Anatomy of the Trigeminal Nerve

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Trigeminal Nerve Nuclei (Fig. 2.1)

The trigeminal nerve has both somatic and motor components with four distinct nuclei controlling neuronal signaling comprising the largest of the cranial nerve nuclei. The motor nucleus is a small, round structure within the pons; whereas the sensory nucleus is quite long extending into the medulla becoming continuous with the posterior horn of the spinal cord. Excluding the fibers to the mesencephalic nucleus, the sensory fibers from the trigeminal nerve travel along axons to their cell bodies in the trigeminal ganglion [1].

All motor and sensory fibers of the trigeminal ganglion enter the brainstem at the level of the mid-pons. The afferent fibers then travel to their respective nucleus in the medulla and even into the spinal cord via the spinal tract to synapse in the long sensory nucleus. Within this framework, the fibers within the brainstem are organized from rostral to caudal as proprioceptive followed by light touch and then pain. In total, the nucleus is divided into four parts from rostral to caudal: mesencephalic nucleus, chief/principal sensory nucleus, motor nucleus, and the spinal trigeminal nucleus. We will discuss each of these in turn [1, 2].

Mesencephalic Nucleus

The mesencephalic nucleus, the most rostral of the nuclei, contains cell bodies of neurons processing proprioceptive input regarding opposition of the teeth and dental pain; and it is the afferent limb for the jaw jerk reflex. The tract and nucleus are located within the caudal midbrain and rostral pons near the periaqueductal gray [1, 2].

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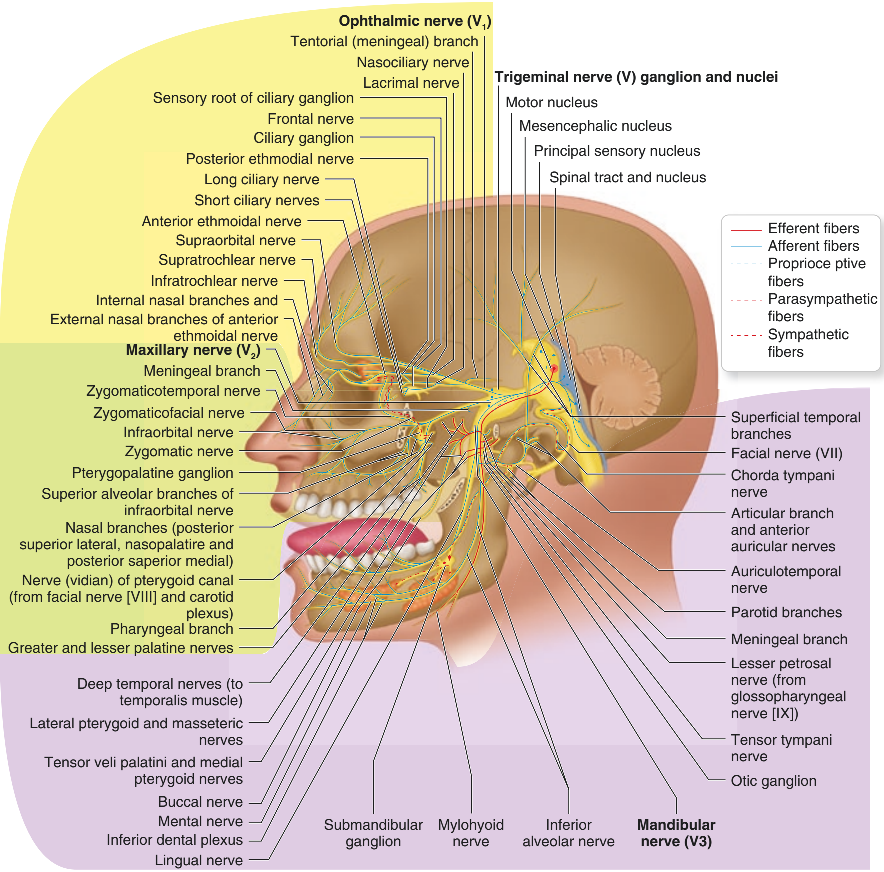

