons through the lateral portion of its ventral surface.

The small motor root, whose cell bodies of origin are located within the pons and , unlike the sensory portion of this nerve, not in the Gasserian ganglion, also includes proprioceptive fibers (proprioception refers to a special type of sensory perception conveyed through muscle and skeletal mechanoreceptors for reflex adjustments of muscle actions and for awareness of position of movement.) derived from the mesencephalic nucleus in the pons. This anterior root is comprised of six to eight rounded filaments of Vulpian, and emerges from the pons slightly superior to the larger posterior sensory root until it passes out of the cranium through the foramen ovale in the sphenoid bone, where it becomes closely united with the mandibular division of the trigeminal nerve.

After leaving the pons in the posterior cranial fossa, the motor and sensory roots pass anteriorly under the tentorium cerebelli in a grove in the petrous portion of the temporal bone in the middle cranial fossa to reach the Gasserian ganglion. This huge ganglion sits in a depression in the temporal bone (Meckle's cave) in the floor of the middle cranial fossa near foramen lacerum and is encased between two layers of dura mater. This collection of nerve cells was first called the Gasserian ganglion by anatomist

Anton B. R. Hirsch in 1765 in admiration of his mentor and professor, Johann Ludwig Gasser.[2] This size of the cavernous area which contains the Gasserian ganglion varies from person to person and even one side to the other in the same person[3]. The mass of this ganglion is basically flat, semilunar in shape, and measures approximately 1 x 2 centimeters[4].

The central cellular processes (i.e., the portio major) exit the concavity of the ganglion, passing under the superior petrosal sinus of the temporal bone. The peripheral fivers leave the convexity of the crescent of the ganglion as the three divisions of the trigeminal nerve. The internal carotid artery and the posterior portion of the cavernous sinus are positioned on the medical aspect of the ganglion, from which sympathetic innervation is provided to the ganglion. The greater superficial petrosal nerve is situated between the ganglion and the petrous portion of the temporal bone. This ganglion is unique in that it is the only site in which primary afferent neuron cell bodies are derived from neural crest cells during development. In addition, it is the largest collection of cell bodies outside of the central nervous system in the body (**Figure 1**).

The cells of the trigeminal ganglion are pseudo-unipolar, this making this structure analogous to the dorsal root ganglion of the spinal cord. Theses neurons are somatotopically (Somatotopic organization: an orderly representation of the various body parts within central nervous system structures that process sensory information such that neighborhood relation in the periphery are preserved in the central nervous system. This organizational representation in the central nervous system is maintained in the spinal cord and throughout the various areas of the brain.) organized from medial to lateral. Each neuron in the ganglion has two branches or processes. The peripheral processes of these ganglion cells form, from medial to lateral, the ophthalmic, maxillary, and mandibular divisions of the trigeminal nerve. The other branches of these ganglion neurons, the central processes, form the large sensory root which courses to the lateral border of the pons, through a groove in the petrous portion of the temporal bone, entering the pons and dividing into upper and lower roots. The upper roots synapse in the principle (chief sensory, main sensory, or pontine) nucleus positioned lateral in the pons. The lower roots descend as the spinal trigeminal root and become continuous with the substantia gelatinosa of Rolando of the spinal cord. Blood supply to the Gasserian ganglion is delivered from branches of the cavernous portion of the internal carotid artery as this vascular structure passes medially and superiorly to the ganglion through the carotid canal in the temporal bone.

Table 1
Components of the Trigeminal Nerve

Component	Function
Special visceral efferent (Autonomics)	(Branchial motor) To muscles of mastication, tensor tympani and tensor veli palatine muscles, zygomandibularis muscle, mylohoid muscle, and the anterior belly of the digastric muscle.
General somatic afferent (General sensory)	From the face, scalp, conjunctiva, bulbus of eye; mucous membranes of the paranasal sinuses, nasal, and oral cavities; the tongue, teeth, and gingivae; part of the external portion of the tympanic membrane; the meninges and dura mater of the anterior and middle cranial fossae.

Afferent Portion of the Trigeminal Nerve
(Portico Major)

The larger afferent portion of the trigeminal nerve provides somatosensory sensations (i.e., mechanoreception, thermal sensitivity, pressure sensation, nociception, and proprioception) to the entire face (except the angle of the mandible), the temple, the external acoustic meatus, and the anterior scalp as far posterior as the vertex of the skull. In addition, portions of the eye, nose, maxillary sinus, nasal pharynx, auditory tube, the temporomandibular joint, the dura mater and periosteum are also innervated by branches of the three divisions of this greatest of all the cranial nerves. Although the cell bodies of the somatosensory neurons are located in the Gasserian ganglion, the cell bodies for proprioception[5] and stretch receptors in the muscles of mastication are located in the mesencephalic nucleus in the dorsal pons

The number of nerve fibers in the human Gasserian ganglion has been calculated by Young[6]. Using an electron microscope, he counted an area and then calculated that there were 124,000 nerve fibers, with approximately half being myelinated and half unmyelinated. The myelinated fibers ranged from 0.2 to 1.3 microns in diameter and the largest unmyelinated fibers ranged up to eleven microns in diameter.

Embryologically, the trigeminal nerve is the nerve of the first branchial arch. Yet, unlike the maxillary (V2) and mandibular (V3) divisions, the ophthalmic (V1) portion is not a branchial component in the human being[7]. Phylogenetically, the trigeminal is the principle cutaneous afferent (sensory) nerve of the head and face as a result of the fusion of the two branchial nerves of the first branchial arch in lower chordates; namely, the ophthalmic and maxillomandibular nerves[8]. The separate origin of these nerves can be seen in amphioxus and in the embryos of some lower vertebrates[9]. As the phylogenetic scale is ascended, the sensory distribution of the trigeminal nerve increases in its influence over the entire nervous system while the influence of the facial, glossopharyngeal and vagal nerves decreases[10].

In the fetal development of the head of the human being, the cranial vault (i.e., the neurocranium) ossifies from membranous bone to form, among other bones, the frontal bone and the squamous portion of the temporal bone[11]. The ophthalmic division of the trigeminal nerve provides afferent innervation of these bones and their superficial and deep structures. The maxillary and mandibular divisions, on the other hand, being derivations of neural crest cells (like the Gasserian ganglion), provided innervation to very specific branchial arch derivatives (e.g., the maxillary nerve and its branches innervate superficial and deep structures which developed from the dorsal portion of the mandibular branchial arch; similarly, the mandibular nerve supplies superficial and deep structures which were derived from the ventral portion of the mandibular branchial arch). However, all three divisions have distributions of their branches corresponding to facial structures that develop from one of three fetal structures; namely, the frontonasal (ophthalmic nerve distribution), maxillary portion of the first branchial arch (maxillary nerve distribution), and the mandibular portion of the first branchial arch (mandibular nerve distribution). In addition, somatic afferent fibers of the facial, glossopharyngeal and vagus nerves, which supply the remainder of the orofacial complex, terminate centrally in the spinal trigeminal tract in the brainstem, thus being subserving the trigeminal nerve concerning afferent innervation of virtually the entire head and neck regions.

At the pons, the fibers of the three divisions of the trigeminal nerve exit the pons with the ophthalmic nerve being most inferior, the maxillary in the middle, and the mandibular division in the superior position[12]. As these nerve roots pass anteriorly in the middle cranial fossa approaching the Gasserian ganglion, they rotate approximately 180 degrees. Accompanying these afferent roots is a loose sleeve of dura mater and arachnoid mater which surrounds the depression in the petrous temporal bone (the cavum trigeminale) in which they are positioned[13].

The trigeminal nerve possesses two specialized afferent receptors in the cornea and the dental pulp. Both of these specialized anatomical areas convey information almost exclusively concerning pain. The afferent fibers of the cornea, which is the most densely innervated surface of the human body, have been an ongoing subject of controversy[14]. Formerly, it was thought that only the ophthalmic division of the trigeminal nerve provided somatosensory innervation to the cornea. However, recent studies using horseradish peroxidase tracer techniques[15] have demonstrated that a significant number of both ophthalmic and maxillary axons are responsible for innervation of the cornea.

The dental pulp receptors of the trigeminal nerve are also unique. Both small myelinated (A-delta fibers) and unmyelinated fibers (C fibers) provided afferent innervation to the pulps of the teeth. Until recently, it was thought that these fibers carried only pain information concerning dental diseases. However, Silverman and Kruger[16] have shown (at least, in rats) that healthy teeth exhibit a high concentration of calcitonin gene-related peptide (CGRP), a neuroactive substance contained within many small and medium diameter sensory ganglion neurons. This suggests that CGRP and the nerve fibers which contain this substance may be involved in effector (motor) mechanisms such as controlling vessel diameter in response to pulpal inflammation as well as immunoregulatory functions, rather than simply conveying pain transmission information.

Motor Portion of the Trigeminal Nerve
(Portico Minor)

Determined by embryological development, the motor fibers (portico minor) of the trigeminal nerve supply all the muscles of the first branchial arch, usually termed the muscles of mastication (**Table 2**). This category of muscles also includes the tensor veli palatine, the tensor tympani, the anterior belly of the digastric, the mylohyoid, and the zygomandibularis, a newly discovered muscle of mastication.[17]

Traditionally it has been taught that the anterior motor root is comprised of six to eight rounded filaments of Vulpian and emerges from the pons slightly superior to the larger posterior sensory root. However, this multi-stranded motor root may arise as two separate groups of small rootlets which always appear as two groups which join to form one. The union of the superior and inferior motor roots passes under the Gasserian ganglion to exit through the foramen ovale in the sphenoid bone. Also, according to Saunders and Sachs[18], the superior group, which numbers from three to six rootlets, represents the classical motor root. The inferior motor rootlets are visualized after retraction of the superior motor group from the sensory root. Though the collective diameter is smaller than that of the superior group, there are more of these rootlets, often numbering as many as ten.

This inferior root is also termed the intermediate root by some authors. The exact function of this intermediate root or inferior motor root is unknown and there is no actual anatomical evidence for the specific functions motor or sensory. Yet, Pelleteir and colleagues[19] contend that the physiological characteristics of this intermediate root were identical to that of the portico minor fibers and subserved either a motor or proprioceptive function father than a sensory function. Young contends that the fibers of the portico intermedia or inferior motor rootlet simply are randomly displaced fibers which provide accessory pathways into or out of the pons or cross communications between the portico major and minor for either sensory or motor fiber. Obviously, further research is needed to determine the actual physiological function of this inferior portico intermedia.

Table 2
Muscles of Mastication and Associated Innervations

Muscle	Nerve branch of motor division V3
Temporalis	Posterior deep temporal – usually two (from Anterior division V3)
Zygomandibularis	Anterior deep temporal (from anterior division Of V3)
Masseter	Masseteric (from anterior division of V3)

Superior belly of lateral pterygoid	Lateral pterygoid (from anterior division of V3)
Inferior belly of lateral pterygoid	Lateral pterygoid (from anterior division of V3)
Medial pterygoid	Medial pterygoid (from main trunk of V3)
Tensor veli palatine*	Branch of the medial pterygoid nerve
Tensor tympani*	Branch of the medial pterygoid nerve
Mylohyoid*	Mylohyoid nerve (from posterior of division V3)
Anterior belly of digastric	Mylohyoid nerve

* Although not true muscles of mastication, these muscles are traditionally included with the masticatory muscles due to the common innervation of branches of V3

In addition to motor fibers of the third division of the trigeminal nerve, proprioceptive fibers, which originate in the mesencephalic nucleus in the pons, accompany the motor root to be distributed throughout the third division[20]. Paradoxically, May and Horsley[21] demonstrated early in this century that afferent fibers to the mesencephalic nucleus ran through the motor root as well.

