1 Anatomy of the Cranial Nerves: Novel Concepts and Traditional Descriptions

Bullet Points

- This chapter describes and richly illustrates the anatomy of the cranial nerves and the visceral (vegetative) nervous pathways in the head.
- It pragmatically relies on traditional systematics; however, it discusses inadequacies in terminology and acknowledges the direction of action potential conduction for describing course and branching.

Introduction

Cranial nerves (CNs) are defined as bundles of nerve fibers, which leave or enter the brain. Hence, they are the white matter of the peripheral nervous system, with all its consequences (*e.g.*, regeneration after injury).

Reflecting the body symmetry, cranial nerves are always paired. The perikarya of the neurons are either located in motor or parasympathetic brain nuclei (multipolar neurons of efferent fibers) or in bipolar or pseudounipolar ganglia along their course (pseudounipolar or bipolar neurons of afferent fibers). The central axons emerging from the pseudounipolar or bipolar ganglion cells then synapse with multipolar neurons in sensory nuclei.

When leaving or entering the brain, the nerves may comprise fibers of all qualities, except for sympathetic. Yet, especially when derived from perikarya located in the superior cervical ganglion, postganglionic sympathetic fibers often join branches of cranial nerves. They use them to travel to blood vessels, brain structures, and glands, particularly salivary and sweat glands in the skin. On their way, they often do not stick to one nerve but "hop" from nerve to nerve or branch to branch until they enter their targets.

Traditionally, some nerves are described as purely sensory (afferent) or purely motor (efferent). However, in most cases, this is a simplification. At least some segments of almost all nerves comprise afferent and efferent fibers. As an example, motor nerves innervate muscle fibers. However, afferent fibers derived from proprioceptors travel as part of the terminal branches.

In the head, a noteworthy general phenomenon is that cranial nerves extensively feature "fiber exchange." This, as in modern literature, is better described as "fiber hopping." Nerve fibers often consecutively join and leave several nerves until they reach their targets. Hence, several cranial nerves and sympathetic fibers resemble a large nerve plexus rather than a system of distinct nerves. The branches of CN V especially "hop on" and "hop off" of nerve fibers. For example, the lingual nerve, a branch of the mandibular nerve, is considered to be composed of general

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somatic afferent (GSA) fibers. However, certain peripheral segments also comprise pre- and post-ganglionic parasympathetic, sympathetic, and special visceral afferent (SVA) fibers in various combinations (see sections "CN V" and "parasympathetic Ganglia"). To overcome the problem of the changing fiber compositions in the description of the "fiber quality" of cranial nerves along their way from the periphery to the brain or vice versa, the following chapters primarily consider the composition of nerves at their exit/entrance from/into the brain or their most central portion when defining general fiber quality.

Systematics

Classic textbooks (*e.g.,* Gray's Anatomy [1]) distinguish twelve pairs of cranial nerves. They are referred to as left and right CN I to CN XII. The sequence reflects the position at which the nerves leave the brain and at which they perforate the dura mater encephali (Fig. 1.1).

However, this traditional classification is highly insufficient and confusing. It essentially ignores many facts learned in the last centuries. Most prominently, it ignores the existence of the terminal nerve (CN 0 or CN XIII) and the true nature of CN II as white matter of the central nervous system. It also considers the motor portion of CN V as part of CN V at large, summarizes the intermediate and facial nerves as CN VII, considers CN XI as a nerve formed by a cranial and a spinal root, and ignores phylogenetic considerations regarding CN XI and CN XII. These weaknesses of traditional nomenclature have triggered a large number of alternative classifications [2–9], and each one makes fair points. Yet, until now, none of the alternatives was successful in replacing the traditional nomenclature.

This chapter will therefore pragmatically rely on the traditional terminology. However, it will group the pairs of cranial nerves relying on obvious similarities and refer to the most prominent of the countless inconsistencies when describing the single "nerves" (Table 1.1).

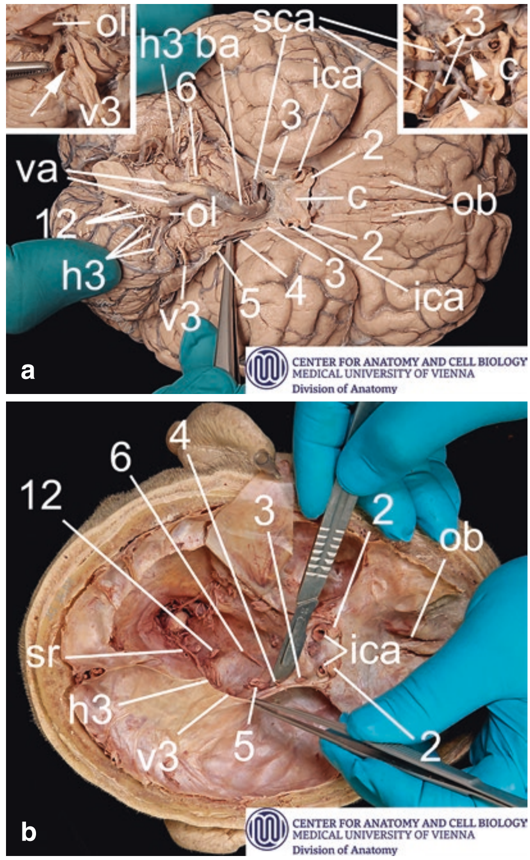

Fig. 1.1 Sequence of cranial nerves (CN) according to conventional nomenclature. Frontal to the right. Note the sequential brain and dura exit/entrance of the cranial nerves. Numbers refer to respective CNs. (**a**) Base of the brain. Except for the pontal cistern, the arachnoid mater forming the basal cisterns is largely preserved. The arachnoid mater covering the ambient cistern is opened, and CN IV [4] is lifted with a forceps. Left-sided inlay highlights the relationship of the nerves of the cerebellopontine angle (v3), Bochdalek's flower basket (arrow), and CN IX (held in forceps) as the most rostral nerve of those, exiting at the anterolateral sulcus (h3). Right-sided inlay magnifies the relationship of CN III [3] with the superior cerebellar (sca) and posterior cerebral arteries (arrowhead). Arachnoid mater of the basal cisterns is removed. The brain displayed in the inlay is different from the brain displayed in the main panel. Note the dimension of the left-sided posterior cerebral artery. (**b**) Skull base with cranial nerves, cut near their penetration through the dura mater. Stumps of right-sided cranial nerves are labeled with numbers. 2, CN II; 3, CN III; 4, CN IV; 5, CN V; 6, CN VI; 12, CN XII; ob, olfactory bulb; ica, internal carotid artery; ba, basilar artery; va, vertebral artery; ol, oliva; c, optic chiasm; sr, sinus rectus

Table 1.1 Traditional systematics of cranial nerves

Cranial nerve	Brain nuclei	Gross position of nuclei in CNS	Skull transition	Inconsistencies with official nomenclature
CN I	Olfactory bulb	Telencephalon	Cribriform plate	Definition of terminal nerve (CN 0, CN XIII)
CN II		Diencephalon	Optic canal	Definition of "nerve" (PNS) versus "tract" (CNS)
CN III	Oculomotor nucleus Accessory oculomotor nucleus	Mesencephalon	Superior orbital fissure	
CN IV	Trochlear nucleus	Mesencephalon	Superior orbital fissure	
CN V	Motor nucleus Mesencephalic nucleus Principal sensory nucleus Spinal trigeminal nucleus	Mesencephalon, Rhombencephalon, Spinal cord	Superior orbital fissure Foramen rotundum Foramen ovale	2 nerves (independent motor and sensory portion)
CN VI	Abducens nucleus	Rhombencephalon	Superior orbital fissure	
CN VII	Motor nucleus Lacrimal nucleus Salivatory nucleus Solitary nucleus	Rhombencephalon	Internal acoustic meatus	2 nerves (N. intermedius and N. facialis)
CN VIII	4 vestibular nuclei (Bechterew, Schwalbe, Roller, Deiters) 2 cochlear nuclei (dorsal, ventral)	Rhombencephalon	Internal acoustic meatus	2 nerves instead of 2 portions of 1 nerve
CN IX	Sensory nucleus Nucleus ambiguous Spinal trigeminal nucleus Solitary nucleus Inferior salivatory nucleus	Rhombencephalon	Nervous part of jugular foramen	
CN X	Dorsal nucleus Nucleus ambiguous Solitary nucleus Spinal trigeminal nucleus	Rhombencephalon	Nervous part of jugular foramen	
CN XI	Nucleus ambiguous Spinal nucleus	Rhombencephalon Spinal cord	Nervous part of jugular foramen	Cranial radix is part of CN X
CN XII	Hypoglossal nucleus	Rhombencephalon	Hypoglossal canal	United segmental nerves

CN cranial nerve, *PNS* peripheral nervous system, *CNS* central nervous system

Thematically, the chapter does not aim to describe every single detail of cranial nerve systematics and topology but merely intends to provide a comprehensive overview. Furthermore, in contrast to traditional textbooks, the descriptions will follow the direction of action potentials whenever possible. This means that afferent (*e.g.,* sensory) nerves are described from the periphery to the central nervous system and efferent (*e.g.,* motor, parasympathetic) nerves from the central nervous system to the periphery. Finally, relationships of cranial nerves and the visceral (autonomic) nervous system will be described in Chap. 27, following the systematic descriptions of the cranial nerves.

Cranial Nerves

Olfactory Nerve (CN I)

CN I is a sensory nerve communicating olfactory information via SVA fibers. The fibers emanate from neurons, which are located in the mucosa overlying the upper nasal concha and septum nasi and ascend toward the cribriform plate. They form bundles, called fila olfactoria. The sum of the fila olfactory is referred to as CN I (Fig. 1.2).

The fila pass separately through the foramina of the cribriform plate and perforate the overlying dura and arachnoid mater. They then immediately enter the olfactory bulb and synapse with its multipolar neurons. Axons of the neurons of the olfactory bulb converge and form the olfactory tract, which travels occipitally, toward the trigonum nuclei and the telencephalic cortex. Although the olfactory bulb and tract are distinct structures, located beneath and isolated from the frontal lobe of the telencephalon (Figs. 1.1 and 1.3), they are the central nervous system.

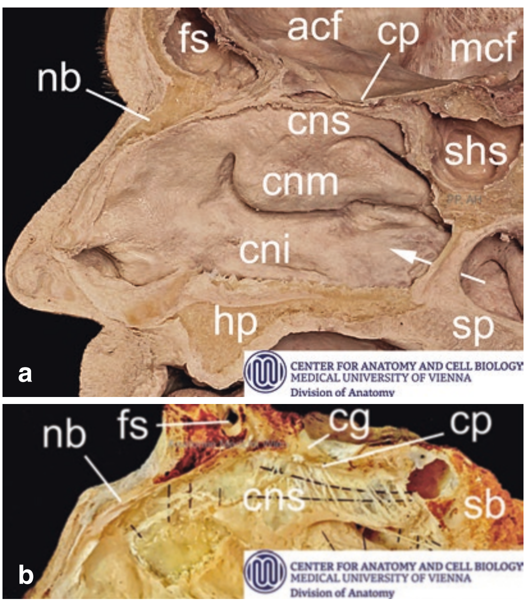

Fig. 1.2 Cranial nerve (CN) I. Lateral wall of left-sided nasal cavities. Frontal to the left. (**a**) Undissected specimen, showing the mucosa covering the concha nasalis superior (cns), concha nasalis medialis (cnm), concha nasalis inferior (cni), and the rest of the lateral nasal cavity. Note the thinness of the cribriform plate (cp), which borders anterior cranial fossa (acf) and nasal cavity. (**b**) Specimen from the historical collection of the Division of Anatomy of the Medical University of Vienna. The mucosa is removed from the cns and the fila olfactoria are displayed. Mcf, medial cranial fossa; cg, crista galli; hp., hard palate; sp., soft palate; sb, sphenoid bone; shs, sphenoid sinus; fs, frontal sinus; nb, nasal bone; arrow points through right choana

Terminal Nerve (CN 0, CN XIII)

SVA fibers, connected to pheromone receptors in the mucosa of the anterior septum, are often considered to be part of CN I. However, their course substantially differs from the course of the fibers forming the fila olfactoria.