Fig. 2.1 Diagram of the trigeminal nerve nuclei and intracranial courses of the main branches of the trigeminal nerve

Unique to the mesencephalic nucleus, it contains no chemical synapses. Rather, the neurons are pseudounipolar receiving proprioceptive information from the mandible, sending projections to the trigeminal motor nucleus to mediate the monosynaptic jaw jerk reflex. Axons from the spinal and principal nucleus form the trigeminocerebellar tract ascending to the cerebellum [3]. This nucleus is the only central nervous system structure to contain the cell bodies of first-order neurons and can thus be considered as a sensory ganglion within the brainstem [4, 5].

Principal Sensory Nucleus

The principal sensory nucleus (chief sensory nucleus, main trigeminal sensory nucleus) receives discriminative sensation and light touch of the ipsilateral face and conscious proprioception from the jaw. It is located within the mid to caudal pons lateral to the trigeminal motor nucleus. The nucleus further divides into the dorsomedial and ventrolateral divisions. The former of these receives input only from the oral cavity. This information travels to the ipsilateral ventral posteromedial (VPM) nucleus of the thalamus via the dorsal trigeminothalamic tract. The ventrolateral division receives sensory input from all the divisions of the trigeminal nerve. Projections then decussate and second-order neuronal fibers convey information via the ventral trigeminothalamic tract to the contralateral VPM nucleus of the thalamus. Together, the second-order neurons of the ventral and dorsal trigeminal tracts are known as the trigeminal lemniscus conveying sensory information from the trigeminal system to the VPM of the thalamus [1, 2].

Spinal Trigeminal Nucleus

The spinal trigeminal nucleus (SpV or Sp5), a sensory tract located in the lateral medulla, is responsible for relaying sensation (deep or crude touch, pain, temperature) from the ipsilateral face. While the predominant afferent fibers are from the trigeminal nerve, it also receives input from the facial nerve (CN VII), glossopharyngeal nerve (CN IX), vagus nerve (CN X), and C1-C3 spinal segments [6]. Further dividing, SpV is separated into three subnuclei or pars. The subnucleus oralis is associated with fine touch from the orofacial region and is continuous with the principal sensory nucleus mentioned above. The subnucleus interpolaris is associated with transmission of touch and dental pain. And the subnucleus caudalis is associated with the transmission of painful and thermal stimuli from the ipsilateral face. The SpV projects to the ventral posteromedial (VPM) in the contralateral thalamus via the ventral trigeminal tract [1, 7].

The subnucleus caudalis is the most caudal segment of the trigeminal sensory nuclear complex. As it closely resembles the laminated structure of the dorsal horn of the spinal cord with which it is continuous, it is often termed the medullary dorsal horn. It is within this nucleus that the upper cervical afferent roots (C1–C3) interact with the descending trigeminal nociceptive afferents. These cervical afferent fibers receive input from the muscles, joints, and ligaments of the upper cervical segments; dura mater; posterior cranial fossa; and the vertebral artery. The bidirectional referral of painful sensations between the neck and trigeminal sensory receptive fields is due to this convergence of fibers [6].

Trigeminal Motor Nucleus

The final nucleus, the trigeminal motor nucleus, is in the dorsolateral pontine tegmentum at the mid-pons. It is located medial to the principal sensory nucleus and lateral to the mesencephalic nucleus. Coming from the primary motor cortex, branchial motor neurons innervate the muscles of mastication and palate to a lesser degree via the mandibular nerve (V3). Efferent motor fibers leaving the nucleus do not decussate; however, due to the bilateral cortical input, a unilateral transection of these nerves will not result in paralysis [2, 8].