After the motor and mandibular sensory divisions of the trigeminal nerve exit the middle cranial fossa through the foramen ovale, they unite to form the mandibular trunk which further divides into anterior and posterior divisions to provide innervation to specific structures which will be discussed in the fourth of this series of articles (The Mandibular Division). This union of the motor and sensory nerves forms a mixed nerve in contrast to the ophthalmic and maxillary which are purely sensory.

Autonomics of the Trigeminal Nerve

The autonomic ganglia associated with the trigeminal nerve belong to the general systemic autonomic nervous system. Although totally separate and independent from the central and peripheral nervous systems, the autonomics are intimately affiliated with them by communicating branches. In the head, the smooth muscles of the orbit, the lacrimal and salivary glands, the ciliary body of the eye, and secretory cells all come under the dual control of the sympathetic and parasympathetic divisions of the autonomic nervous system. Traditionally, all nerves which entered one of the ganglia of the head were called roots of the ganglion. However, since only true roots of a ganglion are nerves which synapse on cells of a ganglion, only parasympathetic fibers are true roots. Sympathetic roots pass through and do not synapse in their respective ganglia.

Autonomic innervation of the trigeminal system does not originate from the trigeminal nerve itself. The sympathetic division originates in the intermediolateral cell column of all thoracic spinal segments and of the upper two or three lumbar segments of the spinal cord[22]. The preganglionic sympathetic fibers associated with the trigeminal system terminate in the superior cervical ganglion of the sympathetic trunk. The postganglionic fibers which leave the superior cervical ganglion travel to the heart and great vessels. Those which travel to the head and neck follow either the external carotid artery and its branches or the internal carotid artery, The sympathetic fibers in the head do not synapse in any of the ganglia, but instead, like sensory trigeminal fibers, pass directly through each ganglion. The fibers that follow the internal carotid leave the upper pole of the superior cervical ganglion and accompany the internal carotid artery as the internal carotid nerve, which divides to form a loose plexus around the internal carotid artery and its branches[23]. All these fibers consist of non-myelinated fibers.

This internal carotid plexus sends filament to several cranial nerves. In the carotid canal two nerves, the caroticotympanic nerves, arise and enter the tympanic cavity to form the tympanic plexus. In the cavernous sinus, the deep petrosal nerve originates. This nerve joins the parasympathetic greater petrosal nerve (from the facial nerve) in the pterygoid canal of the sphenoid bone to form the pterygoid or Vidian nerve which continues to the sphenopalatine ganglion. The sympathetic fibers pass through the ganglion without synapsing and terminate in the glands and blood vessels of the palate, nasal fossa and pharynx.

From the internal carotid plexus also arises the sympathetic roots of the ciliary ganglion (which is actually a misnomer). These fibers reach the ciliary ganglion through the superior orbital fissure with alone or with the long root of the ciliary ganglion (radix longa ganglii ciliaris), a branch of the nasociliary of V1. These fine filaments from the internal carotid plexus supply postganglionic fibers through the ciliary.

A plexus associated with the maxillary and middle meningeal arteries provides postganglionic fibers to and again, through the submandibular and otic ganglia, respectively. From the otic, sphenopalatine, and submandibular ganglia, sympathetic fibers innervate the lacrimal, salivary, palatine, and mucosal glands.

By contrast, the parasympathetic nerves of the head are simpler to categorize and study than the sympathetic nerves. The preganglionic fibers of the parasympathetic nervous system, which affect and interact with the trigeminal system, have their cells of origin in the visceral motor column of the midbrain and medulla oblongata, specifically in cranial nerves III, VII, and IX (respectively, oculomotor, facial, and glossopharngeal nerves). The parasympathetic division is composed of a nucleus in the central nervous system, a long preganglionic fiber which synapses in a parasympathetic ganglion near the target organ or structure, and then a short postganglionic fiber to the target structure. In the head, there are four parasympathetic ganglia (**Table 3**) which are associated with the trigeminal nerve. The parasympathetic ganglia in the head function not only as relay stations or centers for parasympathetic neurons, but also as intersections for fibers of other functions, which pass directly through the respective ganglion and compose the mixed nerve.

The Ciliary Ganglion (ophthalmic orlenticular ganglion)

The ciliary ganglion is located in the posterior part of the orbit between the optic nerve and the lateral rectus muscle in loose connective and adipose tissues. It is an oval shaped, reddish-gray collection of cell bodies about two mm by one mm.[24] The fibers of this tiny ganglion arise from the Edinger-Westphal nucleus of the oculomotor nuclear complex in the midbrain. These parasympathetic fibers accompany the inferior branch of the oculomotor nerve through the superior orbital fissure and reach the ganglion as the short root of the ciliary ganglion. There, they synapse with cells in the ciliary ganglion. The parasympathetic fibers then leave the ganglion as six to ten short ciliary nerves. They divide into twenty or more branches and enter the eyeball in a circular area around the optic nerve. These parasympathetic fibers supply the ciliary muscles and the sphincter of the pupil.

The Sphenopalatine Ganglion (pterygopalatine; ganglion of Meckel)

The largest of the parasympathetic ganglia of the trigeminal nerve, the sphenopalatine ganglion is placed deeply within the pterygopalatine fossa. It is a triangular or heart-shaped, reddish-gray collection of cells located below the maxillary nerve (V2) after the nerve enters the pterygopalatine fossa through the foramen rotundum. The nerve fibers which synapse in the sphenopalatine ganglion are derived from the superior salivary nucleus in the pons and leave the pons with the facial nerve as two nerves; namely, the chorda tympani and the greater superficial petrosal. After coursing through the middle cranial fossa, exiting through the foramen lacerum, the greater superficial petrosal is joined by the deep petrosal (from the internal carotid plexus) in the pterygoid canal to form the Vidian nerve. This mixed nerve leaves the pterygoid canal and enters the sphenopalatine ganglion. Here, the sympathetic fibers pass through the ganglion and terminate in the glands and blood vessels of the palate, nasal fossa and pharynx. The parasympathetic fibers of the greater superficial petrosal nerve synapse on ganglion cell bodies. From the sphenopalatine ganglion the parasympathetic fibers leave through the zygomatic, nasal branches, and pharyngeal nerve to innervate the lacrimal gland, the glands of the nasal fossa, and pharynx. In addition, the greater superficial petrosal nerve continues through the palatine branches f=given off the sphenopalatine ganglion to supply palatal taste buds.

The Submandibular Ganglion

The chorda tympani branch of the seventh cranial nerve, after coursing through the temporal bone and middle ear, emerges through the petro-tympanic fissure of the temporal bone and descends into the infratemporal fossa to join the lingual branch of the mandibular division of the trigeminal nerve. With the lingual nerve, the chorda tympani travels to the submandibular ganglion and the parasympathetic fibers synapse. From the ganglion, some fine filaments are provided to the submandibular gland and others join the lingual nerve to travel to the sublingual gland and ultimately, to the lingual glands, or taste buds, of the tongue.

Sympathetic fibers from the plexus around the facial artery pass through the submandibular gland to reach the submandibular and lingual glands.

The Otic Ganglion

The Otic Ganglion (ganglion oticum or Arnold's ganglion[25]) is a very small, oval-shaped , flat and reddish-gray cluster of cells situated immediately below the foramen ovale and associated with the third division of the trigeminal nerve. The ganglion lies on the medial surface of the mandibular nerve's main trunk near the origin of the medial pterygoid and tensor veli palatini nerves. The fibers of the otic ganglion originate in the inferior salivary nucleus of the glossopharyngeal or ninth cranial nerve in the medulla oblongata. These parasympathetic fibers leave the brain stem in the glossopharyngeal nerve and enter the tympanic branch, which passes through a small canal in the occipital bone between the jugular foramen and the carotid canal to reach the tympanic cavity, passes through the tympanic plexus, and emerges through the roof of the tympanic cavity of the temporal bone as the lesser superficial petrosal nerve. After a few sympathetic fibers from the facial nerve join the lesser superficial petrosal, the nerve proceeds to the otic ganglion. These sympathetic fibers are really derived from the plexus of the middle meningeal artery and do not synapse in the otic ganglion.

The parasympathetic fibers, after synapsing on cells in the otic ganglion, have a wide distribution through the mandibular division of the trigeminal nerve; specifically, trigeminal motor fibers to the medial pterygoid and tensor tympani and tensor veli palatini nerves. But the real contribution of the glossopharyngeal nerve is through the auriculotemporal nerve to provide secretomotor fibers to the parotid gland. Some of the sympathetic fibers which traveled with the lesser superficial petrosal terminate also in the parotid gland.

Table 3
Parasympathetic Ganglia

Ganglia	CN*Cell Origins	Specific nerve	Trigeminal division	Target organ
Ciliary	III	Motor root from Edinger-Westphal Nucleus of CN III	V1	Ciliary muscles
Sphenopalatine	VII	Superficial petrosal	V2 and possibly V1	Lacrimal and Nasal glands
Submandibular	VII	Chorda tympani	V3	Submandibular And sublingual Glands
Otic	IX	Lesser superficial Petrosal	V3	Parotid gland

*CN: Cranial Nerve
V1: Ophthalmic or first division
V2: Maxillary or second division
V3: Mandibular or third division

Trigeminal Sensory Nuclei

There are three sensory or afferent nuclei associated with the trigeminal nerve (**Figure 2**). Collectively, they form a long, continuous column of cells that extends from the superior portion of the midbrain to the upper cervical spinal cord, according to most texts. The principle nucleus forms an enlargement in this column in the mid-portion of the pons and is lateral and slightly dorsal or above the motor nucleus of the trigeminal nerve. The mesencephalic nucleus is superior and medical to the principal nucleus and the spinal nucleus extends inferiorly into the spinal cord from the mid pons region.

Peripheral afferent fibers of the trigeminal nerve, whose cell bodies originate within the Gasserian ganglion, enter the pons to terminate one of three ways. About 50% of the fibers bifurcate and send a short ascending afferent fiber to the principle nucleus and send a much larger and longer branch to the spinal trigeminal tract, which is lateral to the spinal trigeminal nucleus.[25] The remaining fibers do not bifurcate and wither terminate directly in the principle nucleus or turn inferiorly to terminate in the spinal trigeminal tract.

The Principle Nucleus

The principle (chief, main, pontine trigeminal nucleus, superior sensory, or sensory) nucleus of the trigeminal nerve is the largest of the four nuclei (three sensory and one motor) and is located lateral and slightly inferior to the motor nucleus in the mid-portion of the pons. It is considered to be analogous to the posterior dorsal column of the spinal cord and being so, the function of the principle nucleus is to process all types of somatosensory information. This large collection of neurons receives large fiber, heavily myelinated afferents. The nucleus is specifically located in the dorsal –lateral area of the pontine tegmentum at the level of entry of the afferent fibers into the pons. It is continuous with the inferiorly placed spinal nucleus. The principle nucleus is composed of two sub-nuclei: 1. a ventrolateral; and 2. dorsomedial subnucleus. The ventrolateral subnucleus extends from the level of the motor nucleus inferiorly to the subnucleus oralis of the spinal trigeminal tract. The dorsomedial extends more caudally (inferiorly) than its ventrolateral counterpart.[27] The ventrolateral subnucleus is primarily composed of uniformly medium-size cells with small multipolar cells scattered between the larger cells.[23] The dorsomedial subnucleus contains the densest accumulation of cells, where, according to Eisenman, et al.[29] and Johnson and Westrum,[30] there is an aggregation of medium-size fusiform and pear-shaped neurons which surround small islands of neuropil (a complex net of axons, dendrites, and glial arborizations that form the bulk of the central nervous system's gray matter, and in which nerve cell bodies lie embedded). This gives the dorsomedial subnucleus its characteristic appearance.