In the mucosa, these fibers have a close relationship to the branches of the trigeminal nerve. However, they soon leave them and ascend towards the cribriform plate. They perforate this plate, but, contrary to fibers of CN I, they do not penetrate the dura and arachnoidea mater encephali and do not enter the gray matter of the olfactory bulb. Instead, they stay extradural and form an elongated plexus, which extends medially and in parallel to the olfactory tract toward the jugum sphenoidale. Only here do the fibers perforate both the dura and arachnoid mater to continue their occipital course in the subarachnoid space. Finally, the fibers reach and enter the forebrain at the terminal lamina, where they synapse with central neurons.

Considering the course of the fibers of the terminal nerve, their bypassing of the olfactory bulb and the arrangement that permits instant transfer of information to a telencephalic cortical region implies that these fibers have to be considered as a distinct nerve. Since the nerve enters at the terminal lamina, the name "terminal nerve" was suggested, although CN 0 or CN XIII are also in use [5–8].

Optic "Nerve" (CN II)

The optic "nerve" is a component of the visual system (Fig. 1.3). It is traditionally referred to as a nerve, comprising special somatic (SSA) fibers.

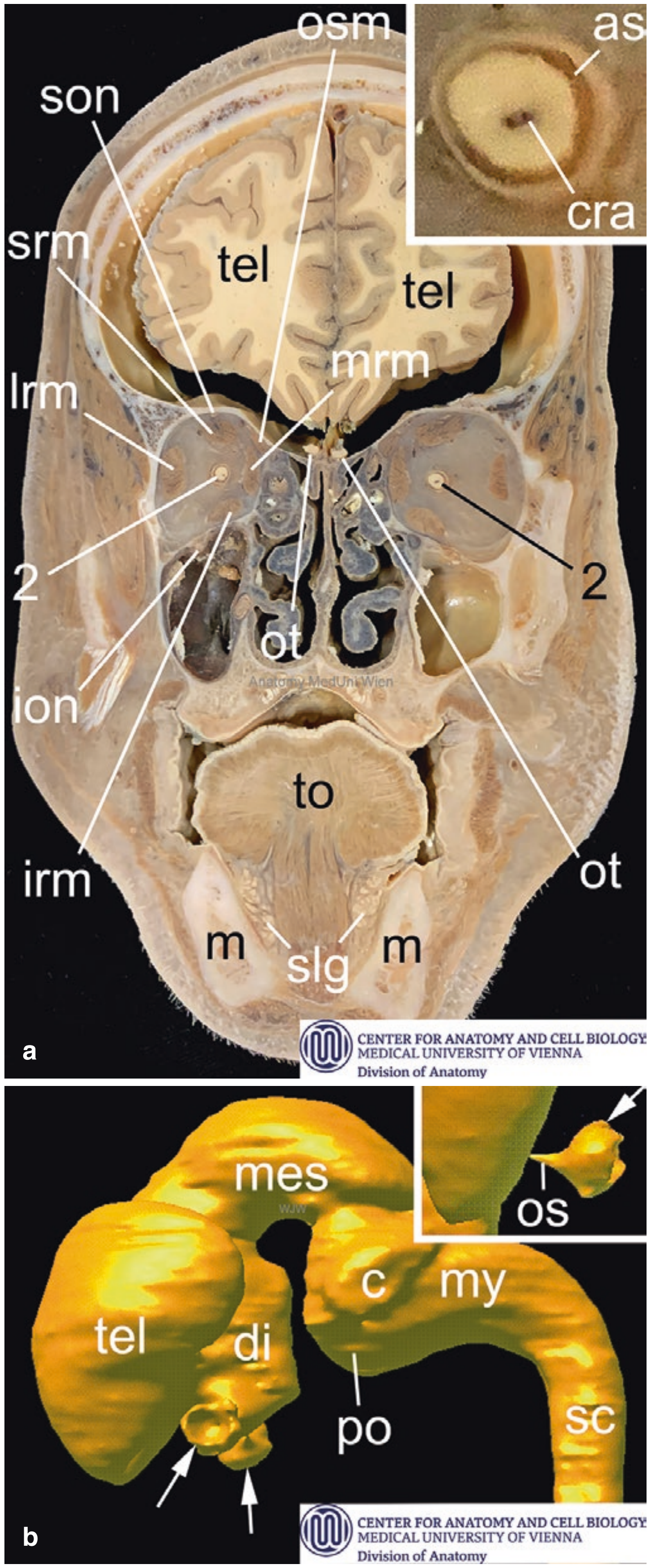

Fig. 1.3 Cranial nerve (CN) II [2], according to conventional terminology. (**a**) Topology of CN II in the orbit. Silicon preserved coronal section through a human head. Specimen from the Anatomy Teaching Unit of the Medical University of Vienna. Dorsal view. Inlay magnifies CN II in the right orbit. It is surrounded by meninges and subarachnoid space (as). In its center travels the central retinal artery (cra). Main panel shows the relationship of CN II and the inferior (irm), lateral (lrm), superior (srm), and medial (mrm) rectus muscles. Small branches of CN III and CN V are discernable near them. The supraorbital nerve (son) is visible beneath the orbital roof and the infraorbital nerve (ion) in a groove at the orbit floor. Also, note the transition zone between the olfactory bulb and tract (ot). (**b**) Three-dimensional (3D) computer model of the forming brain of an early mouse embryo (left view). Optic stalk (os), which remodels to CN II, and optic cup (arrows) are lateral extensions of the gray and white matter of the diencephalon (di). Inlay shows these structures from the anterior. to, tongue; m, mandible; slg, sublingual gland; tel, telencephalon; osm, oblique superior muscle; mes, mesencephalon; c, anlage of cerebellum; po, pons; my, myelencephalon; sc, spinal cord

Yet, the fiber bundle named as CN II is not a nerve, but the white matter of the diencephalon. Per definition, a nerve is a component of the peripheral nervous system, whereas the "optic nerve" and the retina are integral parts of the central nervous system, as clearly visible in early embryos (Fig. 1.3b). The consequences include meningeal cover of the nerve and suppression of regeneration of injured optic nerve fibers, etc.

Ignoring the true nature of the fibers, textbooks usually describe the fiber bundle between the eyeball and optic chiasm as optic nerve. The fibers emerge from the third of the three neurons, which are consecutively arranged in the retina. The first are the sensors, the second are bipolar interneurons connecting the first and third neurons, and the third are the axons, which leave the retina at the optic disc to continue as optic nerve.

Per definition, the optic nerve ends at the optic chiasm. However, this structure does not hold perikaryal, and no fibers terminate or synapse in this structure. There is merely a crossing of fibers derived from neurons located in the nasal segments of the retina. Together with fibers emerging from neurons of the temporal segments of the retina of the ipsilateral eye (which do not cross in the chiasm), they continue as optic tract and finally terminate in the lateral geniculate nucleus of the thalamus. Hence, the axons of the third retinal neurons leaving the retina in the optic disc are the first part of the so-called optic nerve, then of the optic chiasm, and finally of the optic tract, before they synapse with neurons forming the lateral geniculate body (nucleus) of the thalamus.

The optic nerve passes the skull through the optic canal. This canal is also used by the ophthalmic artery, which is the first branch of the subarachnoid segment of the internal carotid artery. The artery transits the canal running below CN II. Once in the orbit, it splits and its terminal branch, the central retinal artery, pierces into the nerve. Surrounded by the nerve fibers, it enters the retina and ramifies in its inner layers.

Inside the optic canal and the orbit, both the artery and the nerve are surrounded by extensions of the dura and arachnoid mater and, consequently, are bathed in cerebrospinal fluid (Fig. 1.3a, inlay).

Nerves Associated with the Parasellar (Cavernous Sinus) Region: CN III to CN VI

CN III–CN VI are in close relationship with the parasellar region (PSR). Hence, the systematic description of CNs III to VI will start with a brief description of the PSR's composition and topology.

Since the PSR is also an important crossroad for sympathetic fibers emerging from the superior cervical ganglion [10], the following passage will also provide a brief description of the pathways of these nerves.

Composition of the parasellar (cavernous sinus) region: The region lateral to the sella turcica is traditionally termed as cavernous sinus due to its resemblance to the corpus cavernosum penis in histologic sections. However, in the last century, it became evident that the extradural space lateral to the sella turcica is not a spongiform sinus formed by interconnected cavernous spaces. The space rather holds a plexus of differently sized veins. To acknowledge this clinically important fact and to acknowledge the composition of its anterior section, this chapter will use PSR instead of cavernous sinus [11].

Detailed analysis revealed that the PSR consists of three compartments, which are separated by connective tissue [11–14]. Two of them, the orbital and pterygopalatine compartments, represent extensions of the extracranial tissue spaces of the orbit and the pterygopalatine fossa. They protrude into the cranial cavity through the superior orbital fissure and are named the orbital and pterygopalatine compartment of the PSR [10, 11]. They have their greatest relative extension in the fetus and infant [12]. The third and largest compartment of the PSR is the lateral sellar compartment, which holds the parasellar venous plexus. Between its venous channel, numerous arteries and nerves make their way toward intra- and extracranial targets (see below).

The parasellar venous plexus receives the superior ophthalmic vein, which drains blood from the orbit and enters through the superior orbital fissure. It also receives the sphenoparietal sinus and, sometimes, superficial cerebral veins.

Occipitally, the veins of the plexus drain into the superior and inferior petrous sinus and the basilar plexus, which in turn connects to the internal vertebral venous plexus. Laterally, the veins of the plexus connect to the veins of the infratemporal region and pterygopalatine fossa through the foramen ovale, spinosum, and rotundum. Finally, the left and right-sided parasellar venous plexus are connected via the midline through highly variable vascular channels, forming the so-called intercavernous sinus. Thus, functionally, the parasellar plexus is part of an extradural venous pathway, connecting the internal vertebral venous plexus and the orbit [15].

Surrounded by the veins of the parasellar plexus, the internal carotid artery takes its course from the internal ostium of the eponymous canal toward the anterior clinoid process. In fetuses and infants, the artery runs rather straight, while in adults it forms the characteristic spiraled siphon [12, 13, 16]. It gives rise to two large trunks, the meningohypophyseal and lateral trunk [17, 18], and to several small vessels. Lateral to the artery, and also embedded in the venous plexus, CN VI makes its way from Dorello's canal toward the superior orbital fissure. In the tissues of the lateral wall, which borders the PSR and middle cerebral fossa, CN III, CN IV, and CN V_1 are arranged to form Parkinson's triangle (Fig. 1.4), with CN IV showing a high variability in course [12, 13, 19].

Parasellar sympathetic pathways: Several sympathetic fiber bundles, which originate in the superior cervical ganglion, transit the carotid canal and enter the PSR together with the internal carotid artery. At least in infants, the bundles enter frontally and occipitally to the artery, and most of the bundles join to form a parasellar sympathetic trunk below the internal carotid artery and medially to CN VI. Often, one of the bundles entering occipitally directly joins CN VI.

The sympathetic parasellar trunk first splits into a large fiber bundle, which joins CN VI. Second, several fiber bundles travel back to the carotid artery. Third, a very small fiber bundle enters the pterygopalatine compartment to connect to the ganglion resting in this compartment [10]. The sympathetic fibers that joined CN VI soon leave it to become integrated in CN V_1. Inside the orbit, some of these fibers form the "sympathetic root" of the ciliary ganglion (see below). The rest use the cutaneous branches of CN V_1 to reach their targets in the skin innervated by CN V_1.

Oculomotor Nerve (CN III)

CN III comprises motor and preganglionic parasympathetic fibers. The motor fibers target the rectus superior, inferior, and medial, and inferior oblique muscles of the eyeball. The parasympathetic fibers synapse in the ciliary ganglion to trigger activation of the sphincter pupillae and ciliary muscle and body.

CN III leaves the mesencephalon at the interpeduncular fossa and enters the interpeduncular cistern. Passing between the superior cerebellar and posterior cerebral artery, it travels toward the PSR and dives into the dura mater forming its roof (Fig. 1.1b and 1.5). It then shifts laterally and descends in the layers of the lateral wall of the PSR to reach the superior orbital fissure (Fig. 1.4b). Here, it usually splits into a superior and inferior branch, which both enter the orbit running inside the annular tendon of Zinn.