Trigeminal Nerve and Distal Projections (Figs. 2.2 and 2.3a, b)

Ophthalmic Nerve

The ophthalmic nerve (V1) provides sensory innervation from the scalp, forehead, upper part of the sinuses, upper eyelid and associated mucous membranes, cornea, and bridge of the nose. Branches of the ophthalmic nerve include the nasociliary, lacrimal, and frontal nerves. Prior to branching into these three main divisions, the ophthalmic nerve gives off the tentorial (meningeal) branch.

Frontal Nerve

The largest of the main V1 branches, the frontal nerve, branches from the ophthalmic nerve immediately prior to entering the lateral portion of the superior orbital fissure traveling superolateral to the annulus of Zinn between the lacrimal nerve and the inferior ophthalmic vein. After entering the orbit, it divides further into the supratrochlear nerve and the supraorbital nerve. These branches briefly re-enter the frontal bone prior to exiting through their respectively named supratrochlear foramen and supraorbital foramen (or notch). They both ascend into the forehead between the corrugator supercilii and frontalis muscles dividing into a medial and lateral branch providing innervation to the forehead, upper eyelid, and conjunctiva.

Nasociliary Nerve

The nasociliary nerve, intermediate in size between the frontal and lacrimal nerves, enters the orbit between the two heads of the lateral rectus muscle between the superior and inferior rami of the oculomotor nerve (CN III). It branches into six terminal nerves including the communicating branch to the ciliary ganglion, long and short ciliary nerves, posterior ethmoidal nerve, anterior ethmoidal nerve, and becomes the infratrochlear nerve (the terminal branch).

Running through the short ciliary nerves, sensations from the eyeball including the cornea, iris, and ciliary body pass through the ciliary ganglion. Without forming synapses, they leave the ganglion in the sensory root joining the nasociliary nerve.

The long ciliary nerves, totaling 2 or 3 in number, accompany the short ciliary nerves from the ciliary ganglion providing sensation again from the eyeball. They also contain sympathetic fibers from the superior cervical ganglion to the dilator pupillae muscle, though the short ciliary nerves also contain sympathetic fibers.

The anterior ethmoidal nerve branches near the medial wall of the orbit traveling through the anterior ethmoidal foramen to the anterior cranial fossa. The anterior ethmoidal nerve provides sensation from the anterior and middle ethmoidal air cells and the meninges. It passes through the cribriform plate into the nasal cavity giving off branches to the roof of the nasal cavity. Here it bifurcates into the lateral internal nasal branch and the medial internal nasal branch. Within the nasal cavity, it provides sensation from the anterior part of the nasal septum. The external nasal branch of the anterior ethmoidal nerve also provides innervation from the skin on the lateral sides of the nose.