The principle trigeminal nucleus gives rise to two ascending pathways or tracts. The largest tract, termed the ventral trigeminal lemniscus, is composed of fibers which, after leaving the principle nucleus, cross the midline and ascend to terminate in the ventral posterior medial nucleus of the thalamus. The smaller, ipsilateral tract, comprises the dorsal trigeminal lemniscus and they, too, terminate in the ventral posterior medial nucleus of the thalamus. The significance of this smaller but somewhat duplicate dorsal trigeminal lemniscus is unclear. However, it terminates in the thalamus alongside the ascending taste pathway (the tractus solitarius), which is also ipsilateral (but, like the trigeminal nerve, the facial nerve also sends bilateral projections to the thalamus). Therefore, taste and sensory sensations from the same side of the mouth are processed in the same area of the thalamus.

Although the principle nucleus receives all types of sensory input, light, discriminate touch and pressure sensations seems to predominate. As fivers enter the pons, they divide, sending filaments to both the principle and spinal trigeminal nuclei. The cells of the principle nucleus have large receptive fields, show high spontaneous activity, and respond to a wide range of pressure stimuli with little adaptation.[1]

The Mesencephalic Nucleus

Afferent fibers from muscle spindles in the muscles of mastication, as well as mechanoreceptors of the gingivae, periodontal ligament fibers, the hard palate, and the temporomandibular joints do not have their cell bodies of origin located within the Gasserian ganglion, but rather, within the central nervous system. They are located within a slender, rather long column of cells termed the mesencephalic nucleus. This anatomical arrangement is unusual as all other sensory fibers of the trigeminal nerve originate outside the central nervous system in the Gasserian ganglion.

The name mesencephalic denotes that this column of cells extends superiorly from the pos to the smallest and least differentiated portion of the brain stem, the midbrain portion of the mesencephalon. The cells of this nucleus are large, pseudounipolar neurons which extend from the level of the motor nucleus of the trigeminal nerve superiorly to the uppermost area of the midbrain. The neurons resemble those of the dorsal root ganglion cells of the spinal cord. The central processes from the mesencephalic tract of the trigeminal nerve which descends to the level of the motor nucleus of the trigeminal nerve. There is recent evidence,[31] at least in the cat, that some of these neuronal cells are bipolar or multipolar with one to nine dendrites, making these cells distinctly different from those of the Gasserian ganglion. Like the principle nucleus, the mesencephalic is composed of two regions. The majority of the pseudounipolar neurons are located in the inferior or caudal portion of the nucleus whose peripheral processes primarily innervate the periodontal ligament fibers. These fibers may also innervate the teeth[32,33] and the ocular muscles.[32]

The multipolar cells are mostly located in the superior or rostral portion of the mesencephalic nucleus. According to Hinrichsen and Larramendi,[34] the heterogenous organization may reflect the dual embryologic origin of the mesencephalic neurons, some from neural crests cells and others from the alar plate.

Several researchers[35-37] have reported specific characteristics of mesencephalic neurons which make them unique from other primary afferent cells. Apparently, both axosomatic and axodendritic synapses are seen. There appear to be gap junctions (electrical, as opposed to chemical synapses) seen between the multipolar cells primarily in the rostral portion of the mesencephalic nuclear. This electronic coupling, which improves efficiency and perhaps, consistency, appears to involve neurons which innervate muscle spindles of the elevator (jaw-closing) muscles of mastication (i.e., the masseter, the temporalis possibly the medial pterygoid, and the zygomandibularis muscles).

The peripheral fibers of the mesencephalic nucleus are distributed through the peripheral processes of the three divisions of the trigeminal nerve. Some central fibers terminate in both the motor nucleus and the principle nucleus. Some collateral fibers give off to the reticular formation and on the thalamus through the trigeminal lemnisci. Also, the mesencephalic nerve send fibers to the cerebellum through the superior cerebellar peduncle.

The Spinal Trigeminal Tract Nucleus

The third sensory nucleus, termed the spinal trigeminal tract nucleus, is perhaps the most influential systemically of all three and is actually composed of three subnuclei. This complex extends from the principle nucleus inferiorly to merge with the substantia gelatinosa of the cervical spinal cord. Therefore, this trigeminal nuclear complex is actually located not in the pons only, but within the medulla and spinal cord, too. Since at lease 1918[38] anatomists have taught that the spinal trigeminal tract descended caudally to the level of the first or second cervical nerve. However, recently several researchers have demonstrated in the cat that the spinal trigeminal tract conveys fibers through the substantia gelatinosa of the spinal cord as far caudally as T-9 and in some cases as far as L-3, or the very end of the spinal cord.[39] There are definite histological differences among these three subnuclei; they are distinctly separate and each processes different types of information.

Afferent fibers of all three divisions of the trigeminal nerve enter the pons in a distinct somatotopical organization. Gibers from the ophthalmic division are more ventrally located, mandibular fibers, positioned dorsally, and those of the maxillary division are intermediately located. This arrangement make the face appear upside down in its anatomic representation. This inverted laminar arrangement of afferent fibers results from a medical rotation of the trigeminal nerve as it enters the pons. Small diameter, lightly myelinated (A-delta fibers) and unmyelinated fibers (C-fibers) enter the pons, descend to form the spinal tract, and terminate on cells of the spinal nucleus, which form a long, laminated cell column positioned medially to the tract.

The spinal trigeminal tract also contains general somatic afferent fibers from four cranial nerves, the facial, the glossopharyngeal, the vagus, they hypoglossal, and from the first three cervical nerves, [40]thus providing general sensory data from part of the external ear, mucosa of the posterior on-third of the tongue, the pharynx and larynx, and some cervical areas.

Other researchers have demonstrated that the spinal trigeminal tract continues in the spinal cord as far caudal as the eighth cervical nerve, [41] as far caudal as the ninth thoracic segment, [39] and there are some who have shown trigeminal fibers throughout the entire length of the spinal cord,[42] thus forming the trigeminospinal tract. Therefore, the trigeminal nerve also processes somatic sensations (chiefly, pain and temperature) for these other cranial nuclei as well.

Subnucleus Oralis

The subnucleus oralis (pars oralis) of the spinal trigeminal tract is the most superior of the three subnuclei and itself is subdivided into three subdivisions. It extends from the caudal pole of the motor nucleus of the trigeminal nerve (see below) inferiorly to the rostral or superior pole of the nucleus of the facial nerve. The most rostral division is interdigitated with the ventrolateral subnucleus of the principle trigeminal nucleus, lying medial to this sub nucleus. The area of these two subnuclei which overlap is termed either the oralis gamma subdivision [29] or the rostrodorsomedial subdivision. [27]

Characteristic to the subnucleus oralis is the vast numbers of multipolar neurons of various sizes.

Subnucleus Interpolaris

Situated between the subnucleus oralis rostrally and subnucleus caudalis caudally is the subnucleus interpolaris. This second of the three subdivisions of the spinal trigeminal nucleus extends rostrally from the rostral pole of the hypoglossal nucleus caudally to the obex (The obex is a "V" shaped area in the midline which is the caudal boundary of the fourth ventricle in the medulla oblongata.).

There appears to be an equal mixture of predominately small and medium-sized neurons in the subnucleus interpolaris, 75% of which are low threshold mechanoreceptors, although all classes of neurons (low-threshold mechanoreceptors, nociceptive-specific neurons, and wide dynamic range neurons) are represented. The interpolaris of all three classes have direct axonal projections to the thalamus, cerebellum, reticular formation, and spinal cord. In addition, interneurons for the jaw-opening reflex are located in the nucleus interpolaris and subnucleus caudalis. This subnucleus appears to be most responsible for processing dental pain.

Subnucleus Caudalis

The subnucleus caudalis is the most inferior or caudal portion of the spinal trigeminal tract. Yet, this portion of the spinal nucleus of the trigeminal nerve is the most significant in the processing of nociception. Inferiorly, it is continuous with the substantia gelatinosa in the dorsal horn of the cervical spinal cord. [39-43]

According to Brodal, [44] there seem to be no clear boundaries between these subnuclei regarding the transmission of pain and mechanoreception. The subnucleus caudalis, in concert with the upper cervical spinal segments of the dorsal horn, are especially important in the conduction of pain perception in the teeth, jaws and face.

Of the three subnuclei of the spinal trigeminal nucleus, caudalis is by far the most complex. Brodal, et al. [44] and Berman[45] subdivided the nucleus caudalis into three separate layers. Tiwari and King[46] further divided this subnucleus into six laminae and later Gobel et al. [47] continued to divide the nucleus into eight layers by including the medullary reticular formation as a portion of this nucleus. But adding the reticular formation, this portion of the spinal trigeminal nucleus draws a closer homology with the dorsal horn of the spinal cord [48] (Johnson et al. 1991). For example, Layer II (according to Johnson et al.), corresponds to Layer II or the substantia gelatinosa of the spinal cord. Also, Layer I in the nucleus caudalis corresponds to the marginal layer of the spinal cord and Layer V (the medullary reticular formation) is analogous to Layer V of the spinal cord. Therefore, Layers I, II, and V in both the nucleus caudalis and the spinal cord respond to nociceptive stimuli and process these stimuli to higher centers in the thalamus and ultimately, to the sensory cortex.

In the next article, the first division, or ophthalmic division, of the trigeminal nerve will be discussed in depth.

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The Trigeminal Nerve. Part II: The Ophthalmic Division

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ABSTRACT: The ophthalmic, or first division (V1) of the trigeminal nerve, is the smallest of the three divisions and is purely sensory or afferent I function. It supplies sensory branches to the ciliary body, the cornea, and the iris; to the lacrimal gland and conjunctiva; to portions of the mucous membrane of the nasal cavity, sphenoidal sinus, and frontal sinus; to the skin of the eyebrow, eyelids, forehead, and nose; and to the tentorium cerebelli, dura mater, and the posterior area of the falx cerebri, At first glance, one might not expect one interested in the diagnosis and treatment of orofacial pain and temporomandibular joint disorders to have a need to be concerned with the ophthalmic division. Although much of this division's influence is dedicated to structures within the orbit, nose, and cranium, still, the ophthalmic division may be afflicted with a lesion or structural disorder which can cause all sorts of orofacial pain. Ignorance of this or any portion of the trigeminal nerve will lead to diagnostic and therapeutic failures. In this, the second of four (4) articles concerning the trigeminal nerve, the first division of this vast cranial nerve will be described in detail.