The superior branch sends fibers to innervate the levator palpebrae superioris and superior rectus muscles. The inferior branch sends preganglionic parasympathetic fibers to the ciliary ganglion (see section "Parasympathetic Ganglia") and motor fibers towards the medial and inferior rectus and the inferior oblique muscles of the eyeball.

Trochlear Nerve (CN IV)

CN IV leaves the caudal mesencephalon lateral to the frenulum veli medullaris superioris. It comprises motor fibers, which innervate the superior oblique muscle of the eyeball.

CN IV is the only cranial nerve leaving the brain dorsally. Consequently, it passes the ipsilateral pedunculus cerebri to reach the skull base with its foramina. On its way, it travels inside the

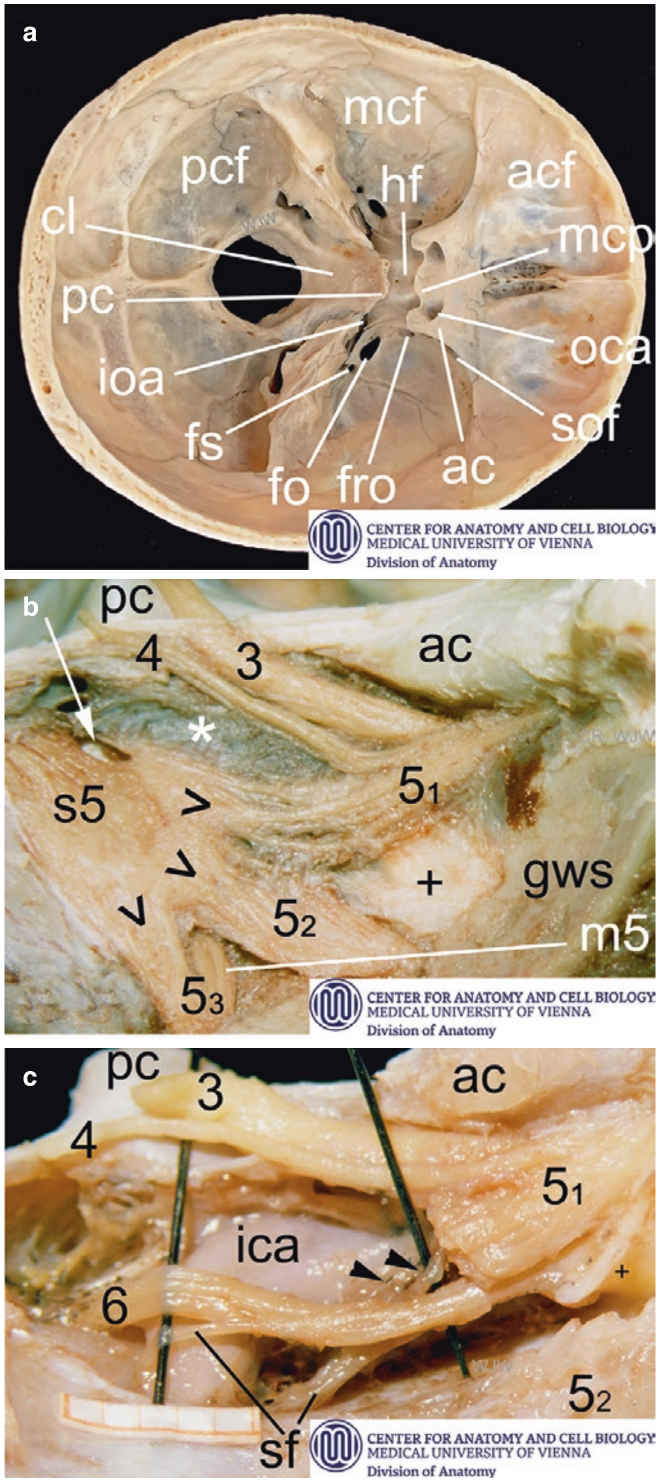

Fig. 1.4 Parasellar region (PSR) and sinus cavernosus, respectively. Frontal to the right. Numbers refer to respective cranial nerves (CNs). (**a**) Adult skull base from superior for orientation. Relevant, right-sided osseous structures related to sella turcica and PSR are labeled. Note this specimen's bilaterally fused anterior (ac) and middle (mcp) clinoid processes. (**b**) Lateral wall of an infant's PSR. Dura mater removed. CN III, CN IV, and CN V_1 are arranged in Parkinson's triangle (asterisk) and head for the superior orbital fissure (sof). The sensory ophthalmic (5_1), maxillary (5_2), and mandibular (5_3) nerves join to form the semilunar trigeminal ganglion (^). The central processes of the pseudounipolar ganglion cells run as sensory portion of CN V (s5) toward the brain. The superior recess of Meckel's cave (arrow) is visible. Proximal to the foramen ovale (fo), CN V_3 is joined by the motor portion of CN V (m5). Note the connective tissue sheath covering the adipose tissue of the pterygopalatine compartment (+). (**c**) Sympathetic pathways in the PSR of an infant. The connective tissue of the lateral wall but also the venous parasellar plexus, s5, m5, semilunar ganglion, and V_3 are removed. V_1 is cut near the ganglion, and V_2 is shifted anterolaterally. Postganglionic sympathetic fibers (sf) enter the PSR through the internal aperture of the carotid canal (ioa), running frontal and occipital to the internal carotid artery (ica). The occipital fibers join the CN VI. The frontal fibers, together with fibers entering the frontomedial, form a parasellar trunk (hidden by CN VI). From here fibers join CN VI and others run back to the ica (arrowheads). Note that fibers connecting CN VI and CN V_1 are covered by the stump of CN V_1. acf, anterior cranial fossa; mcf, middle cranial fossa; pcf, posterior cranial fossa; cl, clivus; fs, foramen spinosum; fro, foramen rotundum; oca, entrance into optic canal, mcp, middle clinoid process; hf, hypophysial fossa; gws, greater wing of sphenoid bone; pc, posterior clinoid process

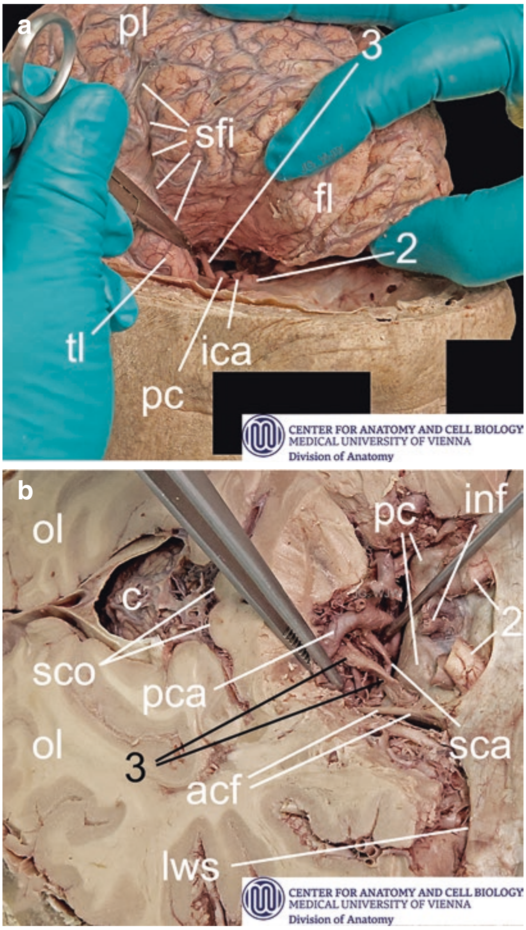

Fig. 1.5 Subarachnoid course of cranial nerve (CN) III. Frontal to the right. Numbers represent respective CNs. Compare with Fig. 1.4. (**a**) Descent to roof of the parasellar region (PSR). Right, frontolateral view of a head after removement of the calvaria with dura mater. Frontal lobe (fl) of telencephalon is lifted and temporal lobe (tl), pressed occipitally by scissor. (**b**) Topology of CN III in the interpeduncular fossa and perforation of the roof of the PSR, near the posterior clinoid process (pc). Superior view at a dissected brain resting in the skull base. Note the relationship of CN III to the posterior cerebral (pca) and superior cerebellar (sca) arteries. pl, parietal lobe, ol, occipital lobe; ica, internal carotid artery; 2, optic nerve; sfi, Sylvian fissure (lateral sulcus); inf, infundibulum of pituitary gland; c, cerebellum; lws, lesser wing of sphenoid bone; acf, anterior petroclinoid fold, forming the edge between roof and lateral wall of PSR; sco, superior colliculi of lamina tecti

ambient cistern near the basal vein of Rosenthal and the posterior cerebral artery. As soon as it arrives at the anterior petroclinoid fold, it enters it to run along the edge between roof and lateral wall of the PSR (Fig. 1.6). However, it soon descends between the layers of the PSR's lateral wall (Fig. 1.4b) and passes into the orbit superolateral to the annular tendon of Zinn. Once inside the orbit, it penetrates the superior oblique muscle from above.

Trigeminal Nerve (CN V)

CN V comprises a sensory and a motor portion and forms three divisions, traditionally termed as "nerves" (CN V_1, CN V_2, CN V_3). It innervates the skin of the face and most of the mucosa of the nasal and oral cavity and the paranasal sinuses, as well as the tensor tympani, the masticatory muscles, and muscles of the diaphragma oris.

Sensory portion of CN V: The perikarya of the pseudounipolar neurons of the sensory portion are located in the trigeminal (semilunar) ganglion of Gasser (Fig. 1.4). The latter is positioned anterior to Meckel's cave, a recess of the subarachnoid space in the occipital part of the PSR's lateral wall (Figs. 1.6 and 1.7). The central processes of the axons of the pseudounipolar neurons travel to the brain and enter it laterally to the pons. The peripheral processes form the ophthalmic, maxillary, and mandibular nerves (Fig. 1.4).

The fibers of CN V, which innervate the skin of the face, are specially arranged. All thicker bundles run between periosteum and mimic muscles, forcing the nerve fibers which start in the skin to perforate the muscles. On their passage, some are joined by fibers innervating the proprioceptors located between the muscle fibers of the mimic muscles.

In general, similar connections exist with many other motor nerves. Therefore, proprioceptive fibers of the muscles of the head largely use CN V to enter the brain.

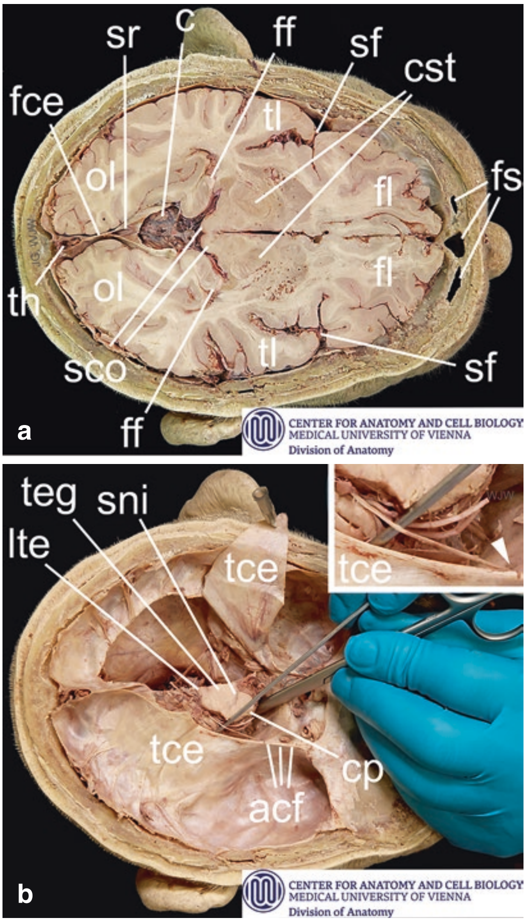

Fig. 1.6 Subarachnoid segment of cranial nerve (CN) IV. Numbers represent respective CNs. Axially cut head from superior. Frontal to the right. Calvaria and upper parts of the brain removed. (**a**) Topology of brain structures in relation to skull base and meninges for orientation. (**b**) Topology of CN IV. Left-sided telencephalon and entire diencephalon are removed. The left-sided tentorium cerebelli (tce) is cut along the transverse sinus and hinged superiorly along the superior petrosal sinus. The brain stem is cut at the level of the caudal mesencephalon and in the midline. Brain material on the left is removed. The right-sided ambient cistern is open. CN IV is exposed and lifted by a probe. Passing the cerebral peduncle (cp) laterally, it runs straight toward the lateral PSR. Inlay magnifies the entrance of CN IV into the anterior petroclinoid fold (acf, arrowhead). Note the superior cerebellar vessels below the probe. fs, frontal sinus; ol, occipital lobe; tl, temporal lobe; fl, frontal lobe; sf, Sylvian fissure; c, cerebellum; fce, falx cerebri; sr, sinus rectus; th, torcular Herophili (confluens of sinuses); ff, fimbria of fornix (hippocampus) emerging from hippocampus formation; sco, right-sided superior colliculus of lamina tecti (lte); cst, corticospinal tract later forming the center of cp; teg, tegmentum; sni, substantia nigra