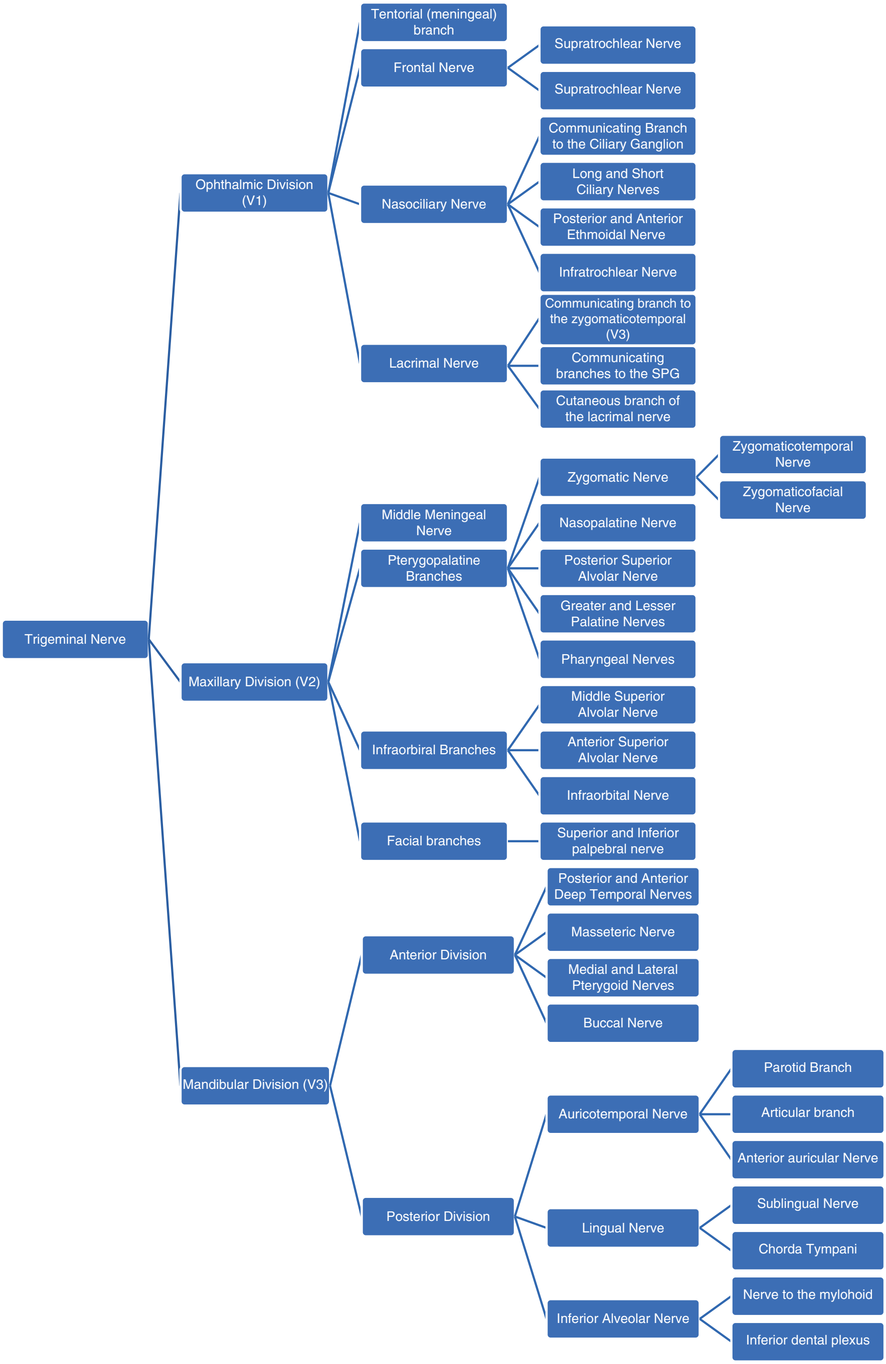

Fig. 2.2 Trigeminal nerve branches

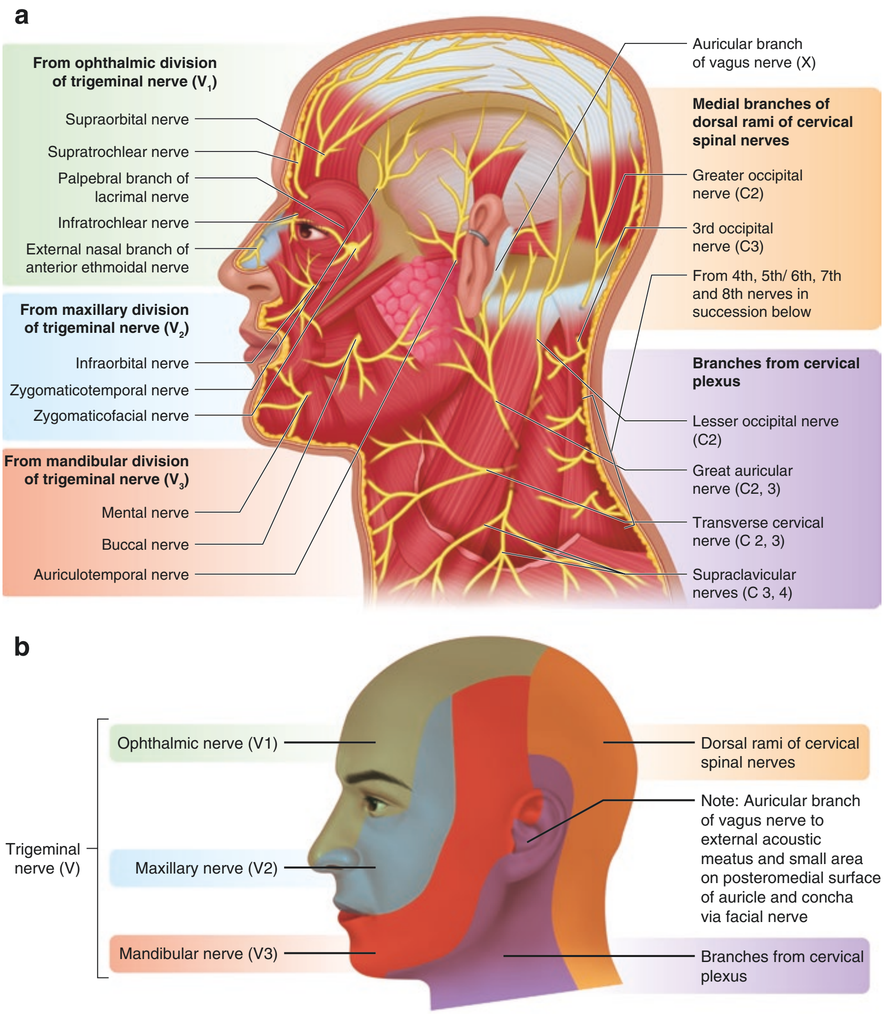

Fig. 2.3 (**a**) Cutaneous sensory branches of the head and neck. (**b**) Distribution of cutaneous sensation of the head and neck

The infratrochlear nerve travels anteriorly along the upper border of the medial rectus muscles beneath the trochlea exiting the orbit medially dividing into smaller sensory branches providing innervation from the skin of the eyelid, conjunctiva, lacrimal sac, lacrimal caruncle, and the side of the nose above the medial canthus.

Lacrimal Nerve

The smallest division of the ophthalmic nerve, the lacrimal nerve, branches immediately before traveling through the superior orbital fissure traveling along the lateral wall with the lacrimal artery and provides a communicating branch to the zygomaticotemporal (branch of V3). It then provides communicating branches carrying postganglionic parasympathetic axons from the pterygopalatine ganglion. The lacrimal nerve travels through the lacrimal gland providing sensory and parasympathetic branches to the gland and finally continues anteriorly as the cutaneous branch of the lacrimal nerve.

Maxillary Nerve

The maxillary nerve (V2) provides sensation from the lower eyelid and associated mucous membranes, middle portion of the sinuses, nasal cavity and middle part of the nose, cheeks, upper lip, some teeth of the upper jaw, and associated mucous membranes, and the roof of the mouth. It also carries parasympathetic preganglionic fibers (sphenopalatine) and postganglionic fibers (zygomatic, greater, and lesser palatine and nasopalatine) to and from the pterygopalatine ganglion.

The maxillary nerve begins as a flattened plexiform nerve passing through the lateral wall of the cavernous sinus and exiting the skull through the foramen rotundum where it becomes more cylindrical. After crossing the pterygopalatine fossa, it enters the orbit through the inferior orbital fissure and runs along the floor of the orbit in the infraorbital groove and the infraorbital canal. It terminates as the infraorbital nerve leaving the skull through the infraorbital foramen. Along this path, it gives off multiple branches providing sensation as noted above.

Intracranially, the first branch of the maxillary nerve is the middle meningeal nerve which branches immediately following its origin prior to entering the foramen rotundum. Accompanying the middle meningeal artery and vein, it enters the cranium through the foramen spinosum providing sensation from the dura mater.