The ophthalmic, or first division (V1) of the trigeminal nerve is the smallest of the three and is purely sensory or afferent in function (**Figure 1**). It supplies sensory branches of the ciliary body, the cornea, and the iris; to the lacrimal gland and conjunctiva; to portions of the mucous membrane of the nasal cavity, sphenoidal sinus, and frontal sinus; to the skin of the eyebrow, eyelids, forehead, and nose; and to the tentorium cerebelli, dura mater, and the posterior area of the falx cerebri (**Table** 1). Never leaving the protection of the cranium, the ophthalmic nerve exits the Gasserian ganglion as the most superior division, This flattened cord is approximately 2.5 centimeters in length.[1] it passes forward along the lateral wall of the cavernous sinus, below the oculomotor and trochlear nerves (cranial nerves III and IV, respectively). Just before entering the obit via the superior orbital fissure along with cranial nerves III, IV, VI, and the ophthalmic vein, it divides into three branches; viz, the lacrimal, the nasociliary, and the frontal nerves.

Sympathetic filaments from the internal carotid plexus join the ophthalmic nerve. The ophthalmic communicates with the oculomotor, trochlear, and abducent nerved (i.e., cranial nerved III, IV, and VI), possibly providing proprioception for these cranial nerves from the trigeminal.[2] There may also be small filaments given to these same cranial nerves for purely sensory innervation to the extrinsic ocular muscles.[3]

The Lacrimal Nerve

The lacrimal nerve (n. lacrimalis) is the smallest of the three divisions of the ophthalmic nerve, Traveling forward in a separate tube of dura mater after leaving the ophthalmic nerve just prior to the superior orbital fissure of the sphenoid bone, the lacrimal nerve enters the orbit through the narrowest portion of the superior orbital fissure and travels above and parallel to the lateral rectus muscle and receives a communicating branch from the maxillary or second division of the trigeminal nerve, which provides postganglionic parasympathetic motor fibers for the lacrimal gland. According to Goss,[4]

These parasympathetic fibers, carried by the zygomaticotemporal nerve, have their cells bodies of origin in the sphenopalatine ganglion. They travel from the sphenopalatine ganglion through the zygomatic nerve, which divides into the zygomaticofacial and zygomaticotemporal nerves, thus bringing secretomotor fibers to the lacrimal gland, Parasympathetic and sympathetic innervation are also provided to the lacrimal gland by the mixed greater superficial petrosal nerve, a branch of the seventh cranial nerve.[5] Further, additional sympathetic fibers, also from the carotid plexus, after running with the sixth cranial or trochlear nerve, are given to the lacrimal gland.[5]

As the lacrimal nerve enters the lacrimal gland with the lacrimal artery, it also gives off branches to the conjunctiva (Figure 1). The nerve continues further to pierce the orbital septum and terminate in the skin of the lateral edge of the upper eyelid. There, the lacrimal nerve anastomoses with a branch of the temporal division of the facial, or seventh cranial nerve.

Goss[4] and the present writer have observed that often the lacrimal nerve is lacking and replaced by the zygomaticotemporal branch of the maxillary nerve. Further, Goss stated that: "Sometimes the latter (the Zygomaticotemporal nerve) is absent and a communication of the lacrimal is substituted for it."[4]

The Nasociliary Nerve

The nasociliary nerve (nasal nerve; n. nasociliaris) is intermediate in size when compared to the lacrimal and the frontal nerves. It runs deeper within the orbital contents than the former two nerves. The nasociliary enters the orbital cavity through the superior orbital fissure of the sphenoid bone between the two heads of the rectus lateralis muscle, between the superior and inferior rami of the oculomotor nerve, and with the abducent nerve (cranial nerve VI) within the tendinous ring from which the four rectus muscles (superior rectus; inferior rectus; medial rectus; and lateral rectus) take their origin to lie within the cone formed b the extrinsic ocular muscles.[7] From there, the nasociliary curves anteromedially and travels superior to the ophthalmic artery and the optic nerve to leave the muscular cone, travels between the superior oblique and medial rectus muscles, and approaches the anterior ethmoidal foramen.

The nasociliary nerve then enters the anterior ethmoidal foramen in the ethmoid bone of the medial wall of the orbit just posterior to the frontoethmoidal suture and actually becomes the anterior ethmoidal nerve (n. ethmoideus anterior; internal nasal) and enters the cranial cavity just superior to the cribiform plate of the ethmoid bone. Continuing, the anterior ethmoid nerve dives down, passes through a slit at the side of the crista galli, enters the nasal cavity, and divides into three branches:

1. The internal or septal branch
2. The lateral branch: and
3. The anterior or superficial branch.

The internal or septal branch of the ethmoidal nerve travels inferiorly and anteriorly , supplying the anterior portion of the nasal septum of the nose with afferent fibers.

The lateral branch of the ethmoidal nerve actually is comprised of two or three filaments which are distributed to the anterior portions of the lateral walls of the nasal fossa, which includes the middle and inferior conchae. [1]

The anterior or superficial branch of the ethmoidal nerve is the largest of the three branches and is actually considered the continuation of the ethmoidal nerve. It passes inferiorly in a longitudinal canal in the nasal bone until the bone reaches the nasal cartilage where the canal ends. From there, the anterior branch travels under the nasalis muscle and terminates in the wing, spine, and tip of the nose[1] and is named the external nasal nerve.

Table 1

Branches of the Ophthalmic Division of the Trigeminal Nerve

Division	Branches	Area of distribution
Frontal nerve	Supraorbital, medial branch	Forehead, medial; conjunctiva; skin of upper eyelid; frontal sinus
	Supraorbital lateral	Forehead, later; scalp
	Supratrochlear	Medial upper eyelid; forehead
Nasociliary nerve	Long Ciliary nn*	Sclera
	Long root of the ciliary ganglion	Ciliary ganglion
	Ciliary nerves to sclera	Sclera
	Anterior ethmoid	Anterior air cells; dura mater
	Posterior ethmoid	Posterior ethmoidal air cells; dura mater; Sphenoidal sinuses
	Nasal branches	Medial and lateral nasal cavity and septum
	Infratrochlear	Skin of both eyelids; skin of lateral nose; Conjunctiva; lacrimal sac; caruncula lacrimalis
	External nasal	Skin of dorsum and lateral nose
Lacrimal nerve	Nerve to lacrimal gland	Lacrimal gland
	Nerve to eyelid	Lateral skin of upper eyelid
Tentorial nerve	Tentorial nerve or branch	Tentorial cerbelli and dura mater of middle Cranial fossa

* nn: nerve

Prior to entering the anterior ethmoidal foramen and subsequently becoming the anterior ethmoid nerve, the nasociliary nerve gives off at least four (4) branches: Viz,

1. The long root of the ciliary ganglion;
2. The long ciliary;
3. The infratrochlear; and
4. The posterior ethmoid.

The long root of the ciliary ganglion (radix longa ganglii ciliaris) generally originates from the nasociliary nerve between the two heads of the lateral rectus muscle.[3] This long but slender nerve travels forward on the lateral side of the optic nerve and enters the ciliary ganglion but does not synapse with any cell bodies. This sensory nerve, after leaving the ciliary ganglion, divides into several fine filaments and supplies the bulb of the eye. These fine filaments are known as the short ciliary nerves or ciliary nerves to the sclera. Most likely, the long root of the ciliary ganglion is joined in the ciliary ganglion by a filament from the internal carotid plexus, which, the later being derived form the superior cervical ganglion, provides sympathetic innervation.

The long ciliary nerves (nn. ciliares longi) number two or three. These branches of the nasociliary nerve leave the main trunk as it crosses over the optic nerve on its way to the medial wall of the orbit. These are accompanied by the short ciliary nerves (of the long root of the ciliary ganglion). They pierce the posterior portion of the sclera and continue anteriorly between the sclera and choroid, and are finally distributed to the cornea and iris. Like the short ciliary nerves, the long ciliary nerves are accompanied by branches of the superior cervical ganglion to bring sympathetic innervation to the papillary dilatator muscles.

The infratrochlear nerve (n. infratrochlearis) is probably the largest branch of the nasociliary. Being one of the two terminal branches of the nasociliary – the other being the anterior ethmoidal- it precedes from the nasociliary just before the latter enters the anterior ethmoidal foramen. Traveling with the medial rectus muscle, it runs parallel with the supratrochlear nerve (from the frontal branch of the ophthalmic nerve) and is joined by a filament form the supratrochlear near the tendinous pulley of the superior oblique muscle. The infratrochlear continues to the medial aspect of the orbit and divides into two sets of branches.[1] The superior branches supply the skin of the eyelids. The branches of the inferior group supply the conjunctiva, lacrimal sac, lacrimal caruncle, the lacrimal duct, and the skin of the root of the nose.

Frequently the nasociliary gives off small branches to the superior ad inferior recti muscles.[1] Also, a branch to the levator palpebrae superioris has been reported.

The posterior ethmoidal nerve (n. posterior ethmoidalis; the sphenoethmoidal) comes off the nasociliary nerve in the anterior medial corner of the eye and enters the posterior ethmoidal foramen. From there, the nerve provides afferent innervation to the posterior ethmoidal air cells, the mucous membranes of the sphenoidal sinuses, and the dura mater.

The Frontal Nerve

The frontal nerve (n. frontalis) is the largest division or branch of the ophthalmic nerve. It should be regarded as the continuation of the ophthalmic past its entrance to the orbit through the superior orbital fissure. From this large fissure in the sphenoid bone, the nerve runs forward between the levator palpebrae superioris muscle and the periosteum of the sphenoid bone. The frontal then divides into two branches, the larger supraorbital and smaller supratrochlear nerves.

The supraorbital nerve continues anteriorly through the orbit and exits through the supraorbital foramen, which is often a fissure, groove, or just a notch in the frontal bone, to reach the substance of the forehead. At this point, just superior to the supraorbital margin of the frontal bone,[9] the supraorbital nerve gives off a smaller medial branch, thus giving from that point two actual supraorbital nerves, both of which become cutaneous nerves. Cryer[1] stated:

> *Occasionally the division of the supraorbital nerve takes place within the orbit, the larger branch passing through the supraorbital foramen, while the smaller branch extends internally around the supraorbital arch or through the frontal notch, which is occasionally present*.

These branches bring afferent innervation to the frontalis muscle of the forehead and scalp, reaching as far posterior as the vertex.[10] However, this author has personally dissected branches of the supraorbital as posterior as the lamdoidal suture. Cryer[1] confirms this finding.

The supraorbital nerve also innervates the upper eyelid, the mucous membrane of the frontal sinus of the frontal bone, the galea aponeurosis (Latin: a leather helmet; the fascial tissue which extends between the frontalis and occipitalis muscles of the skull.), and the orbicularis oculi. In addition, these branches anastomose with the temporal branches of the facial, or seventh, cranial nerve as well as send small twigs to the pericranium (the periosteum of the skull) to innervate the frontal and parietal bones.

The supratrochlear nerve (n. supratrochlearis) branch is the smaller of the two terminal branches of the frontal nerve. It travels anterior and medially, over the trochlear muscle to the pulley of the superior oblique muscle and gives off a descending filament or branch which anastomoses with the infratrochlear nerve branch of the nasociliary nerve. The supratrochlear nerve then turns superiorly on the medial portion of the supraorbital margin of the frontal bone and supplies sensory innervation to the medial portion of the upper eyelid, the conjunctiva, and substance of the forehead.

In the next article, the larger and very influential maxillary nerve or second division of the trigeminal will be presented in detail.