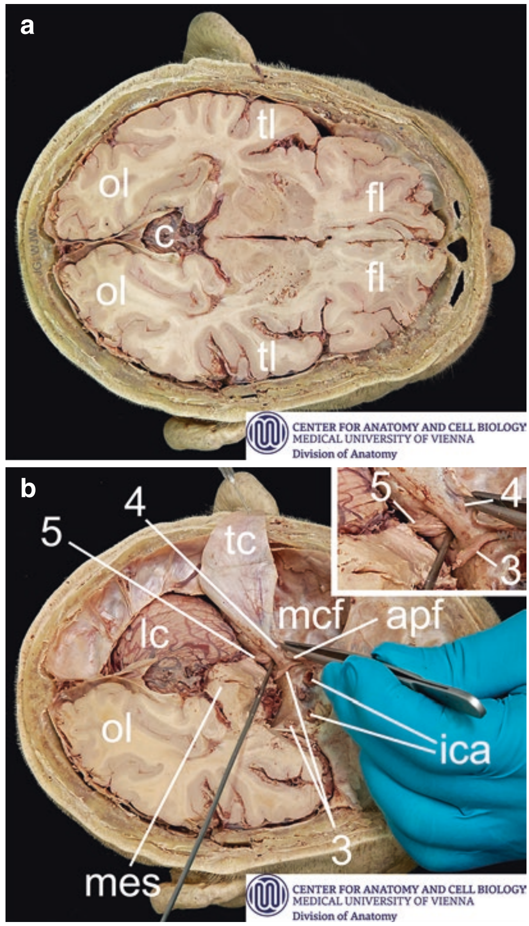

Fig. 1.7 Subarachnoid segment of cranial nerve (CN) V. Numbers refer to respective CNs. Axially cut head from superior. Frontal to the right. Calvaria and upper parts of the brain removed. (**a**) Topology of brain structures in relation to skull base and meninges for orientation. Compare to Fig. 1.6. (**b**) Topology of nerve. Left-sided telencephalon, entire diencephalon, and entire right-sided telencephalon are removed. The left-sided tentorium cerebelli (tce) is cut along the transverse sinus and hinged superiorly along the superior petrosal sinus. The brain stem is cut at the level of the caudal mesencephalon (mes). The tip of a probe is inserted in Meckel's cave. Inlay shows the relation of CN V and Meckel's cave. Ol, occipital lobe; tl, temporal lobe; fl, frontal lobe; c, cerebellum; lc, left cerebellar hemisphere; mcf; middle cranial fossa; ica; apf, anterior petroclinoid fold; internal carotid artery; apf, anterior pertoclinoid fold; 3, CN III; 4, CN IV; 5, CN V

Ophthalmic nerve (CN V_1): CN V_1 is composed of GSA fibers, which innervate the tentorium cerebelli, forehead, upper orbit, superior nasal cavity, nasal ridge, and the mucosa of the frontal sinus, sphenoid sinus, and ethmoidal cells. The nerve is formed inside the skull, near the superior orbital fissure, by fusion of three main nerve bundles, named lacrimal, frontal, and nasociliary nerve. Inside the skull, it passes in the layers of the lateral wall of the PSR and receives a meningeal branch, which chiefly innervates the tentorium cerebelli. Postganglionic sympathetic fibers from the superior cervical ganglion traveling via the internal carotid nerve, the parasellar trunk, and CN VI join it (see above).

- *Lacrimal nerve*: The nerve comprises fibers which innervate the lacrimal gland and the nearby tissues, including the conjunctiva. In the upper orbit, it is joined by postganglionic sympathetic and parasympathetic fibers (Fig. 1.8) that had used the zygomatic nerve to enter the orbit via the inferior orbital fissure (see section "Parasympathetic Ganglia"). Finally, the nerve enters the skull via the superior orbital fissure, running inside the annular tendon of Zinn.
- *Frontal nerve*: The nerve is formed by unification of the supratrochlear and supraorbital nerves [20]. The supratrochlear nerve comprises fibers innervating the skin of the medial forehead, while the supraorbital nerve fibers innervate the skin of the lateral forehead (Fig. 1.3a). Both turn around the superior rim of the orbit, with the supraorbital nerve using the foramen/incisura supraorbitalis (Fig. 1.8b). Once in the orbit, the nerves pass between the periosteum of the roof of the orbit and the levator palpebrae superioris muscle and unite. The resulting frontal nerve enters the skull through the superior orbital fissure, above Zinn's tendon.
- *Nasociliary nerve*: The nasociliary nerve is formed in the orbit by unification of the anterior and posterior ethmoidal nerves. The anterior ethmoidal nerve starts as the external nasal nerve in the skin overlying the nasal ridge. It enters the nasal cavity between nasal bone and cartilage. Inside the cavity, it ascends along the nasal bone toward the cribriform plate and is constantly joined by fibers coming from the local mucosa. It then changes name to anterior ethmoidal nerve and enters the skull through the anterior part of the cribriform plate. Staying beneath the dura mater, it runs for a few millimeters occipitally and then dives into the ethmoid cells. Here, it again receives fibers innervating the local mucosa before it enters the orbit through the anterior ethmoidal foramen. Inside the orbit, the nerve is joined by the posterior ethmoidal nerve, which comprises fibers innervating the mucosa of the posterior ethmoidal cells and sphenoid sinus.
- The nasociliary nerve connects with the ciliary ganglion. The connecting fibers had started in the cornea, ciliary body, and iris and reached the ganglion as part of the long ciliary nerves (compare to section "Parasympathetic Ganglia"). After this, the nerve also receives the infratrochlear nerve, which is formed by fibers innervating the skin of the medial canthus, skin and conjunctiva of the medial eyelids, and the tissues of and near the lacrimal sac.
- After having received all these nerve bundles, the nasociliary nerve transits the superior orbital fissure inside the tendinous annulus of Zinn and joins the lacrimal and frontal nerves inside the skull.

Maxillary nerve (*CN V_2*): CN V_2 comprises GSA fibers from the lower nasal cavity, soft palate and the teeth, mucosa, gingiva, and skin associated with the maxilla, palatine, and zygomatic bone.

The nerve is formed in the pterygopalatine fossa by unification of the infraorbital and zygomatic nerve and a small branch communicating with the pterygopalatine ganglion (Fig. 1.8). It enters the skull through the foramen rotundum and continues in the lateral wall of the parasellar region (Fig. 1.4b). Here, it is joined by a meningeal nerve, which innervates significant parts of the dura of the middle cranial fossa.

- *Infraorbital nerve*: Three main branches form the infraorbital nerve. The external nasal branches start in the skin of the lateral nose; the inferior palpebral branches in the skin of

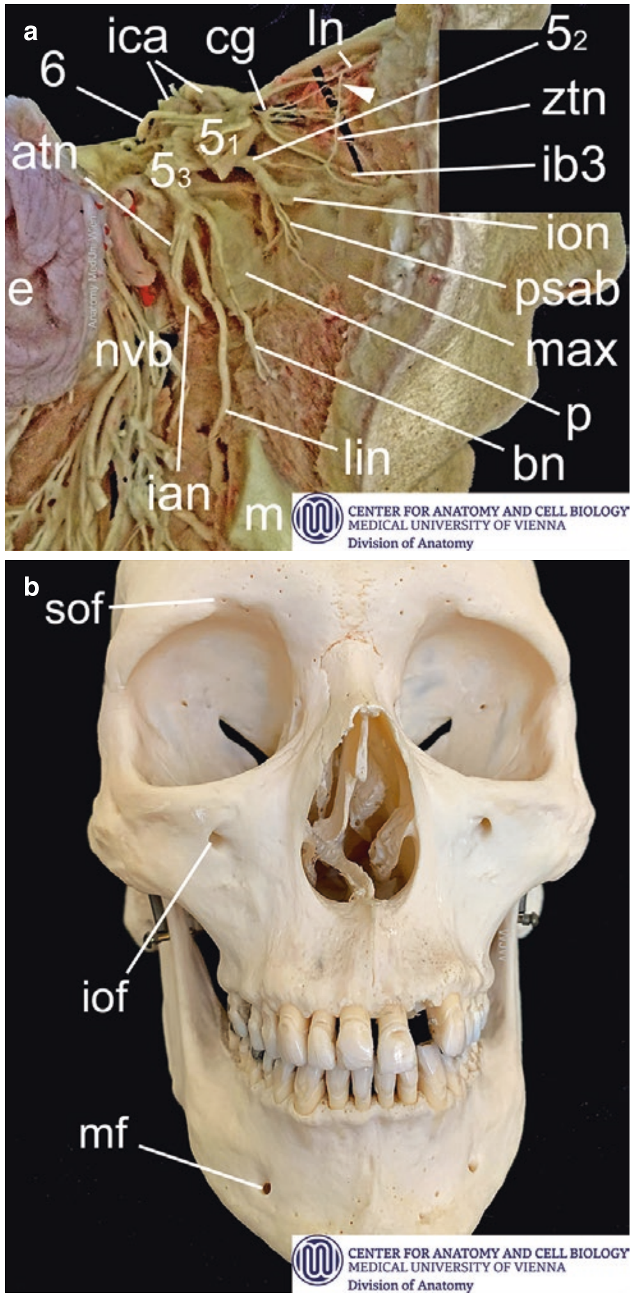

Fig. 1.8 Peripheral branches of cranial nerve (CN) V. Numbers refer to respective CNs. (**a**) Head specimen from the historical collection of the Division of Anatomy of the Medical University of Vienna. Parasellar region, lateral orbit, and the neurovascular bundle (nvb) of the laterophryngeal region are exposed by removing soft tissues and bones. The main stem of CN V and the trigeminal ganglion are resected. The intracranial segment of CN V_1 is hinged laterally, and the venous plexus of the PSR is removed to expose CN VI [6] and the internal carotid artery (ica), forming the carotid siphon. In the orbit, the ciliary ganglion (cg) with branches and the inferior branch of CN III (ib3) are visible. The lacrimal nerve (ln) receives postganglionic parasympathetic fiber (arrow) from the pterygopalatine ganglion via the zygomaticotemporal (ztn) and the zygomatic nerve (compare section "Parasympathetic Ganglia"). The bones shielding the upper lateral parts of the pterygopalatine fossa and the lateral foramen rotundum are removed. The infraorbital (ion) nerve and the posterior superior alveolar branches (psab) are discernable. Likewise, the lateral border of the foramen ovale is cleared away, and the sensory nerves of CN V_3, such as the buccal (bn), lingual (lin), inferior alveolar (ian), and auriculotemporal (atn) nerves, are exposed. The two latter are cut, since the mandible (m) is split and the two processes are removed. (**b**) Skull from ventral, showing the osseous structures, where the mental, infraorbital, and frontal nerves transit. p, pterygopalatine process; max, maxilla; e, auricle; 5_2, maxillary nerve; mf, mental foramen; iof, infraorbital foramen; sof, supraorbital foramen

the lower lid; and the superior labial branches in the skin of the upper lip. They converge near the infraorbital foramen and the resulting infraorbital nerve immediately enters the infraorbital foramen (Fig. 1.8b). It continues inside a canal or semicanal at the bottom of the orbit (Fig. 1.3a), which almost extends toward the inferior orbital fissure at the apex of the orbit. Inside the canal, the nerve receives branches from teeth and associated structures (*i.e*., anterior and middle superior alveolar nerves) and from the mucosa covering the maxillary sinus. Transiting the inferior orbital fissure, the nerve dives into the pterygopalatine fossa and receives posterior superior alveolar branches from the posterior teeth and associated structures (Fig. 1.8).