Pterygopalatine Branches

After passing through the foramen rotundum, there are six branches from the maxillary nerve: the zygomatic, nasopalatine, posterior superior alveolar, greater and lesser palatine, and pharyngeal nerves. The zygomatic nerve branches at the pterygopalatine ganglion traveling through the fossa through the inferior orbital fissure into the orbit where it divides into the zygomaticotemporal and zygomaticofacial nerves which travel through the respectively named foramina into the zygomatic bone. This branch contains sensory axons providing innervation from the skin overlying the temporal and zygomatic bones. It also carries postganglionic parasympathetic axons that have their cell bodies in the pterygopalatine ganglion. As mentioned previously, these axons travel to the lacrimal nerve through a communicating branch.

The nasopalatine nerve (i.e., long sphenopalatine nerve) enters the nasal cavity through the sphenopalatine foramen. It passes across the roof of the nasal cavity to reach the septum. It descends along the roof of the mouth through the incisive canal and communicates with the nerve of the contralateral side and the greater palatine nerve. It provides sensation from the structures around the maxillary central incisors, lateral incisors, and canines. It also provides minor sensory signaling from the nasal septum via the medial superior posterior nasal branch.

The molars, by contrast, have sensory afferents through the posterior superior alveolar nerve. This nerve branches from the maxillary nerve just prior to the infraorbital groove descending on the tuberosity of the maxilla. It also provides sensation from the gingiva and mucous membrane of the cheek. After entering the alveolar canals on the maxilla, it communicates with the middle superior alveolar nerve and provides sensation from the maxillary sinus.

The greater (anterior) and lesser palatine nerves descend through the greater palatine canal. Within the pterygopalatine canal, the greater palatine nerve branches into the lateral posterior inferior nasal branch which enters the nasal cavity through the palatine bone ultimately distributing fibers to the soft palate. The greater palatine nerve exits through the greater palatine foramen onto the hard palate passing forward as far as the incisors. It provides sensation to the gingiva, mucous membrane of the hard palate, and communicates with the terminal filaments of the nasopalatine nerve. The lesser palatine nerve exits through the lesser palatine foramen providing sensation from the nasal cavity, soft palate, tonsils, and uvula.

The final branch in the area of the pterygopalatine fossa is the pharyngeal nerve. It passes through the palatovaginal canal and provides sensation from the nasal portion of the pharynx.

Infraorbital Branches

The first of the three main branches of the maxillary nerve within the infraorbital portion is the middle superior alveolar nerve which is present in a minority of individuals. In most, the anterior superior alveolar nerve provides sensation from this distribution. This middle branch provides sensation from the sinus mucosa and the roots of the maxillary premolars and first maxillary molar. The anterior superior alveolar nerve branches before the infraorbital nerve exits from the infraorbital foramen and descends within the anterior wall of the maxillary sinus. It then divides into branches which supply the incisors and canine teeth. In conjunction with the posterior superior alveolar nerve and the middle superior alveolar nerve, it forms the superior dental plexus providing sensation from the upper jaw.

The final infraorbital branch, the infraorbital nerve, is clinically relevant in headaches. This terminal branch arises onto the anterior surface of the maxilla through the infraorbital foramen where it divides into terminal branches—palpebral, nasal, and superior labial. The palpebral branch provides sensation from the lower eyelid; the nasal branch from the side of the nose and nasal septum; and the superior labial branch to the skin of the anterior cheek and upper lip. The infraorbital nerve also crosses and forms a plexus with the facial nerve [9].

Facial Branches

Facial branches of the maxillary nerve consist of the inferior palpebral nerve and the superior labial branches. The former of these supplies the skin and conjunctiva of the lower eyelid joining the facial and zygomaticofacial nerves at the lateral orbit. The latter provides sensation from the skin of the upper lip, the mucous membrane of the mouth, and labial salivary glands.