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The Trigeminal Nerve. Part III: The Maxillary Division

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ABSTRACT: The maxillary nerve gives sensory innervation to all structures in and around the maxillary bone and the midfacial region including the skin of the midfacial regions, the lower eyelid, side of nose, and upper lip; the mucous membrane of the nasopharynx, maxillary sinus, soft palate, palatine tonsil, roof of the mouth, the maxillary gingivae, and maxillary teeth. This vast and complex division of the trigeminal nerve is intimately associated with many sources of orofacial pain, often mimicking maxillary sinus and /or temporomandibular disorders, knowledge of this nerve must be second nature. Just providing the difficult services of a general dental practice should be stimulus enough to understand this trigeminal division, but if one hopes to correctly diagnose and treat orofacial pain disorders, dedication to understanding this nerve cannot be overstated. In this, the third of a four part series of articles concerning the trigeminal nerve, the second or maxillary division will be described and discussed in detail.

The maxillary nerve (n. maxillaries; superior maxillary nerve), or second division of the trigeminal nerve, is intermediate in size in comparison to smaller ophthalmic and largest mandibular divisions. Designated as V2, this large nerve with multiple branches, like the ophthalmic nerve (V1), is purely sensory in function. The maxillary nerve gives sensory innervation to all structures in and around the maxillary bone and the midfacial region including the skin of the midfacial regions, and lower eyelid, side of nose and upper lip; the mucous membrane of the nasopharynx, maxillary sinus, soft palate, palatine tonsil, roof of the mouth, the maxillary gingivae and maxillary teeth (Figure 1).

The maxillary nerve has its origin in the middle portion of the Gasserian ganglion, between the ophthalmic and mandibular nerves, as a rather flattened band. It passes anteriorly, low in the lateral wall of the cavernous sinus, to the foramen rotundum of the sphenoid bone, where it becomes more cylindrical and compact.[1] After exiting the cranium through the foramen rotundum, the maxillary nerve passes through the superior portion of the pterygopalatine fossa within the infratemporal fossa encased within adipose tissue, giving off several branches. For clarification, a fossa (Latin: a ditch) is defined by Brash and Jamieson[2] as: "A depression, usually broad and shallow." Cryer[3] described the maxillary nerve in this fashion: "It then enters the pterygopalatine fossa, and becomes more rounded and firmer in texture."

Continuing anteriorly, the maxillary nerve inclines laterally on the posterior surface of the orbital canal through the inferior orbital fissure in the maxillary bone. There, the maxillary nerve becomes the infraorbital nerve.

In the infraorbital canal, which passes through the superior and medial region of the maxillary sinus, the infraorbital nerve continues its anterior course through the maxillary bone in the floor of the orbit. This nerve exits the orbit through the infraorbital foramen directly under the levator labii superioris muscle and divides into three terminal branches: 1.0 the inferior palpebral; 2. the lateral nasal; and 3. the superior labial nerves. In addition, these terminal infraorbital branches, especially the superior labial branched, communicate with branches of the facial, or seventh cranial nerve.

The branches of the maxillary nerve can be divided into four groups, each of which corresponds to its anatomic origin. (**Table 1**).

In the Cranium

Originating within the cranium, the middle meningeal nerve (n. meningeus medius; meningeal or dural branch) arises from the maxillary nerve immediately after the maxillary leaves the Gasserian ganglion within the middle cranial fossa just before the foramen rotundum. This smaller filament accompanies the frontal branch of the middle meningeal artery and provides innervation to areas of the dura mater of the middle cranial fossa. Smaller filaments leave the middle meningeal nerve and supply the dura as far anteriorly as the anterior cranial fossa. It also receives a filament providing sympathetic fibers from the internal carotid plexus. This is certainly the smallest branch of the maxillary nerve.

Nerves Originating in the Pterygopalatine Fossa

There are at least 15 separate branches (with numerous minor branches) of the maxillary nerve which leave the nerve within the pterygopalatine fossa, a depression deep within the infratemporal fossa. In addition, this region contains the sphenopalatine ganglio, a cluster of cells which subserve the maxillary region concerning autonomic functions.

Table 1
Branches of the V2

Origin of branch	Nerve or branch
In the cranium	Middle meningeal
In the pterygopalatine fossa	Ganglionic branches
	Zygomatic
	Orbital
	Orbital branches
	Pharyngeal
	Posterior palatine
	Middle palatine
	Anterior palatine (greater palatine)
	Lateral posterior superior nasal branches
	Medial posterior superior nasal branches
	Posterior Inferior nasal branches
	Nasopalatine
	Zygomandibularis
	Posterior superior alveolar
In the infraorbital	Middle Superior alveolar
Canal	Anterior superior alveolar
On the face	Inferior palpebral
	Lateral nasal
	Superior labial

The ganglionic branches. After the maxillary nerve exits the middle cranial fossa through the foramen rotundum of the sphenoid bone and enters the pterygopalatine fossa, two nerves, providing sensory innervation to the sphenopalatine ganglion, These two small nerves thereafter branch themselves. A few of their branches provide sensory innervation to the ganglion itself, with other branches passing directly to the palatine nerves.

The zygomatic nerve. The zygomatic nerve (n. zygomaticus; orbital nerve; temporomalar nerve) arises from the maxillary nerve in the pterygopalatine fossa and travels anteriorly and superiorly to enter the orbit through the inferior orbital fissure. After entering the orbit, the zygomatic nerve divides in two branches: a. the zygomaticotemporal and b. zygomaticofacial nerves.

The zygomaticotemporal nerve (ramus zygomaticotemparalis; temporal branch) travels along the infer-lateral angle of the orbit in a groove in the zygomatic or malar bone. It supplies a communicating branch to the lacrimal nerve of the ophthalmic nerve (V1), or first division of the trigeminal nerve. At times, when the lacrimal nerve is lacking, the zygomaticotemporal becomes its replacement and innervates the lacrimal gland. Exiting the zygomatic bone through the zygomaticotemporal foramen, the nerve travels within the substance of the temporalis muscle superior to the zygomatic arch, ascends to the surface of the muscle and pierces the temporal fascia, and branches to areas of the skin in the lateral forehead and anterior temporal areas of the skull. The zygomaticotemporal nerve produces a small branch which runs in fascia to the lateral corner of the eye and provides a communicating branch to the auriculotemporal nerve, a major branch of the mandibular division (V3) of the trigeminal. Lastly, this nerve also communicates with the facial nerve.

The zygomaticofacial nerve (ramus zygomaticofacialis; malar nerve) is the second branch of the zygomatic nerve. This sensory nerve passes along the inferior and lateral edge of the orbit and appears on the face as two branches after passing through the zygomaticofacial foramen of the zygomatic portion of the zygomatic arch, anterior to the zygomaticotemporal foramen. It perforates the orbicularis oculi muscle and innervates the skin on the anterior portion of the cheek. It hen anastomoses with the maxillary branch of the facial nerve.

The orbital nerve. Although not normally mentioned in anatomy textbooks, the orbital nerve has been observed by this writer and described in detail in primates as the orbitociliary nerve by Ruskell.[4]

After leaving the main trunk the maxillary nerve in the pterygopalatine fossa, the orbital nerve arises anteriorly and superiorly, passes through the inferior orbital fissure, passes through the ciliary ganglion without synapsing, and pierces the globe of the eye.

The orbital branches. Different from the orbital nerve, there are two or three small rami which originate from the sphenopalatine ganglion, pass through the inferior orbital fissure, and provide sympathetic innervation to the orbitalis muscle and orbital periosteum; the sympathetic filament being supplied by the internal carotid plexus.

The pharyngeal nerve (pterygopalatine nerve). The pharyngeal nerve is a small maxillary branch arising from the posterior portion of the sphenopalatine ganglion. Being purely afferent, this small filament travels with the pharyngeal branch of the maxillary artery in the pharyngeal canal (palatino-vaginal canal) in the roof of the nasal fossa, placed between the body of the sphenoid bone and the sphenoidal process of the palatine bone. It brings innervation to the mucous membrane of the pharynx and the sphenoidal sinus.[2]

The posterior palatine (n. palatinus posterior; least palatine nerve) *nerve.* The posterior palatine nerve descends posteriorly and inferiorly from the sphenopalatine ganglion through the pterygopalatine canal which runs between the maxillary bone and the perpendicular plate of the palatine bone to open as a foramen. After exiting the pterygopalatine foramen, the posterior palatine nerve supplies the soft palate, palatine tonsils, and uvula.

The middle palatine (n. palatinus medius; lesser palatine nerve) *nerve.* This minor palatine nerve, after leaving the sphenopalatine ganglion, travels through a small canal of the same name in the palatine bone and provides sensory innervation to the uvula, palatine tonsil, and the soft palate. This nerve and the posterior palatine nerve anastomose with branches of the glossopharyngeal nerve (cranial nerve IX) to form a tonsil plexus (circulus tonsillaris) around the palatine tonsil.

In addition, Williams, et al.[1] Stated: "Fibers conveying taste impulses from the palate probably pass via the palatine nerves to the sphenopalatine ganglion and through it to the nerve of the pterygoid canal and greater petrosal nerve to the facial ganglion, where their somata are situated." These authors continued by writing: "The central processes of these neurons traverse the sensory root of the facial nerve (nervus intermedius) to pass to the nucleus solitarius." This innervation provides taste sensation of the posterior soft palate.

The anterior palatine (n. palatinus anterior; greater palatine nerve) *nerve.* This largest of the palatine nerves leaves the sphenopalatine ganglion, travels directly inferiorly through the pterygopalatine (greater palatine) canal of the maxillary bone, and exits through the greater palatine foramen. Then, the nerve continues anteriorly on the hard palate in a groove between the horizontal and perpendicular plates of the maxillary bone to reach the anterior palate and anastomose with the nasopalatine (incisive) nerve. It provides sensory innervation to the gingivae, the mucous membrane, and glands of the hard palate. While in the pterygopalatine canal, the anterior palatine nerve gives off the posterior inferior nasal branches.

The medial posterior superior nasal (rami nasals medialis posteriors superiors) *branches.* These nerves, usually two or three in number, leave the sphenopalatine ganglion, cross the roof of the nasal fossa below the opening of the sphenoidal sinus to provide innervation to the mucosa of the posterior portion of the roof and the nasal septum.

The posterior inferior nasal nerves. These nerves, which vary in number, arise from the anterior palatine nerve while the latter courses through the greater palatine canal. These branches travel through the perpendicular plate of the palatine bone through unnamed foramina to provide sensory innervation to the inferior conchae of the nose and the walls of the middle and inferior meatuses and to the soft palate via a palatine branch of this group.

The nasopalatine nerve. The largest nerve emerging from the sphenopalatine ganglion, the nasopalatine nerve travels through the sphenopalatine foramen to enter the nasal fossa just below the orifice to the sphenoidal sinus to reach the nasal septum. From there, it runs in an oblique direction anteriorly and inferiorly between the periosteum and mucous membrane of the nasal septum. Continuing inferiorly and after anastomosing with the opposite nasopalatine, it exits the maxilla through the nasopalatine foramen (incisive foramen), posterior and between the maxillary central incisor teeth, and is thereafter called the incisive nerve. According to Williams, et al.[1] at times both the posterior and anterior incisive foramina may exist in the nasal fossa, with the left nasopalatine nerve leaving the fossa through the anterior foramen and the right nerve through the posterior foramen before uniting as the incisive nerve. The incisive nerve communicates with both anterior palatine (greater palatine) nerves to provide sensory innervation to the nasal septum and the muscosa of the anterior hard palate.

The pre-temporal or zygomandibularis nerve. Recently described by Shankland, et al., [5] the pre-temporal nerve seems to arise from the sphenopalatine ganglion and travel anterior and laterally to innervate the zygomandibularis muscle, possibly conveying parasympathetic fibers and somatosensory innervation.