- *Zygomatic nerve*: The zygomatic nerve is formed in the lateral orbit by union of the zygomaticofacial and zygomaticotemporal nerves. It enters the pterygopalatine fossa through the inferior orbital fissure. The zygomaticofacial nerve collects fibers from the skin of the upper cheek and the zygomaticotemporal nerve fibers from the skin of the temple. Both nerves enter the orbit through eponymous foramina (also compare Figs. 1.14 and 1.15). Inside the orbit, the zygomaticotemporal nerve connects with the lacrimal nerve and exchanges fibers with the lacrimal nerve (Fig. 1.8; also compare section "Parasympathetic Ganglia").

Mandibular nerve (CN V_3): CN V_3 is the division of CN V which is composed of GSA fibers but also joined by motor fibers. The latter run medially to the sensory part of CN V and meet the sensory fibers near the oval foramen (Fig. 1.4b). Together, the motor and sensory fibers transit the oval foramen and enter the infratemporal fossa.

Sensory portion: The sensory portion of the mandibular nerve is formed near the oval foramen by unification of the sensory fibers traveling with the inferior alveolar, lingual, buccal, and auriculotemporal nerve.

- *Inferior alveolar nerve*: This nerve starts as the so-called mental nerve, which enters the mandibular canal through the mental foramen after having collected cutaneous branches from the lower lip and anterior lower jaw (Fig. 1.8b). Inside the canal, it changes its name to inferior alveolar nerve, which runs close to the inferior alveolar vessels. On its way it continuously thickens by receiving fibers from the teeth and associated apparatuses. Finally, the nerve leaves the canal through the mandibular foramen and ascends between the medial and lateral pterygoid muscles. From the mandibular to the oval foramen, the nerve runs close to, but independent from, the lingual nerve, although they often exchange fibers. Motor fibers ultimately forming the mylohyoid nerve accompany this segment.
- *Lingual nerve*: This nerve has GSA and SVA fibers. The GSA fibers innervate tactile receptors of the anterior 2/3 of the tongue (anterior to the terminal sulcus), the mucosa of the floor of the mouth, and parts of the gingiva of the lower yaw. Its stem runs between the tongue and mandible and then between the medial and lateral pterygoid muscles toward the oval foramen.
- Near the tongue, the nerve also receives SVA fibers from the taste buds of the anterior 2/3 of the tongue. They travel as part of the nerve until the nerve has reached the level of the pterygoid muscles. Here, these fibers leave the lingual nerve and form the chorda tympani—a nerve fiber bundle comprised of SVA and preganglionic parasympathetic fibers, which finally enter the brain as part of Wrisberg's nerve (see CN VII). The preganglionic parasympathetic fibers entering the lingual nerve via the chorda tympani use the nerve to travel toward the submandibular region, where they leave the nerve to synapse at perikarya of the submandibular ganglion (see section "Parasympathetic Ganglia").
- *Buccal nerve*: The buccal nerve starts in the mucosa and skin of the cheek and squeezes between the venters of the lateral pterygoid muscle to join CN V_3 below the oval foramen (Fig. 1.8).
- *Auriculotemporal nerve*: The auriculotemporal nerve starts in the skin of the temple, external acoustic meatus, tympanic membrane, tragus, and a small region immediately anterior to the ear. In the temple, it runs together with the superficial temporal artery. The nerve enters the tissues of the parotid gland anterior to the tragus and then passes medially to the temporomandibular joint to join CN V_3 below the oval foramen (Fig. 1.8). When passing below the foramen spinosum, the nerve is joined by a meningeal branch. It innervates the dura mater of the middle cranial fossa and leaves the skull through the foramen.

- Occipital to the foramen spinosum, the auriculotemporal nerve is joined by postganglionic parasympathetic fibers arising from the otic ganglion and sympathetic fibers, leaving the plexus surrounding the middle meningeal artery. They accompany the nerve toward the parotid gland, where they leave it to join CN VII (see section "Parasympathetic Ganglia").

Motor portion of CN V and CN V_3: The perikarya of the motor portion are located in the motor (masticator) nucleus. They leave the brain lateral to the pons. Running below and often separated from the sensory fibers, they head for the oval foramen, where they join CN V_3 medially (Fig. 1.4b). As soon as CN V_3 has passed the foramen, most of the motor fibers split off to innervate the masticatory, tensor tympani, and tensor veli palatini muscles. Merely a few motor fibers continue as part of the inferior alveolar nerve and soon leave it as the mylohyoid nerve. Hence, the motor fibers of CN V are only integrated for an astonishingly short distance in the main stem of CN V_3 and one of its branches.

- *Branches to muscles of mastication*: Once the motor portion has entered the infratemporal fossa as part of CN V_3, the fibers spread for the masticatory muscles. Thus, they form a masseteric nerve, which passes through the incisura mandibulae; a medial pterygoid nerve, which enters the medial pterygoid muscle; a lateral pterygoid nerve, which innervates the lateral pterygoid muscle; and several deep temporal nerves, which ascend toward the temporal muscle. Quite frequently, the fibers of the lateral pterygoid nerve stay as part of the buccal nerve until it squeezes between the bellies of the lateral pterygoid muscle.
- *Branches to muscles of the skull base and auditory system*: Immediately below the foramen ovale, CN V_3 also gives rise to fibers, which head for the tensor tympani and tensor veli palatini muscles.
- *Mylohyoid nerve*: A larger bundle of motor fibers stays with the inferior alveolar nerve. Before it enters the mandibular foramen and the mandibular canal, this bundle leaves the nerve as mylohyoid nerve. This descends toward the diaphragma oris to innervate the mylohyoid and anterior belly of digastric muscle.

CN V—peculiarities: The motor portion of CN V can be considered as more or less entirely separated from the sensory portion. It often exits the brain independent from the sensory portion and merely joins the sensory CN V_3 near the oval foramen to immediately split into motor nerves outside the skull. The only exceptions are the mylohyoid nerve, which travels for a short distance as part of the inferior alveolar nerve, and in some variation the lateral pterygoid nerve, which may travel for a short distance with the very proximal portion of the buccal nerve. Consequently, it seems to be much more correct to consider CN V as two separate nerves: a sensory CN V and a motor CN V.

Many branches of CN V are joined by visceral (autonomous) nerve fibers. Their precise cranial course and connections are described in the section "Parasympathetic Ganglia".

Abducens Nerve (CN VI)

CN VI leaves the brain near the caudal rim of the pons. It comprises motor fibers, which innervate the lateral rectus muscle of the eyeball.

From its exit, CN VI ascends and perforates the dura mater covering the clivus. Amidst the veins of the basilar plexus, it continues its ascend and enters the PSR through the canal of Dorello. Inside the PSR, it runs lateral to the internal carotid artery, surrounded by the veins of the parasellar venous plexus (Fig. 1.4c).

The parasellar segment of CN VI is joined by postganglionic sympathetic nerve fibers, which instantly leave it for CN V_1 (compare section "Parasellar Sympathetic Pathways"). CN VI finally leaves the PSR through the superior orbital fissure, running inside the annulus tendon of Zinn. In the orbit, it heads for the lateral rectus muscle and innervates it. Quite frequently it transits the PSR as two roundish bundles [21].

Nerves of the Cerebellopontine Angle (CN VII and CN VIII)

The fibers of CN VII and CN VIII leave/enter the brain in close vicinity at the site where the pons, medulla oblongata, and cerebellum, respectively, its inferior peduncle, come together (cerebellopontine angle). Running in the cerebellopontine cisterna, they head for the internal acoustic meatus and leave/enter it together with the labyrinthine artery (Fig. 1.9).

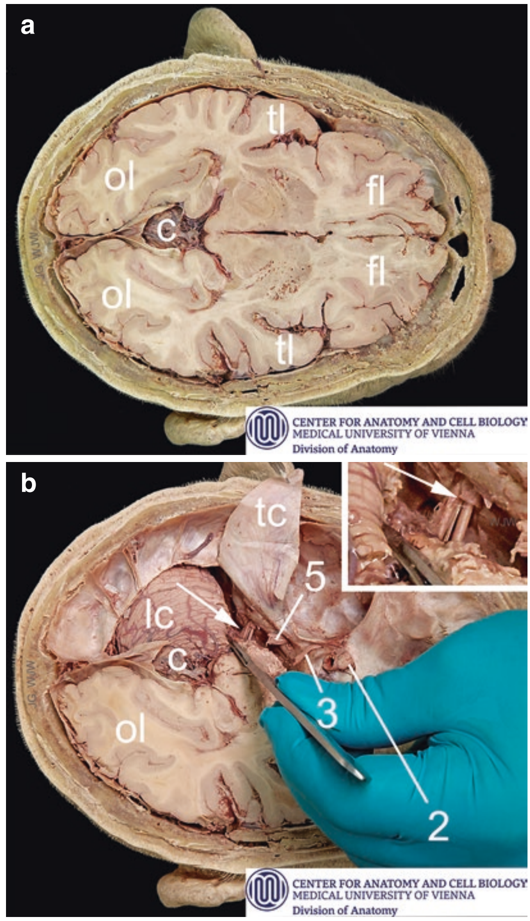

Fig. 1.9 Subarachnoid course of the nerves of the cerebellopontine angel (v3)—*i.e.,* cranial nerve (CN) VII and CN VIII. Numbers refer to respective CNs. Axially cut head from superior. Frontal to the right. Calvaria and upper parts of the brain removed. (**a**) Topology of brain structures in relation to skull base and meninges for orientation. Compare to Fig. 1.6. (**b**) v3 and labyrinthine artery (arrow). The left-sided telencephalon and the entire diencephalon are removed. The left-sided tentorium cerebelli (tc) is cut along the transverse sinus and hinged superiorly along the superior petrosal sinus. The brain stem is cut at the level of the caudal mesencephalon and in the midline. Brain stem material on the left is removed. Inlay magnifies the situation at the internal acoustic porus, the opening leading into the internal acoustic meatus. ol, occipital lobe; tl, temporal lobe; fl, frontal lobe; c, cerebellum; lc, left cerebellar hemisphere; tc, hinged left tentorium cerebelli; 2, cranial nerve (CN) II; 3, CN III; 5, CN V

(Intermedio) Facial Nerve (CN VII)

CN VII is composed of two bundles. One is the "proper" facial nerve consisting of motor fibers. The second is the nervus intermedius (intermediate nerve of Wrisberg) comprising preganglionic parasympathetic, GSA, and SVA fibers. Quite frequently, the motor fibers and the intermediate nerve leave the brain separately and join near the internal acoustic porus. Together, they pass through the meatus and enter the facial (Fallopian) canal, which branches off from the internal acoustic meatus in a frontolateral direction.

The canal changes its direction twice and consequently has three segments. The first (labyrinthine) segment continues the frontolateral direction of the internal acoustic meatus. After a knee-like bend, the second (tympanic) segment heads occipitolaterally. Then, the canal curves downwards, and the third (mastoid) segment descends and terminates at the stylomastoid foramen. Consequently, the intrapetrous portion of CN VII features three eponymous segments and two curves. The first curve, between the labyrinthine and tympanic segments, is termed as the external knee of the facial nerve. It is formed by all fibers of CN VII. The internal knee of the facial nerve is formed inside the brain and only by motor fibers, which round the abducens nucleus and curl up the facial colliculus of the rhomboid fossa.

Intermediate nerve: Wrisberg's nerve holds efferent (preganglionic parasympathetic) and afferent (GSA and SVA) fibers. It innervates the lacrimal, submandibular, sublingual, and small salivatory glands, taste buds at the anterior 2/3 of the tongue and in the palatal mucosa, and a small skin area at the outer ear. The perikarya of the afferent neurons form the geniculate ganglion, a ganglion located at the apogee of the external knee of CN VII.

The nerve splits into two large nerve bundles, the greater petrosal nerve and the chorda tympani. In addition, a small connection exists between CN X and the mastoid segment of CN VII, which transfers GSA fibers innervating the skin of the external acoustic meatus, mastoid, and pinna. All bundles that leave the intracanalicular segment of CN VII travel in osseous canals (see section “Parasympathetic Ganglia”).