Mandibular Nerve

The mandibular nerve (V3) is the sole branch the provides both sensory and motor information. It provides sensation from the outer part of the ear, lower part of the mouth and associated mucous membranes, anterior 2/3 of the tongue, lower teeth and associated mucous membranes, lower lip, and chin. It should be noted that special sensation (taste) of the tongue is provided by the chorda tympani branch of the facial nerve. While the motor and sensory roots take a briefly separate course, they join prior to exiting the skull through the foramen ovale. It is near this junction that the meningeal (recurrent) branch of the mandibular nerve enters the skull via the foramen spinosum with the middle meningeal artery on its way to providing sensation from the dura mater and mastoid cells. The mandibular nerve then courses through the infratemporal fossa where it branches into anterior and posterior divisions.

Anterior Division

Immediately after the anterior-posterior split, the anterior division branches into several nerves. The posterior and anterior deep temporal nerves ascend above the lateral pterygoid muscle entering the temporal fossa. They provide motor innervation to the temporalis which elevates and retracts the mandible. The deep branch also provides an articular branch providing minor innervation to the temporomandibular joint (major supply is via the auriculotemporal nerve).

The masseteric nerve branches from the anterior division passing laterally just medial to the temporomandibular articulation and posterior to the tendon of the temporalis. Along with the masseteric artery, it crosses the mandibular notch to the deep surface of the masseter. The masseter elevates the mandible with bilateral contraction closing the jaws. The deep part of the masseter also retracts the jaw. Similarly, the masseteric nerve also provides minor innervation to the temporomandibular joint.

The medial and lateral pterygoid nerves, which innervate the respective pterygoid muscles, are the next branch of the anterior division. The medial also provides innervation to the tensor tympani (noise reduction during mastication) and tensor veli palatine (tensing of the soft palate) muscles. The latter of these is the only muscle of the soft palate—palatoglossus, palatopharyngeus, levator veli palatine, and musculus uvulae—which is not innervated by the pharyngeal plexus via the vagus nerve [10]. The lateral pterygoid nerve enters and provides motor stimulation to the lateral pterygoid muscle. The medial pterygoid muscles elevate and protrude the mandible with bilateral activation and provide side–side motion with unilateral activation. The lateral pterygoid muscles protrude the mandible depressing the chin with bilateral activation and similarly provide side–side motion with unilateral activation.

The sole sensory nerve of the smaller anterior division is the buccal nerve. After branching from the mandibular nerve after the foramen ovale, it descends under the tendon of the temporalis muscle and the masseter muscle. It provides sensory information from the cheek. The buccinator, a muscle of facial expression rather than mastication, is provided by the buccal branches of the facial nerve (CN VII).

Posterior Division

Soon after splitting from the anterior division, the posterior division gives rise to the lingual nerve and auriculotemporal nerves and becomes the inferior alveolar nerve.

Auricotemporal

Coming off the posterior division, two nerve roots encircle the middle meningeal artery prior to joining as a single auriculotemporal nerve. After giving off a secretomotor parotid branch, the nerve turns superior where it divides into the articular branch and anterior auricular nerves. It crosses superficial to the zygomatic process of the temporal bone and branches into multiple superficial temporal branches. In total, it supplies sensation from the auricle, external acoustic meatus, outer side of the tympanic membrane, and the skin in the temporal region. The posterior auricular nerve, which supplies the auricularis posterior muscle and supplies sensation from the occiput, is a branch of the facial nerve (CN VII).

Lingual Nerve

Responsible for providing sensation from the anterior 2/3 of the tongue, the lingual nerve branches from the posterior division descending between the medial pterygoid muscle and the angle of the ramus of the mandible. It is joined here by the chorda tympani nerve (branch of the facial nerve CN VII) at an acute angle which provides taste sensation from the anterior 2/3 of the tongue. After passing between the hyoglossus and the submandibular gland crossing the duct of the submandibular gland from lateral to medial, it runs along the tongue becoming the sublingual nerve. The posterior 1/3 of the tongue is supplied by the glossopharyngeal nerve.