The posterior superior alveolar nerves. Traditionally taught as just one nerve, this group of branches (rami alveolares superiors poateriores; superior alveolar nerve) arise from the maxillary nerve in the pterygogpalatine fossa just prior to the maxillary's entrance to the inferior orbital fissure in the maxilla. Cryer[3] reported the posterior superior nerve leaves the maxillary just after the former provides its two branches to the sphenopalatine ganglion. These nerves descend on the maxillary tuberosity to enter the posterior portion of the maxilla. This is true, but in addition, the present writer has noted on numerous occasions during anatomical dissections that the posterior superior alveolar nerve generally enters the maxilla laterally and not posteriorly, just superior to the apices of the second and third molar teeth. Mercuri[6] agreed with this finding and reported that the posterior superior alveolar nerve divided into an external gingival branch (corresponding to the lateral foramina observed) and an internal dental branch. This fact is demonstrated by examining dry human skulls and reviewing photographs like those demonstrated by White and Folkens.[7]

After entering the maxilla in numerous unnamed foramina, the posterior superior alveolar nerves travel forward under the mucosa of the maxillary sinus, supplying afferent innervation to these membranes. Continuing anteriorly, the posterior superior alveolar nerves communicate with the middle superior alveolar nerve and give branches which form a dental plexus and innervate the second and third molars as well as the palatal and distobuccal roots of the maxillary first molar. In addition, the posterior superior alveolar nerve provides innervation to the maxillary posterior gingivae and mucous membranes of the buccal mucosa.

Nerves Originating in the Infraorbital Canal

After the maxillary nerve enters the maxilla through the inferior orbital fissure and becomes the infraorbital, the latter travels through the medial and superior area of the maxillary sinus, traveling below the orbit to emerge on the face through the infraorbital foramen. In the maxillary bone, two main branches arise from the infraorbital.

The middle superior alveolar nerve (ramus alveolaris medius; middle superior dental nerve) leaves the infraorbital nerve in the posterior portion of the infraorbital canal. This nerve descends downward and runs forward in a canal in the lateral wall of the maxillary sinus to produce three terminal branches which enter the mesiobuccal root of the first molar and the apices of each of the premolar teeth. The middle superior alveolar also anastomoses with the posterior superior alveolar. This nerve is not without controversy. Wood[8] denied that there was a frequent occurrence of the middle superior alveolar nerve. But Fitzgerald[9] disagreed, demonstrating that in his dissections, a middle superior alveolar nerve was present in 82% of his specimens and absent in only 18%, being replaced by the anterior superior alveolar branch. Yet, Loetscher and Walton (1988) reported that in such cases, the posterior superior alveolar supplied innervation when the middle branch was missing.

The anterior superior alveolar nerve (ramus alveolaris superior anteriores; superior dental nerve) is the other branch which arises from the infraorbital in the infraorbital canal. This nerve, being larger than the middle superior alveolar, leaves the infraorbital just prior to the infraorbital's exit through the infraorbital foramen. It descends inferiorly in a canal in the anterior wall of the maxillary sinus and divides into branches which innervate the central and lateral incisor teeth as well as the canine. After communication with the middle superior alveolar nerve, a nasal branch is give off which travels through a small, unnamed foramen in the lateral wall of the inferior meatus of the nasal fossa, thus supplying sensory innervation to the mucous membrane of the anterior portion of the inferior meatus and floor of the nasal cavity. This nasal branch continues further to anastomose with the nasal branches of the sphenopalatine ganglion.

Nerves Originating on the Face

After the maxillary division of the trigeminal nerve enters the maxilla and becomes the infraorbital nerve, it continues to travel anteriorly, giving off the middle superior and anterior superior alveolar nerves and ultimately, after leaving the maxilla through the infraorbital foramen, ends as three nerves, each of which is composed of several branches: 1. the inferior palpebral nerve; 2. the lateral nasal nerve; and 3. the superior labial nerve.

The *inferior palpebral branches* (rami palpebrales inferiors), which are usually two or three in number, ascend posterior to the orbicularis oculi muscle to supply afferent innervation to the skin and conjunctiva of the lower eyelid. These branches then communicate with the zygomatic branch of the facial nerve near the lateral canthus of the eye. A branch of the inferior palpebral nerve also anastomoses with the external nasal branch of the ophthalmic (V1) division of the trigeminal nerve.

The *lateral nasal nerve*, usually two or three in number, supply the skin of the nose and the movable portion of the nasal septum and also join the external nasal branch of the ophthalmic nerve. In addition, the lateral nerve innervates the mucous membrane lining of the nostril and communicates with the nasociliary of the ophthalmic nerve.

The *superior labial nerve* is the largest of the three branches, both in area of distribution and numbers of branches. After exiting the infraorbital foramen, the superior labial nerve descends inferiorly beneath the quadratus labia superioris muscle, divides into several branches, and provides afferent innervation to the upper lip and its skin, labial mucous glands, and the mucous membrane of the upper lip and buccal vestibule. These superior labial branches anastomose with the zygomatic branch of the facial nerve to form the infraorbital plexus.

In the fourth and last article, the third division or mandibular nerve will be discussed in detail.

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The Trigeminal Nerve. Part IV: The Mandibular Division

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ABSTRACT: The mandibular or third division of the trigeminal nerve is the largest of the three divisions. It is considered a mixed nerve. That is, like the ophthalmic and maxillary divisions, the mandibular conveys afferent fibers. But unlike the former two divisions, the mandibular also contains motor or efferent fibers to the muscles of mastication, the mylohyoid and anterior digastric muscles, and the tensor veli palatine and tensor tympani muscles. So intimately associated with dentistry, the mandibular nerve has also been termed the dental nerve by anatomists in the past. This extensive and complicated division of the trigeminal nerve can cause confusion to both patient and doctor. Pain is often referred within its branches and even into other trigeminal divisions, chiefly the maxillary. This fourth and last article about the trigeminal nerve will present in detail the mandibular division.

The mandibular division (V3) of the trigeminal nerve (n. mandibularis; inferior maxillary nerve) is the largest of the three major divisions of the trigeminal nerve. Unlike the ophthalmic and maxillary divisions which are purely afferent or sensory, the mandibular division is a mixed nerve, meaning that there are both sensory and motor comments to various branches of the nerve (**Figure 1**). The mandibular division is composed of two separate roots: 1. a large sensory root which proceeds from the inferior angle of the Gasserian ganglion; and 2. a small motor root, which originates within the pons of the central nervous system. This trigeminal division supplies afferent innervation to the teeth and gingivae of the mandible; the skin of the temporal region and lower one-third of the face, the ear, and the lower lip; the muscles of the first bronchial arch; and the mucous membrane of the anterior two-thirds of the tongue and the floor of the mouth. The mandibular division also brings motor innervation to the muscles of the first branchial arch (the muscles of mastication, the tensors veli palatine and tympani, the mylohyoid muscle, and anterior belly of the digastric muscle), **Table 1**.

The motor innervation of the branchial muscles is quite interesting. Generally, voluntary or striated muscles, termed somatic or parietal muscles, are derived embryologically from myotomes which are products of mesenchyme, Mesenchymal tissue is not a product of a specific germ layer (e.g., ectoderm, mesoderm, or endoderm), but instead, it is a primitive type of connective tissue, formed into a mesh or network and may develop into one of many different types of tissues depending upon chemical influences derived from the developing embryo. The muscles of mastication (as well as the tensor veli palatine, and tensor tympani muscles, the mylohyoid muscle, and anterior belly of the digastric muscle) develop embryologically from splanchnic (Gk: one of the viscera) mesoderm and not mesenchymal mesoderm. Therefore, the muscles of mastication are referred to as the visceral musculature.

Unlike muscles of the viscera, these muscles are voluntary and striated.[1] These visceral muscles, better referred to as branchial muscles, are innervated by cranial nerves; chiefly, the fifth, seventh, ninth, and tenth cranial nerves. However, only the fifth or trigeminal nerve also contains somatic sensory fibers, which also provide afferent processing of most of the afferent information for the latter three cranial nerves. Hyman[1] stated:

Because of the very large spread of the somatic sensory part of the trigeminus in order to supply practically the skin of the whole head, the somatic sensory component of the remaining branchial nerves is greatly reduced or wanting.

The main trunk of the mandibular nerve divides into two rather large divisions and a small trunk. All three of these subdivisions are considered mixed nerves, being that each portion of the division carry both afferent and efferent components (**Table 2**).

The mandibular division of the trigeminal nerve, after exiting the middle cranial fossa through the foramen ovale in the sphenoid bone, descends into the infratemporal fossa. This irregularly shaped cavity is located inferiorly and medially to the zygomatic arch. The medial wall of the fossa is formed anteriorly by the lateral pterygoid plate and posteriorly by the tensor veli palatine and medial pterygoid muscles. The anterior boundary is formed by the infratemporal or posterior surface of the maxilla. The anterior and medial walls of the infratemporal fossa are separated superiorly by the pterygomaxillary fissure through which the infratemporal fossa communicates with the pterygopalatine fossa. This small space between the upper part of the posterior surface of the maxilla and the roof of the lateral pterygoid plate houses, among other structures, the sphenopalatine ganglion and the maxillary artery.

The posterior extent of the infratemporal fossa is the articular tubercle of the temporal bone (including the temporomandibular joint), the carotid sheath, the styloid process, and the spina angularis of the sphenoid bone. The roof of the infratemporal fossa is composed of the greater wing of the sphenoid bone and the squamous portion of the temporal bone. Superiorly and laterally, the infratemporal fossa blends into the temporal fossa and the body of the temporalis muscle. The roof and anterior wall of the infratemporal fossa are separated by the inferior orbital fissure. The floor of the fossa is continuous with the soft tissues of the neck.

Contained within the infratemporal fossa are muscles (the lower portion of the temporalis, the medial and lateral pterygoids, the zygomandibularis), the maxillary artery and vein, and the maxillary (V2) and mandibular (v3) nerves. Also, forming portions of the medial and anteromedial boundaries of the fossa are the pterygomaxillary fissure which leads into the pterygopalatine fossa, where the maxillary nerve begins to form its various branches.

Table 1

Muscles of Mastication and Associated Innervations

Muscle	Nerve branch of motor division of V3
Temporalis	Posterior deep temporal –usually 2 (from anterior division of V3)
Zygomandibularis	Anterior deep temporal (from anterior division of V3)
Masseter	Masseteric (from anterior division of V3)
Superior belly of lateral pterygoid	Lateral pterygoid (from anterior division of V3)
Inferior belly of lateral pterygoid	Lateral pterygoid (from the anterior division of V3)
Medial pterygoid	Medial pterygoid (from main trunk of V3)
Tensor veli palatine*	Branch of the pterygoid n.
Tensor tympani*	Branch of the medial pterygoid n.
Mylohyoid*	Mylohyoid n. (from posterior division of V3)
Anterior belly of digastric	Mylohyoid n.

*Although not considered muscles of mastication, these muscles are traditionally included with the masticatory muscles due to the common innervation of the branches of V3.