- *Greater petrosal nerve*: It comprises SVA fibers and preganglionic parasympathetic fibers and joins CN VII at its external knee. The SVA fibers start at the taste buds of the palatal mucosa. The parasympathetic fibers travel quite complexly to the pterygopalatine ganglion (see section “Parasympathetic Ganglia”).
- *Chorda tympani*: The chorda tympani connects the mastoid segment of CN VII and the lingual nerve at its transition between the medial and lateral pterygoid muscles. It comprises SVA fibers and preganglionic parasympathetic fibers. The SVA fibers start from taste buds at the anterior 2/3 of the tongue (anterior to the terminal sulcus) and accompany the lingual nerve all the way from the tongue to the connection with the chorda tympani. The preganglionic parasympathetic fibers join the lingual nerve as part of the chorda tympani and leave the nerve proximal to the submandibular fossa to enter the submandibular ganglion (see section “Parasympathetic Ganglia”).

Motor fibers/nerves of CN VII: The motor fibers of CN VII innervate the stapedius, mimic, some auricular, and the posterior suprahyoid muscles.

The first motor nerve arising from CN VII is the stapedial nerve. It splits from its mastoid segment proximal to the chorda tympani and runs in an osseous canal toward the eponymous muscle.

Immediately after passing through the stylomastoid foramen, three branches split from CN VII. First is the posterior auricular nerve, which ascends occipital to the pinna to innervate the occipital belly of the occipitofrontalis muscle. It also forms small branches to innervate the rudimentary posterior auricular and upper intrinsic muscles of the auricle. Second is the stylohyoid nerve, which leaves for the stylohyoid muscle. Third is the digastric nerve, which heads for the posterior belly of the digastric muscle.

The main stem of the facial nerve then dives into the parotid gland and usually splits into two main trunci, named cervicofacial and temporofacial division, although there is a broad variability. The branches of the trunci form a plexus between the superficial and profound portion of the parotid gland (Fig. 1.10). From this plexus, a highly variable number of fiber bundles are formed, which emerge from the anteroinferior borders of the parotid gland (Fig. 1.10a). According to their targets, five main groups are usually distinguished. They are termed as temporal, zygomatic, buccal, marginal mandibular, and cervical branches and spread toward the mimic muscles located in the respective areas [22, 23].

Vestibulocochlear Nerve (CN VIII)

CN VIII is composed of a cochlear and vestibular portion. It comprises sensory and motor fibers and is involved in hearing and balance.

Sensory fibers: CN VIII mainly comprises SSA fibers stemming from bipolar neurons in the modiolus of the cochlea (spiral ganglion) and the internal acoustic meatus (vestibular ganglion of Scarpa).

The central (efferent) axons of both ganglia join and straightly run toward the cerebellopontine angle. The cochlear portion synapses in the ventral and dorsal cochlear nucleus; the vestibular portion in the medial (Schwalbe), lateral (Deiters), superior (Bechterew), and inferior (Roller) vestibular nucleus. All these nuclei are located ventral to the rhomboid fossa.

The peripheral (afferent) axons of the spiral ganglion connect with inner and outer hair cells of Corti’s organ. The peripheral (afferent) axons of the vestibular ganglion reach the ganglion as two fiber bundles. The inferior bundle starts at sensory cells of the anterior and lateral semicir-

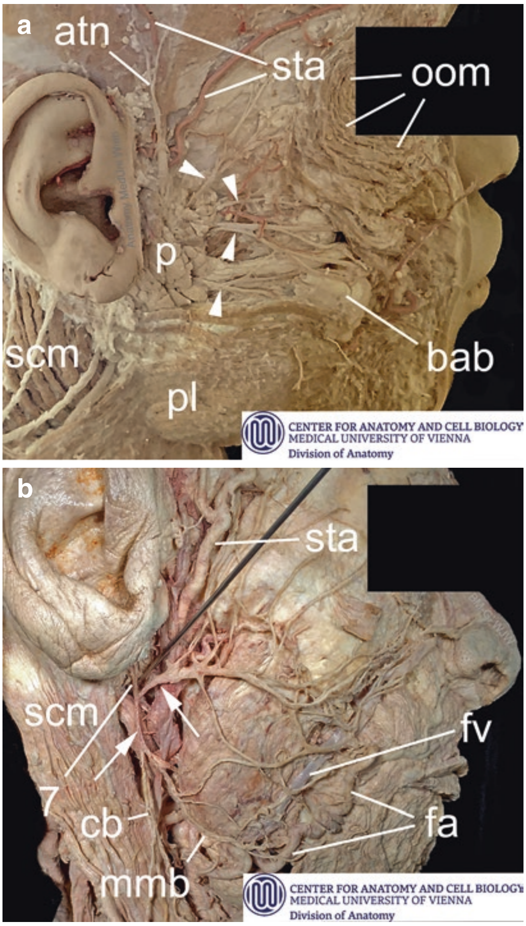

Fig. 1.10 Extracranial branches of cranial nerve (CN) VII. Numbers refer to respective CNs. Head specimen from right. Skin and subcutis are removed. Frontal to the right. (**a**) Specimen from the historical collection of the Division of Anatomy of the Medical University of Vienna. Major terminal motor branches of CN VII (arrowheads) leave the parotid gland (p) at its borders. The inferior branches are covered by the platysma (pl). Note the relationship between auriculotemporal nerve (atn), a branch of CN V_3 and the branches of the superficial temporal artery (sta). (**b**) Specimen, in which platysma and parotid gland are removed. CN VII splits into a superior and inferior trunk (arrows). The cervical branch (cb) and the marginalis mandibulae branch (mmb), both formed by the inferior trunk, are now visible. Note that branching of CN VII is highly variable, and this is only one of many normal variations. oom, orbicularis oculi muscle; scm, sternocleidomastoid muscle; fv, facial vein; fa, facial artery; bab, buccal adipose body (Bichat's fat pad)

cular canals and the utriculus. The superior bundle starts at sensory cells of the posterior semicircular canal and the sacculus.

Motor fibers: In addition to SSA fibers, both the cochlear and vestibular portion hold motor fibers, which emerge from the superior olivary complex and the ventral rhombencephalon, respectively [24, 25]. They terminate at sensory cells and are considered to modulate their responsiveness [26].

Nerves Exiting from the Anterolateral Sulcus (CN IX–CN XI)

A large number of nerve fiber bundles exit the brain at the posterolateral (dorsolateral) sulcus (retroolivary groove) of the medulla oblongata, ventral to the oliva, and caudal to Bochdalek's flower basket (Fig. 1.1). They head for the nervous part of the jugular foramen (Fig. 1.11). On their way, the three to four most rostral bundles join to form CN IX, the next eight to ten form CN X, and the most caudal ones form the cranial root of CN XI. Inside the jugular foramen, the nerves are ensheathed by a recess formed by dura and arachnoid mater. A connective tissue septum divides the recess in two compartments. One contains CN X and CN XI; the other contains CN IX.

CN IX and CN X comprise both efferent and afferent fibers. Hence, each of the two nerves has two pseudounipolar ganglia; one inside and a second just below the jugular foramen. At the level of its superior ganglion, the vagus nerve is joined by a large nerve fiber bundle, the "internal ramus" of CN XI (see below).

Glossopharyngeal Nerve (CN IX)

CN IX innervates parts of the tympanic cavity, pharynx, pharyngeal isthmus, parotid gland, and both the taste buds and sensory receptors of the posterior 1/3 of the tongue (posterior to the terminal sulcus). It comprises GSA, SVA, and preganglionic parasympathetic and motor fibers, which contribute to various plexus and some small nerves.

Tympanic plexus: The first branch of CN IX is the tympanic (Jacobson's) nerve. It comprises most of the preganglionic parasympathetic fibers

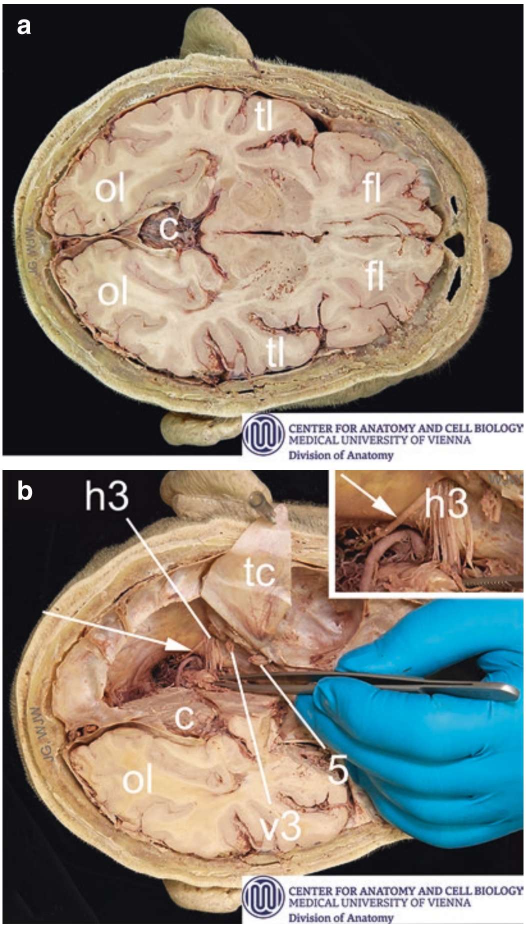

Fig. 1.11 Subarachnoid course of the nerves exiting from the anterolateral sulcus (h3), *i.e.,* cranial nerve (CN) IX, CN X, and CN XI. Numbers refer to respective CNs. Axially cut head from superior. Frontal to the right. Calvaria and upper parts of the brain removed. (**a**) Topology of brain structures in relation to skull base and meninges for orientation. Compare to Fig. 1.6. (**b**) Topology of h3 at the entrance into the pars nervosa of the jugular foramen. Left-sided telencephalon and entire diencephalon are removed. The left-sided tentorium cerebelli (tc) is cut along the transverse sinus and hinged superiorly along the superior petrosal sinus. The brain stem is cut at the level of the caudal mesencephalon and in the midline. Brain stem material on the left is removed. Note the plethora of rootlets and the spinal root of CN XI (arrow). Inlay magnifies the situation. ol, occipital lobe; tl, temporal lobe; fl, frontal lobe; c, cerebellum; tc, hinged left tentorium cerebelli; v3, nerves of the cerebellopontine angle; 5, trigeminal nerve

of CN IX and a small number of sensory fibers. The nerve leaves CN IX near its inferior ganglion, ascends, and enters the tympanic cavity through the tympanic canaliculus (compare Fig. 1.14). Inside the tympanic cavity, it splits into a plexus (tympanic plexus), innervates the local mucosa and the mucosa of the mastoid cells and tuba Eustachii, and connects with the greater petrosal nerve. Finally, some plexus fibers converge again and form a small nerve bundle, the lesser petrosal nerve. This nerve comprises the preganglionic parasympathetic fibers, which head for the otic ganglion (see section “Parasympathetic Ganglia”).

Pharyngeal plexus: After exiting from the nervous part of the jugular foramen, the main stem of CN IX accompanies the levator pharyngis muscle toward the pharynx (Fig. 1.12). Here, its fibers become part of the pharyngeal plexus. This plexus innervates the mucosa and the muscles of the pharynx and is described to be built up by both CN IX and CN X; the fibers of CN IX chiefly contribute to the cranial part of the plexus and consequently innervate the proximal segments of the pharynx.

Tonsillar plexus: Together with the middle and posterior palatine nerves (see below), fibers of CN IX form a tonsillar plexus, which innervates the mucosa and intrinsic muscles of the soft palate, the levator veli palatini, the pharyngeal isthmus, and the tonsils.

Lingual branches: CN IX receives sensory fibers from the tongue. These lingual branches comprise GSA and SVA fibers and innervate both the mucosa and taste bodies of the tongue posterior to the terminal sulcus.

Carotid sinus nerve: Finally, a small bundle of nerve fibers connects CN IX with sensors located in the glomus body and the wall of the carotid sinus near the carotid bifurcation.

Vagus Nerve (CN X)

CN X innervates targets not only in the head and neck region but also in the thorax and abdomen. It comprises GSA, SVA, preganglionic parasympathetic, and motor fibers.