Prior to branching from the lingual nerve toward the facial nerve, the fibers of the chorda tympani traverse with the lingual nerve carrying both sympathetic and parasympathetic nerve fibers. Near the posterior border of the mylohyoid muscle, the submandibular ganglion is suspended from the lingual nerve by two nerve filaments. It is through this ganglion that the sympathetic fibers cross and parasympathetic nerves synapse.

Inferior Alveolar Nerve

The final major branch of the posterior division of the mandibular nerve is the inferior alveolar nerve. Soon after forming this last branch prior to entering the mandibular foramen, the nerve to the mylohyoid takes off descending in a groove on the inner surface of the mandible innervating the mylohyoid muscle (tongue and hyoid elevation) and the anterior belly of the digastric muscle (elevates the hyoid).

The inferior alveolar nerve then passes through the mandibular foramen into the mandibular canal in the ramus of the mandible. Here it forms the inferior dental plexus giving off gingival and dental nerves to the lower molars and second premolar. At the level of the lower second pre-molars, it gives off the mental nerve which exits via the mental foramen providing sensation to the chin and lower lip. It continues as the mandibular incisive nerve providing sensation to the lower canines and incisors.

Associated Structures

Otic Ganglion

The otic ganglion is a 2–3-mm parasympathetic ganglion located within the infratemporal fossa just distal to the foramen ovale on the medial surface of the mandibular nerve at the junction of the motor and sensory roots. Preganglionic parasympathetic fibers of the inferior salivary nucleus of the glossopharyngeal nerve arrive at the otic ganglion synapsing with postganglionic fibers. These fibers, via communicating branches to the auriculotemporal nerve (branch of V3), proceed to the parotid gland where they produce vasodilatation and secretomotor effects.

Passing through the ganglion without synapsing, the postganglionic fibers from the superior cervical ganglion pass through to reach the parotid gland via the same auriculotemporal nerve. These produce vasomotor function within the parotid gland. As mentioned previously, motor nerves to the medial pterygoid, tensor palati, and tensor tympani also pass through the ganglion though do not synapse here.

Submandibular Ganglion

The submandibular ganglion, a small fusiform ganglion located near the posterior border of the mylohyoid muscle, is suspended from the lingual nerve (branch of V3) by two nerve filaments. Within this ganglion, preganglionic parasympathetic fibers from the superior salivary nucleus (chorda tympani via the lingual nerve) of the pons synapse. The postganglionic fibers transmit the parasympathetic secretomotor signals to the oral mucosa, submandibular salivary gland, and the sublingual salivary gland. Sympathetic fibers from the external carotid plexus pass through the submandibular ganglion.

Sphenopalatine Ganglion

The sphenopalatine ganglion (also known as pterygopalatine ganglion, Meckel's ganglion, or SPG) is a parasympathetic ganglion found within the sphenopalatine fossa. While it is mostly innervated by the facial nerve (via the greater petrosal nerve), it has projections through branches of the trigeminal nerve. Within the fossa, it is located just inferior to the maxillary nerve as it traverses the fossa. It supplies the lacrimal gland; paranasal sinuses; gingiva; and the mucosal glands of the nasal cavity, pharynx, and hard palate.

Two sphenopalatine branches of the maxillary nerve provide a few sensory fibers from the SPG. The majority of fibers from the SPG serve in the parasympathetic nerve system. Stemming from the facial nerve, preganglionic fibers from the greater petrosal nerve synapse with postganglionic parasympathetic fibers providing vasodilation and secretory efferent fibers. Sympathetic fibers pass through the ganglion without synapsing arriving from the superior cervical ganglion through the carotid plexus, then the deep petrosal nerve and greater petrosal nerve. Both the sympathetic and parasympathetic efferent fibers transmit via the infraorbital nerve, superior alveolar nerves, nasopalatine nerve, and the greater and lesser palatine nerves.

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