Table 2

Branches of V3

Division	Nerve	Sensory	Neurological component motor	Prop
Undivided trunk	Meningeal	x		
	Medial pterygoid	x	x	x
	Tensor veli palatine	x	x	x
	Tensor tympani	x	x	x
Anterior division	Buccal	x	x*	
	Lateral pterygoid	x	x	x
	Massetric	x	x	x
	Anterior deep temporal	x	x	x
	Posterior deep temporal	x	x	x
Posterior division	Auriculotemporal	x	x**	
	Lingual	x	x***	
	Inferior alveolar	x		
	Mylohyoid	x	x	

* There are differences of opinions concerning motor fibers in the buccal nerve.

** Carries postganglionic parasympathetic fibers to the parotid gland from the glossopharyngeal nerve via the otic ganglion.

*** Carries preganglionic parasympathetic fibers from the facial nerve via the chorda tympani nerve which joins the lingual to innervate the submandibular and sublingual glands.

The Undivided Trunk

After the mandibular nerve, both sensory and motor portions, leaves the middle cranial fossa through the foramen ovale, just prior to the main trunk dividing into anterior and posterior divisions, four nerve branches leave the undivided trunk.

The recurrent meningeal nerve. The first branch off the undivided trunk is the recurrent meningeal or nervous spinosus. This small nerve re-enters the cranium through the foramen spinosum with the middle meningeal artery from the maxillary artery. The nerve, bringing sensory innervation to the dura mater of the middle cranial fossa, divides into anterior and posterior divisions. The anterior branch communicates with the meningeal branch of the maxillary nerve and the posterior branch sends filaments to the mucous membrane of the mastoid air cells.[2]

The medial pterygoid nerve (n. pterygoideus medius; n. pterygoideus internus) exits the undivided trunk below the foramen ovale, travels through the otic ganglion with some synapsing, and provides sensory, motor, and proprioceptive innervation to the medical pterygoid muscle.

The tensor veli palatine nerve. The nerve to the tensor veli palatine muscle is given off the undivided mandibular trunk and like the medial pterygoid nerve, travels through the otic ganglion to enter the tensor veli palatine near its origin at the base of the medial pterygoid plate of the sphenoid bone. This short nerve provides sensory and motor innervation to the muscle.

The tensor tympani nerve may arise separately or in common with the tensor veli palatine nerve from the undivided trunk. Like the medial pterygoid and tensor veli palatine nerves, it too, passes through the otic ganglion and yet, does not synapse with any cell bodies. The nerve pierces the cartilage of the auditory canal and enters the tensor tympani muscle to supply motor and sensory innervation.

The nerves to the tensor muscles are usually described in anatomical texts as branches originating form the otic ganglion, a collection of parasympathetic cell bodies of the ninth cranial, or glossopharyngeal nerve. However, according to Crafts[3] and from the present writer's dissections, these two nerves have no anatomical connection to the otic ganglion aside from passing through the ganglion, with occasional filaments arising and synapsing within the ganglion.

Some authors[4] contend that the tensor veli palatine and tensor tympani nerves are not separate bur are branches of the medial pterygoid nerve. These two small branches arise from the medial pterygoid nerve as the latter passes through the otic ganglion.

The Anterior Division

After providing the above mentioned four nerve branches, the main trunk travels approximately 7.7 millimeters[5] inferior to the foramen ovale and divides into a smaller anterior division and a larger posterior division. The two divisions are separated by a fibrous band termed the pterygospinous ligament. This structure may ossify which forces the anterior division to pass through a separate opening in the bone, the pterygospinous foramen.[2]

Although both divisions are mixed nerves, the anterior carries most of the motor fibers. The branches of this smaller division supply the muscles of mastication, the buccal mucosa and skin of the cheek, and even portions of the mandibular buccal (lateral) gingivae.

The <u>*buccal nerve*</u> (n. buccinatorius; n. buccalis; buccinator nerve; long buccal nerve) is the only branch of the anterior trunk which carries sensory fibers only. It courses laterally in the infratemporal fossa and passes between the two heads of the lateral pterygoid muscle. Continuing laterally, a small branch is given to the temporalis muscle as the nerve pierces this large structure. The buccal nerve passes superiorly to the medial pterygoid muscle and penetrates the buccinator muscle, terminating by dividing into superior and inferior divisions. The buccal nerve delivers sensory innervation to the buccinator muscle, the buccal mucosa, and the skin of the corner of the mouth. It anastomoses with the buccal branch of the facial nerve as the latter provides motor innervation to the buccinator, the only muscle of the first branchial arch not to receive motor fibers form the trigeminal nerve.

An unusual nerve, the buccal appears to be the only branch of the anterior division or the mandibular nerve not to contain motor fibers. However, Crafts[3] reported that the buccal was a mixed nerve to the point of the emergence of temporalis branch.

At times the buccal nerve is the main trunk for the anterior division. If this occurs, the buccal nerve gives off at least five branches as it courses form deep within the infratemporal fossa to its destination in the buccinator muscle: 1.0 two or three lateral pterygoid branches; 2. an anterior deep temporal branch, which joins the posterior deep temporal nerves; 3. a descending temporalis branch which innervates the muscle's insertion into the coronoid process of the mandible; 4. superior terminal branches which supply the superior portion of the buccinator muscle as well as the skin and mucosa of the inferior zygomatic arch and cheek regions; and 5. inferior terminal branches which travel anteriorly to the corner of the mouth to bring afferent fibers to the skin, buccal mucosa, and mucous glands in the area. Both terminal branches anastomose with the buccal branch of the facial nerve. Generally, these nerves are individual branches which arise from the anterior trunk. The anterior division is the most varied of all the branches of the entire trigeminal nerve.

The *nerve to the lateral pterygoid muscle* (n. pterygoideus lateralis) may arise separately or in conjunction with the buccal nerve off the anterior division of V3. Cryer[6] reported that the lateral pterygoid nerve may even arise with the medial pterygoid nerve from the undivided portion of the mandibular nerve. Needless to say, this nerve is the most inconsistent of all the individual branches of the entire trigeminal nerve. When absent, the buccal or masseteric nerves provide innervation to the two separate heads of the lateral pterygoid muscle. When present, the lateral pterygoid nerve enters both bellies on the deep surfaces of the muscle, bringing afferent, efferent, and proprioceptive fiber innervation.

The *masseteric nerve* (n. massetericus). After leaving the anterior division of the mandibular nerve, the masseteric nerve courses laterally through the infratemporal fossa, passing superior to the lateral pterygoid muscle and anterior to eh temporomandibular joint, giving several small branches to the anteromedial aspect of the joint, most likely for proprioception.[8]

Traveling further, the masseteric nerve runs through the mandibular notch between the condylar and coronoid processes of the mandible, posterior to the temporalis tendon and ultimately to the deep surface of the masseter muscle. This nerve, which often replaces the lateral pterygoid, carries sensory, motor, and proprioceptive fibers.

The *anterior deep temporal nerve* (n. temporalis profundus anteriores) carrying sensory, motor and proprioceptive fibers, leaves the anterior division of the mandibular nerve superior to the lateral pterygoid muscle. It often arises with the buccal nerve, being one or two in number. It courses anteriorly in the infratemporal fossa and then turns superiorly, passing into the temporal fossa on the lateral aspect of the skull to enter the anterior portion of the temporalis on its deep surface. Recently, it has been reported that either the anterior deep temporal nerve or a branch of this nerve provides innervation to a newly described muscle of mastication, the zygomandibularis.[7] This makes sense academically. Even though the anterior deep temporal nerve is listed in many anatomy texts, its destined structure to innervate is not listed.

The *posterior deep temporal nerves* (nn. Temporalis profundus posteriors) arise with their anterior mate and basically travel together with the anterior branch as well. The posterior deep temporal nerves, generally two or three in number, after arising to the level of the temporal fossa, enter the temporalis muscle on its deep surface about an inch above the zygomatic arch. From there, the nerves branch, course upward and somewhat posteriorly to communicate with the auriculotemporal and facial nerves. These nerves also give sensory branches to the medial portion of the temporomandibular joint. Like the anterior deep temporal, the posterior deep temporal nerves carry afferent, efferent, but mostly proprioceptive fibers according to Mahan and Alling.[8]

The Posterior Division

The larger posterior division of the mandibular nerve, although still classified as a mixed nerve, is primarily sensory. It does carry some motor fibers, but even at this time, there are questions as to what extent the motor fibers exert influence.

The *auriculotemporal nerve* (n. auriculotemporalis) is a large nerve, innervating a vast area. Throughout its course, the auriculotemporal itself produces five terminal branches. The common representation of the origin of the auriculotemporal is either that of two short roots that tightly envelop the middle meningeal artery and then combine or of a large, posterior branch of the mandibular nerve that splits to enclose the artery, only to recombine again. For more than a century this was the accepted and undisputed anatomy of the nerve.

However, Baumel et al.[9] reported that the roots of the auriculotemporal nerve do not, contrary to accepted anatomical dogma, form a loop around the middle meningeal artery. Rather, they discovered that the nerve was formed by two roots, both of which sprung from the undivided trunk, and not the posterior division, of the trigeminal nerve. Further, they wrote: "The upper, larger root lies lateral to the middle meningeal artery; the lower, smaller root is medial to the artery." In the 85 cadavers measured, the vertical mean distance between these two roots was six mm and the roots were relatively long (mean average of 15mm). Lastly, they reported, contrary to former understanding, that the auriculotemporal nerve consistently formed six, not five, terminal branches.

The main trunk of the auriculotemporal nerve passes out of the infratemporal fossa posteriorly to the lateral pterygoid muscle, proceeds between the neck of the mandibular condyle and the sphenomandibular ligament. It then ascends posterior to the temporomandibular joint and anterior to the cartilaginous tragus of the ear and deep to the parotid gland to rise superiorly, traveling with but deep to the superficial temporal artery to provide distribution in a similar fashion to that of the superficial temporal artery on the lateral aspect of the skull.

The auriculotemporal nerve is closely associated with the seventh cranial or facial nerve, but rarely were actual communications mentioned in anatomical textbooks. The facial nerve provides motor innervation for the muscles of facial expression and parasympathetic secretomotor fibers to the buccal and labial glands, the lacrimal gland, mucous membranes of the nose, the paranasal air sinuses, the submandibular and sublingual glands, and glands in the hard and soft palate. This branchial cranial nerve also carries neurons which originate within the geniculate ganglion to provide taste sensation to the anterior two-thirds of the tongue.

After exiting the sylomastoid foramen of the temporal bone, the facial nerve divides into two major branches in the parotid gland, the upper (temporofacial) and the lower (cervicofacial) divisions. These two divisions give off the temporal, zygomatic, buccal, mandibular and cervical branches of the facial nerve. The buccal branches are derived from both the upper and lower divisions, which anastomose with each other.

It was not until a report published in 1994 that these communicating branches were known. Namking, et al.[10] classified the various types of anastomosing of these two nerves. They reported that in 60.4% of their 55 cadaver specimens, the facial and auriculotemporal nerves communicated via two separate branches only between the upper division of the facial nerve posteriorly at the posterior border of the masseter muscle. They also noted one communicating branch in 20.7% of the specimen and three branches in 15.1% of the cadavers.

Classically, it has been accepted that the auriculotemporal nerve provides five branches along its course from the infratemporal fossa to its termination in the temporalis muscle. However, there are really eight and not five branches of this important nerve:

1. *Communicating branches with the otic ganglion* (rami communicantes n. auriculotemporalis cum ganglia otico). Usually two in number, these communicating branches run between the auriculotemporal nerve near its origin and the otic ganglion. They carry postganglionic parasympathetic fibers from the glossopharyngeal nerve (ninth cranial nerve) via the lesser superficial petrosal nerve which travel with the auriculotemporal nerve to be distributed to the parotid gland.