The nerve leaves the skull through the jugular foramen and descends in the parapharyngeal space, running inside the carotid sheath, sand-

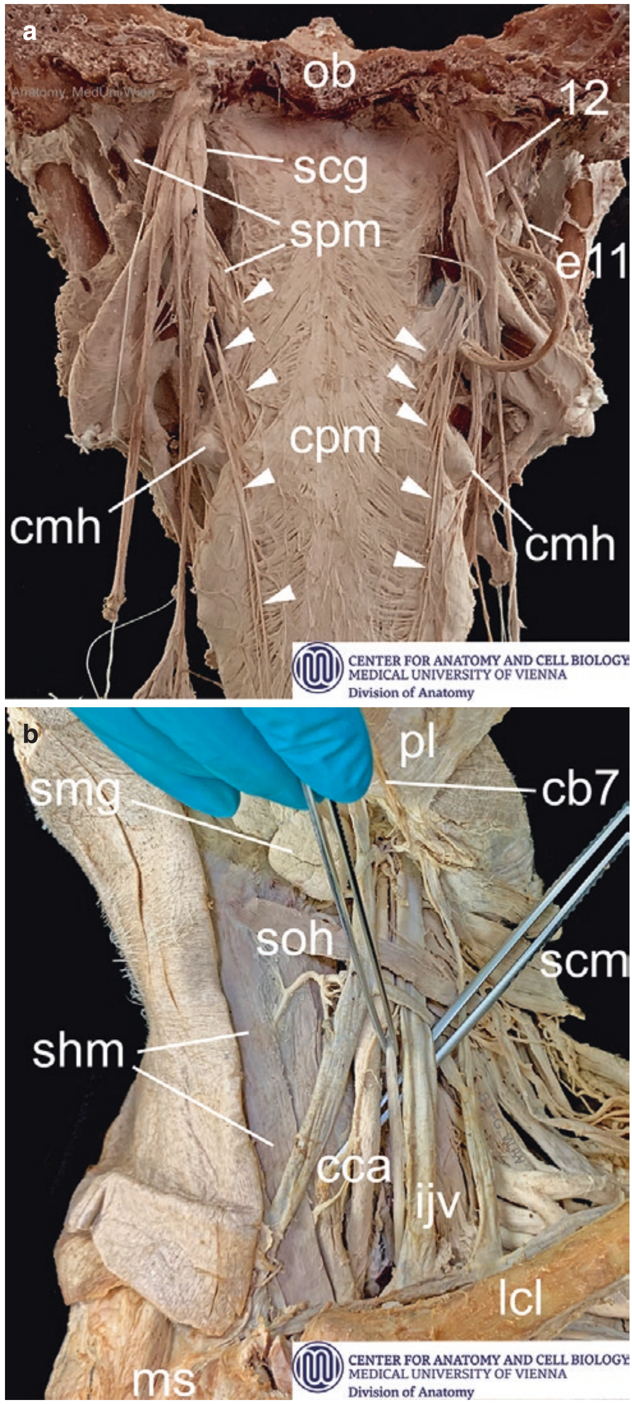

Fig. 1.12 Cranial nerves (CN) IX, CN X, CN XI, and CN XII in the neck. Numbers refer to respective CNs. (**a**) Specimen from the historical collection of the Division of Anatomy of the Medical University of Vienna. Dorsal wall of pharynx and the parapharyngeal neurovascular bundles are exposed. Dorsal view. Branches of CN IX run along the stylopharyngeus muscle (spm) toward the constrictor pharyngis muscles (cpm). Arrowheads indicate branches of CN IX and CN X that form the pharyngeal plexus. Note the spiral course of CN XII [12] and the external ramus of CN XI (e11). (**b**) Left-sided parapharyngeal nerves and vessels from anterolateral. Skin, subcutis, superficial, and middle cervical fasciae, and vagina carotica are removed. Platysma (pl) with innervating cervical branch of CN VII (cb7) and sternocleidomastoid (scm) muscle are hinged superolaterally. The omohyoid muscle is cut, and its cranially shifted venter superior (soh) is positioned between the superficial and deep veins of the neck. CN X, descending between common carotid artery (cca) and internal jugular vein (ijv), is held and lifted by a forceps. ob, occipital bone; cmh, dorsal tip of larger horn of hyoid bone; scg, superior cervical ganglion (of sympathicus); ms, manubrium of sternum; lcl, left clavicle; smg, submandibular gland; shm, sternohyoid muscle

wiched between internal carotid artery and jugular vein (Fig. 1.12b). It enters the thorax and passes dorsal to the hilum of the lung to join the esophagus. In the caudal mediastinum, the left CN X shifts anterior and, together with a few fibers of the right, forms the anterior vagal trunk, which passes the esophageal hiatus of the diaphragm anterior to the esophagus. On the contralateral side, the majority of the fibers of the right CN X shift posteriorly and form the posterior vagal trunk. This passes the diaphragm also through the esophageal hiatus but posterior to the esophagus. In the abdomen, the trunks spread to form a plexus anteriorly and posteriorly to the stomach. The shift of the majority of the left CN X to the anterior and the right CN X to the posterior wall of the stomach has its reason in the leftward rotation of the stomach's greater curvature in early embryogenesis.

Segment of CN X inside the jugular foramen: Inside the jugular foramen, at the level of its superior ganglion, the nerve is joined by a meningeal branch and an auricular branch (Arnold's nerve). The first innervates the dura mater of the posterior cranial fossa, the second the skin of the inner parts of the concha, the posterior wall, and floor of the external acoustic meatus and adjacent parts of the tympanic membrane. It enters the jugular foramen through the mastoid canaliculus and connects to CN VII.

Head and neck segment of CN X: In the neck, CN X occasionally receives fibers of the cervical spinal nerves via the ansa cervicalis [27]. It gives rise to GSA and motor fibers, which contribute to the pharyngeal plexus and innervate the caudal parts of the pharynx (Fig. 1.12b). Small bundles of GSA and SVA fibers run toward and innervate the mucosa and extralingual taste buds located at and near the epiglottis [28].

Preganglionic parasympathetic fibers of the neck segment also form superior cardiac branches. Independently from the main stem of the nerve, they descend to ganglia near the heart. This reflects the early innervation of the heart during embryogenesis, which starts prior to the relative "descensus" of the heart into the thorax.

Finally, the neck segment forms the superior laryngeal nerve, which splits into an external and internal laryngeal nerve. The external innervates the cricothyroid muscle, the internal the mucosa of the cranial larynx.

Thoracic segment of CN X: Inside the chest, CN X gives rise to the recurrent laryngeal nerve. It comprises GSA, preganglionic parasympathetic, and motor fibers. On the left side, the nerve slings around the aortic arch segment between the origin of the left common carotid and left subclavian artery and then ascends between esophagus and trachea toward the laryngopharynx. On the right side, it slings around the proximal segment of the right subclavian artery and then takes a comparable course—the rounded aortic arch and right subclavian artery segments are both derivatives of the fourth pair of pharyngeal (aortic) arch arteries [29].

The nerve enters the pharynx and continues climbing cranially by running below the mucosa covering the piriform recess and the posterior cricoarytenoid muscle. It changes name to the inferior laryngeal nerve and connects to the superior laryngeal nerve, thereby forming the ansa galeni. The branches of the inferior laryngeal nerve innervate the local pharynx mucosa, the larynx mucosa caudal to the vocal fold, and the inner muscles of the larynx.

The recurrent nerve gives rise to the inferior cardiac branch. This comprises preganglionic parasympathetic fibers, which chiefly synapse in Wrisberg's ganglion, near the heart.

In addition to the recurrent laryngeal nerve, the thoracic portion also forms a pulmonary plexus dorsal to the lung hilum. Fibers of this plexus enter the ipsilateral lung to innervate bronchial glands and muscles.

Abdominal segment of CN X: The abdominal segment is responsible for the parasympathetic innervation of the components of the gastrointestinal tract, from esophagus to Cannon's point (see "Parasympathetic Ganglia" section). Fibers of the vagal trunks become integrated into the celiac and superior mesenteric plexus. These plexuses form around the eponymous arteries and are also named as solar plexus. They contain preganglionic parasympathetic (fibers of CN X), postganglionic sympathetic, and GVA fibers.

The fibers of the vagus nerves finally synapse at intramural ganglion cells of the organs orally to Cannon's point (compare to "Parasympathetic Ganglia" section).

Accessory Nerve (CN XI)

CN XI is traditionally considered as a motor nerve with a cranial and spinal root. Each root has several rootlets. The cranial rootlets leave the posterolateral (dorsolateral) sulcus of the medulla oblongata caudal to the rootlets of CN X. The spinal rootlets leave the segments C1–C5 of the spinal cord, between the ventral and dorsal roots of the cervical spinal nerves. The rootlets of the spinal root ascend and consecutively unify, wherefore a single spinal root then transits the foramen magnum and runs toward the nervous portion of the jugular foramen (Figs. 1.1 and 1.11). Here, it meets the cranial root to form CN XI.

Transiting the foramen in the same compartment of the dura and arachnoid recesses that holds CN X, CN XI splits into an external and internal ramus. The internal becomes integrated in CN X. The external—essentially the fibers of the spinal root—exits the jugular foramen separately and runs to the dorsal aspect of the sternocleidomastoid muscle (Fig. 1.12). Then, it crosses the posterior triangle of the neck in a characteristic meandering course and enters the trapezius muscle [30]. It innervates these muscles together with branches directly emerging from the cervical plexus (sternocleidomastoid and trapezius branch).

Even traditional textbooks (*e.g.*, [1]) emphasize that the concept of a two-rooted CN XI is unsatisfactory. Considering the cranial radix as part of CN X and the spinal radix as CN XI would be more appropriate, since the fibers forming the external ramus essentially emerge from segments of the cervical spine. Hence, both, the sternocleidomastoid and trapezius muscle, are innervated by neurons of the perikarya, which are located in the anterior cornua of segments of the cervical spinal cord.

Hypoglossal Nerve (CN XII)

CN XII is composed of motor fibers innervating the intrinsic and extrinsic muscles of the tongue. It leaves the anterolateral (ventrolateral) sulcus of the medulla spinalis in several rootlets. They pass the vertebral artery (Fig. 1.13) and unify into 1–3 (but in principle up to four) bundles, which head for the hypoglossal canal. The canal is usually composed of 1–2 tunnels, with up to four being possible. Inside the canal, each nerve bundle is surrounded by an extension of dura and arachnoid mater.

After leaving its canal, CN XII is situated dorsal to the vein and nerves transiting the jugular foramen. It starts descending and spirals these nerves and vessels (Fig. 1.12). Then, it curves and crosses the parapharyngeal bundle anteriorly to enter the gap between the mylohyoid and hyoglossus muscles. The curved segment is crossed by the stylomastoid artery on its way from the external carotid artery to the eponymous muscle. Finally, CN XII splits and terminates inside the muscles of the tongue.

The nerve innervates all ipsilateral intrinsic tongue muscles (transversal, vertical, and longitudinal muscle fiber bundles) as well as all muscles connecting the tongue to skeletal elements (genioglossus, hyoglossus, and styloglossus muscles).

Intracranially, CN XII is joined by a meningeal branch consisting of GSA fibers innervating the dura mater of the posterior cranial fossa. They are considered to merely join CN XII for the transit from intra- to extracranially. Extracranially, these fibers immediately leave CN XII to join CN X. Together with these fibers, postganglionic sympathetic fibers starting in the superior cervical ganglion are exchanged. They leave C12 with the meningeal branch and travel with it into the cranial cavity to innervate the arteries of the posterior cranial fossa.

In the neck, large fiber bundles from spinal nerves C1 and C2 join CN XII. These fibers accompany the nerve only for a few millimeters and leave it to form the upper root (superior radix) of the ansa cervicalis (profunda), which innervates the infrahyoid muscles.

The multi-sectioned canal and the existence of several nerve bundles reflect that CN XII is essentially formed by the fusion of the anterior roots of four spinal nerves, which emerge between the occipital somites and fail to form dorsal roots—occipital somites exist in the early embryo and contribute to the occipital bone. Hence, the status of CN XII as a "cranial nerve" is questionable from an anatomic perspective.