2. *Communicating branches with the facial nerve* (rami communicates n. auriculotemporalis cum n. faciali). These are the communicating nerves described by Namking, et al.[10] and briefly discussed above.

3. *The anterior auricular nerve* (n. auricularis anteriores). This branch of the auriculotemporal usually divides to become two in number. They course laterally, turn posteriorly and run with the superficial temporal artery and vein. The anterior auricular nerves then pierce the interval between the lamina of the tragus of the ear and crus of the helix to supply the skin above and below the point of entry.[10]

4. *The external acoustic meatus nerve* (n. meatus acusticus externus). Like the auricular nerve, the external acoustic meatus nerve generally is duplicate, one being superior and the other inferior. Forming a neurovascular plexus with fine twigs of the auricular artery, they both pass between the temporal bone and cartilage to enter the external acoustic meatus.

Both branches enter the acoustic canal at is osseocartilaginous junction. The superior branch pierces the wall of the external acoustic meatus at the squamotympanic fissure just posterior to the postglenoid tubercle,[9] thus supplying one or two twigs to the temporomandibular joint and the tympanic membrane. The inferior branch enters the anterior and inferior area of the bony canal. Both the superior and inferior branches of the external acoustic meatus nerves penetrate deep into the cutaneous lining and divide numerous times.

5. *The articular nerve* (n. articularis). This branch of the auriculotemporal nerve enters the posteriolateral aspect of the joint capsule of the temporomandibular joint and divides into an anterior and posterior division. These nerves provide most of the joint's innervation, evidenced by the fact that

anesthesia of the joint can easily be obtained by administering a local anesthetic block of the auriculotemporal nerve or the articular nerve itself.

6. The *parotid branches* (nn. Parotidel rami). This may be a single nerve arising from the auriculotemporal which, upon entering the parotid gland, divides into numerous filaments or twigs. Or, there may be several of these rami which arise from the main trunk of the auriculotemporal nerve and enter the parotid. In either case, sensory and secretomotor innervation is brought to the parotid gland.

7. *Vascular rami* (rami vasculares). Apparently present infrequently, Bramel, et al.[9] reported communications between the peri-arterial nerve plexes of the maxillary, middle meningeal, superficial temporal arteries with fine branches from the auriculotemporal nerve. Most likely, these nerves convey autonomic fibers to the arterial walls. Laubmann [11] first reported these findings in conjunction with the auriculotemporal nerve.

8. *Superficial temporal branches* (temporales superficiales) are the terminal branches of the auriculotemporal nerve. These branches accompany the branches of the superficial temporal artery which travel to the vertex of the skull. These numerous branches supply afferent innervation to the skin of the anterior temporal region and communicate with the zygomaticotemporal and zygomatic branch of the facial nerve.

The lingual nerve (n. lingualis; gustatory). The lingual nerve is a large branch of the posterior division of the mandibular nerve. It brings sensory innervation to the mucous membrane of the anterior two-thirds of the tongue and terminates in the filiform and fungiform papillae. In addition, the lingual nerve provides small branches to the mucosal tissues medial of the mandible.

The lingual nerve, along with the inferior alveolar nerve and medial to it, comes off the posterior mandibular trunk off the mandibular nerve. The lingual, which travels within the alveolar, is often joined by the lingual artery, a small branch of the maxillary artery.[12] The chorda tympani nerve, which brings secretomotor (parasympathetic) fibers of the seventh cranial nerve, passes between the heads of the lateral pterygoid muscle and joins the lingual nerve. The lingual/chorda tympani bundle splits from the inferior alveolar nerve as all three pass between the medial pterygoid muscle and the medical aspect of the angle of the mandible. At this point, the position of the lingual nerve may vary in its relationship to the medial and superior surfaces of the mandible.

Kiesselbach and Chamberlain[13] described that the lingual nerve was approximately 2.28 millimeters below the height of the mandible and approximately 0.58 mm medial to the mandible. However, in their study they also reported that in 17.6% of cadavers examined, the lingual nerve lay at or above the height of the medial surface of the mandible, thus putting this important nerve at great surgical risk. Pogrel, et al.[14] reported that the position of the lingual nerve on one side bore no statistical relationship to the position of the nerve on the opposite side.

After leaving the inferior alveolar, the lingual crosses obliquely, over the superior constrictor and syloglossus muscles to enter the submandibular ganglion. From there, the lingual and chorda tympani nerves cross Wharton's duct (the submandibular duct) and enter the lateral muscles of the tongue to innervate the mucous membrane of the anterior two-thirds of the tongue. Branches of the lingual nerve also innervate the gingivae and mucosa on the medial (lingual) side of the mandible.

The inferior alveolar nerve (n. alveolar inferior; inferior dental nerve). The inferior alveolar nerve is the largest ranch of the mandibular division of the trigeminal nerve. Arising form the posterolateral area of the main mandibular trunk, the inferior alveolar descends with the inferior alveolar artery (from the maxillary artery) to run below the inferior head of the lateral pterygoid muscle, lateral to the sphenomandibular ligament and medial to the mandibular ramus to enter the pterygomandibular space to travel inferiorly and laterally to reach and ultimately enter the mandible on its posteriomedial aspect posterior to the third molar tooth through the mandibular foramen. Nicholson[15] reported that in 75% of cases which he studied, the mandibular foramen was located below the occlusal surfaces of the molar teeth. Generally, after passing through the mandibular foramen, the inferior alveolar nerve travels through the mandible and divides near the mental foramen into two terminal branches: 1. the incisive and 2. mental nerves.

Before entering the mandible, the inferior alveolar nerve gives rise to the mylohyoid nerve and after entering the mandible, dental branches, which innervate the teeth. There have been rare reports of a bifid mandibular nerve, each division entering the mandible through separate mandibular foramina.[16]

Just prior to entering the mandibular foramen, the neurovascular bundle of the inferior alveolar nerve (inferior alveolar nerve, artery and vein) come together and are encased in a thick fascial sheath.

Wadu, et al.[17] recently reported that the vein was anterior to the artery which was anterior to the inferior alveolar nerve. However, Fawcett[18] described, in his excellent description of the mandibular canal, that:

At the entrance into the canal, the artery lies behind the nerve; beyond that point , and so long as the canal descends, the artery usually lies below and behind the nerve; subsequently the artery in nearly all cases lies on the outer side of the nerve.

The inferior alveolar nerve is configured as a slightly S-shaped curve between its origin and the entrance into the mandibular foramen. This shape provides the necessary slack for the straightening of the nerve during wide opening of the mandible. The Creator used this simple yet ingenious technique of curves in nerves and vessels to provide necessary slack when required (e.g., the facial artery and retromandibular vein).

There have been well-documented studies which have demonstrated the existence of well-defined foramina in the retromandibular fossa of the mandible (the area just posterior to the third molar). These foramina appear to be passages for accessory innervation of the mandible. DuBrul[20] reported an aberrant inferior alveolar branch which is sometimes released superior to the mandibular foramen and enters an anterosuperior foramen on the ramus of the mandible which courses through a separate bony canal to innervate, along with the normal inferior alveolar nerve, the third molar.

The intramandibular course of the inferior alveolar verve may be quite varied. Carter and Keen[21] classified three types of distribution of the nerve:

Type 1: A single nerve running in a bony canal close to the root apices of the mandibular teeth:

Type 2: Was positioned more inferiorly in the body of the mandible than Type 1, giving off longer dental branches to the teeth which were oriented obliquely:

Type 3: The inferior alveolar splits into two divisions, a minor superior one and a more inferiorly placed trunk which continued anteriorly in the body of the mandible to divide into mental and incisive branches.

Carter and Keen[21] also reported that radiographically, Type 1 had an unbroken complete margin of the mandibular canal. Types 2 and 3 tended to show a broken upper wall or were completely lacking in definite mandibular canal.

Cryer[22] described the mandibular canal as a cribiform tube and that this porous nature is lost at or near the molars. However, other researchers, this present writer included, insist that the mandibular canal continues anteriorly primarily intact at least to the mental foramen region.[23-25] Andersen, et al.[25] reported that the inferior alveolar nerve might course through the mandible as a single trunk or as a plexus composed of a various number of different-sized bundles. It is accurate to say that the anatomy of the inferior alveolar nerve is quite varied.

The mental nerve (n. mentalis) exits the mandible through the mental foramen and divides beneath the triangularis muscle generally into three branches; one branch descends to the skin of the chin and two branches ascend to the skin and mucous membrane of the lower lip. However, this present writer has witnessed as many as five branches of the mental nerve. These branches all anastomose with branches of the mandibular branch of the facial nerve. The mental nerve is purely sensory, with no motor fibers.

The incisive nerve, the smallest terminal branch of the inferior alveolar nerve, generally consists of a plexus instead of a nerve trunk. Olivier[27] described the incisive canal as the canal housing the incisive nerve. Barr and Stephens[28] reported that the mandibular canal divided into two small canals, both of which run forward and cease to exist in the bone beneath the mandibular incisor teeth. However, Denissen, et al.[29] did not find and incisive canal when they studied cadaver mandibles. It has been this author's experience that the incisive nerve should be termed the incisive plexus and this agrees with Starkie and Stewart.[30] Generally, the incisive plexus innervates the lateral and central incisors and the canines. At times, there is overlap across the midline at the mental symphysis of the incisive nerves of plexi which never extends past the lateral incisor.

The dental branches of the inferior alveolar nerve supply mostly the molars, premolars, the mandibular bone and medullary spaces, as well as the gingivae. These dental branches are small nerves which arise from the inferior alveolar nerve and generally innervate the molar and premolar teeth, but may also provide innervation to the canine teeth as well.[30] Sutton[31] and Rood[32] have both reported the presence of numerous unnamed accessory foramina which appear to be channels for additional mandibular innervation, especially of the dental pulps. Such additional dental pulpal innervation may be provided by an aberrant inferior alveolar branch, branches of the superficial cervical plexus, the lingual nerve, the mylohyoid nerve, and the masseter, buccal, deep temporal and posterior superior alveolar nerves.[33] Even the auriculotemporal nerve has been identified as another source of mandibular tooth innervation,[34] in addition tot the inferior alveolar nerve.

Above the inferior alveolar nerve, the dental branches form a plexus of nerves which form a plexus of nerves which form fine filaments that pass through the apical foramina in the roots of the teeth to supply innervation to both the external and internal portions of the teeth.

The *mylohyoid nerve* (n. mylohoideus), after leaving the trunk of the inferior alveolar, descends and pierces the sphenomandibular ligament, and runs in a small groove on the medical surface of the mandible. Traveling forward below the mylohyoid line of the mandible, the nerve is joined by the submental artery and vein in the submandibular fossa and reaches the inferior surface of the mylohyoid muscle, releasing several branches which supply the muscle with both sensory and motor innervation. There appears to be good evidence that along its course to the mylohyoid muscle, the mylohyoid nerve frequently provides small branches which enter unnamed medial (lingual) mandibular foramina of the mandible to most likely innervate mandibular anterior teeth.[31,35-39]

From the mylohyoid muscle, the mylohyoid nerve provides one or two branches, continues anteriorly, and provides motor and sensory innervation to the anterior belly of the digastric muscle.[19] The mylohyoid nerve continues anteriorly as a thin cutaneous nerve to the skin of the inferior mental symphysis.

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