Parasympathetic Ganglia and Postganglionic Nerves in the Head and Neck

Four cranial nerves (CNs III, VII, IX, and X) comprise, among others, preganglionic parasympathetic fibers when exiting the brain. Those of CN III, VII, and IX head for four large multipolar or one of the several, very small scattered visceral ganglia located in the head. On the contrary, the parasympathetic fibers of CN X synapse at intramural ganglion cells of the intestine and ganglia scattered near the large organs of thorax and abdomen.

As all ganglion cells, those of the visceral ganglia are derived from neural crest cells, migrating into the body tissues during early embryogenesis. Usually, there is an amplification, with one preganglionic fiber on average synapsing with three postganglionic neurons.

The four main head ganglia are briefly characterized in Table 1.2. The ganglia only comprise multipolar perikarya of parasympathetic neurons. Yet, the ganglia also connect to postganglionic sympathetic and general somatic afferent (GSA) nerves. Therefore, nerves emerging from the ganglia, or at least the nerves joined by postganglionic parasympathetic fibers, hold postganglionic parasympathetic, postganglionic sympathetic, and GSA fibers.

Ciliary Ganglion

The ciliary ganglion rests in the orbit, temporal to the optic nerve and approximately halfway between the eyeball and the apex of the orbit (Fig. 1.8). Preganglionic parasympathetic fibers, derived from the accessory nucleus of the oculomotor nerve (Edinger Westphal), synapse. They reach the ganglion by traveling as part of CN III.

GSA fibers of CN V_1 and postganglionic sympathetic fibers traveling as part of the nasociliary nerve also enter the ganglion, with the latter having joined the parasellar segment of CN V_1. They do not synapse but merely pass through and become integrated in the nerves leaving the ganglion.

The ganglion gives rise to so-called short ciliary nerves, which hold GSA and postsynaptic sympathetic and parasympathetic fibers. These nerves enter the eyeball. The parasympathetic fibers innervate the ciliary body and muscle and sphincter pupillae. The sympathetic fibers innervate the dilatator pupillae and occasionally travel with the long ciliary nerves (direct branch of nasociliary nerve) instead of passing through the ganglion.

Pterygopalatine Ganglion

The pterygopalatine ganglion rests in the pterygopalatine fossa. It receives preganglionic parasympathetic fibers from the superior part of the salivatory nucleus (lacrimal nucleus) via the intermediate, greater petrosal, and Vidian nerve (nerve of the pterygoid canal).

Table 1.2 Cranial parasympathetic ganglia

	Position	Preganglionic neurons	Preganglionic fibers (CN)	Parasympathetic targets
Ciliary	Orbit	Nucleus of Edinger-Westphal (accessory nucleus)	CN III	Sphincter pupillae, ciliary muscle, and body
Pterygopalatine	Pterygopalatine fossa	Superior salivatory nucleus	CN VII (intermediate)	Lacrimal gland
Submandibular	Submandibular region	Superior salivatory nucleus	CN VII (intermediate)	Submandibular gland
Otic	Infratemporal fossa, near oval foramen	Inferior salivatory nucleus	CN IX	Parotid gland

The greater petrosal nerve splits off the intermediate nerve of Wrisberg at the level of the external knee of CN VII. It carries GSA and SVA fibers and passes in an osseous canal through the petrosal part of the temporal bone. After leaving the canal and entering the middle cranial fossa through a small hiatus (hiatus of greater petrosal nerve), it continues extradurally in a small osseous groove towards the foramen lacerum. After passing through this foramen, it joins the profound petrosal nerve. This is a bundle of postganglionic sympathetic fibers, which branches from the internal carotid nerve before it enters the carotid canal (compare Fig. 1.13).

The unified greater and profound petrosal nerves are named as nerve of the pterygoid canal (Vidian nerve). This passes through the eponymous canal at the base of the pterygoid process (Vidian canal) and reaches the pterygopalatine ganglion in the pterygopalatine fossa (Fig. 1.14).

The pterygopalatine ganglion is situated below the level of the foramen rotundum and is also entered by a big bundle of sensory fibers from CN V_2 (compare to CN V). The parasympathetic fibers synapse, while the sympathetic GSA and SVA fibers only pass through. Hence, the nerves arising from the ganglion are composed of postganglionic parasympathetic and sympathetic fibers, as well as two types of sensory fibers.

Most of the nerves arising from the ganglion descend to innervate the mucosa, taste buds, and minor salivary glands of the palate, nasopharynx, and posterior and lower nasal cavity. Two ascend through the inferior orbital fissure to reach targets in the orbit (Fig. 1.15).

Nasopharyngeal nerve: The nerve passes through the palatovaginal canal to reach the nasopharynx near the ostium of the auditory tube.

Greater palatine nerve: The nerve gives rise to lateral posterior inferior nasal branches and then transits the greater palatine foramen to innervate most of the hard palate (Fig. 1.15b).

Lesser palatine nerves: These are usually 2–3 nerves which pass through the lesser palatine canal and innervate the soft palate, uvula, and palatine tonsil.

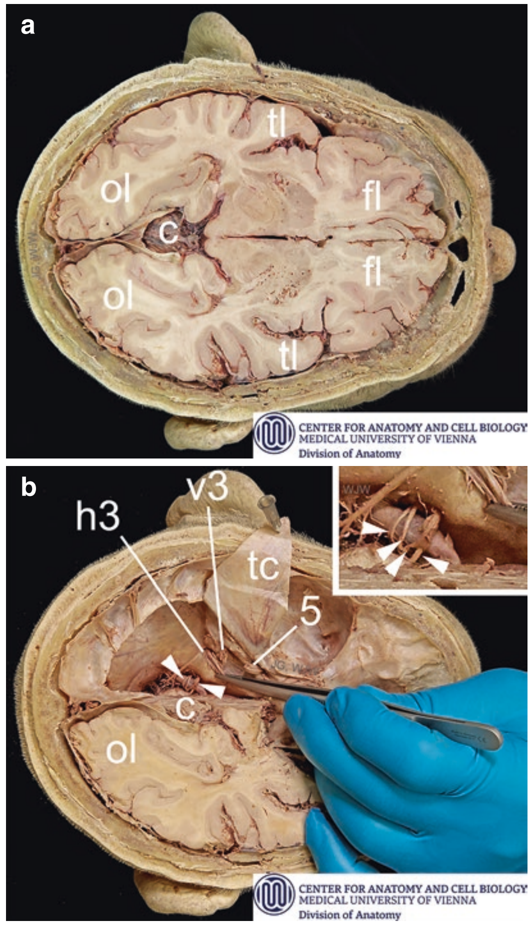

Fig. 1.13 Cranial nerve (CN) XII. Numbers refer to respective CNs. Axially cut head from superior. Frontal to the right. Calvaria and upper parts of the brain removed. (**a**) Topology of brain structures in relation to skull base and meninges for orientation. Compare to Fig. 1.6. (**b**) Intracranial course of CN XII. Left-sided telencephalon and entire diencephalon are removed. The left-sided tentorium cerebelli (tce) is cut along the transverse sinus and hinged superiorly along the superior petrosal sinus. The brain stem is cut at the level of the caudal mesencephalon and in the midline. Brain stem material on the left is removed. Inlay magnifies the situation near the hypoglossal canal. The rootlets of the nerves, which leave the brain at the anterior lateral sulcus (h3) are shifted frontally by a forceps to expose CN XII. Its rootlets (arrowheads) converge and enter a bipartite hypoglossal canal. Note their relationship to the vertebral artery. ol, occipital lobe; tl, temporal lobe; fl, frontal lobe; c, cerebellum; tc, hinged left tentorium cerebelli; v3, cranial nerves of the cerebellopontine angle

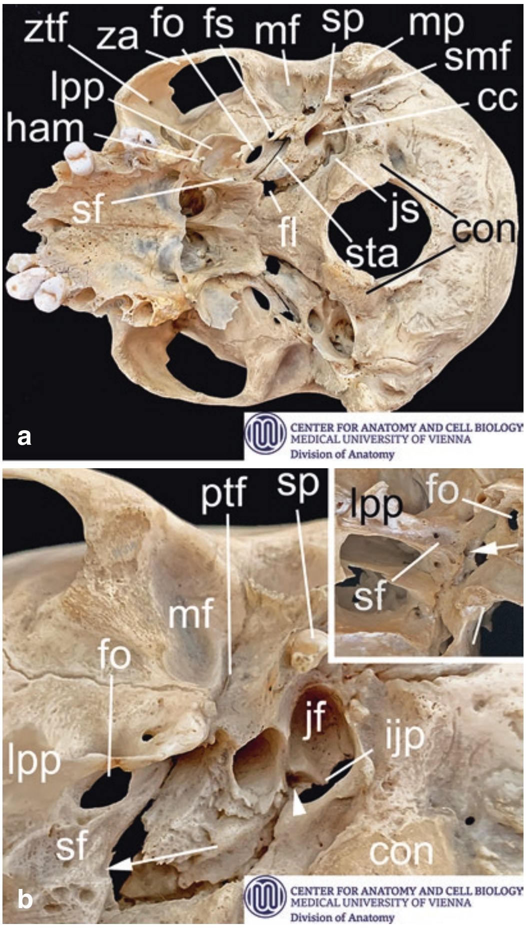

Fig. 1.14 Osseous pathways taken by postganglionic parasympathetic nerve fibers. Skull base from inferior. Frontal to the left. (**a**) Overview for orientation. (**b**) Magnification of A in a slightly oblique angle showing basal parts of the temporal and adjacent sphenoidal and occipital bones. The petrotympanic fissure (ptf), being the passage for the chorda tympani, and the tympanic canal (arrowhead), being the passage for the tympanic nerve, are clearly visible. The tympanic canal starts at the nervous portion of the jugular foramen, medial to the jugular spine (intrajugular process, ijp) of the temporal bone. Note the jugular fossa (jf) lateral to the spine. Inlay shows again a magnification of this specimen in again a slightly different angle. It highlights the entrance into the pterygoid (Vidian) canal (arrow) beneath the scaphoid fossa (sf), which is the passage of the Vidian nerve into the pterygopalatine fossa (compare Fig. 1.15). con, condyle; mp, mastoid process; smf, sp., styloid process; smf, stylomastoid foramen; cc, external ostium of carotid canal; js, jugular spine (intrajugular process of occipital bone; mf, mandibular fossa; lpp, lateral pterygoid plate; fo, foramen ovale; fs, foramen spinosum; sta, (semi-)canal for pharyngotympanic tube; fl, foramen lacerum; lpp, lateral pterygoid plate; ham, hamulus on medial pterygoid plate; za, zygomatic arch; ztf, zygomaticotemporal foramen

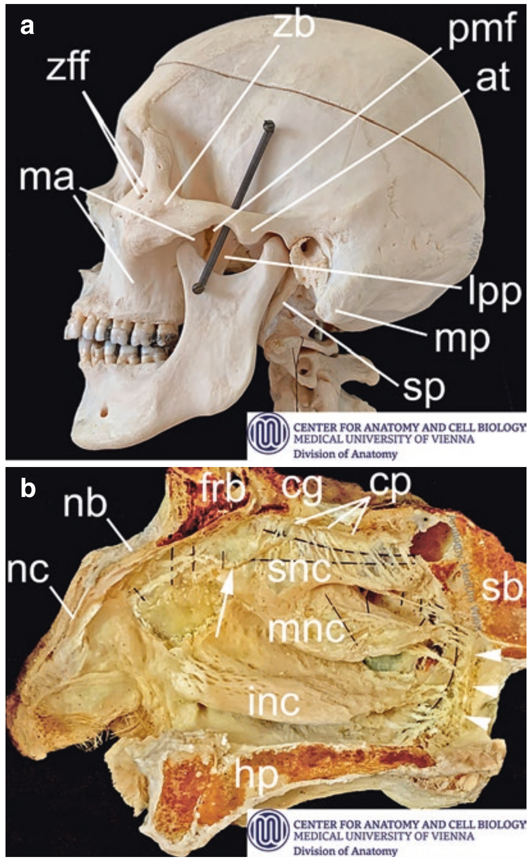

Fig. 1.15 Major nerves arising from the pterygopalatine ganglion to innervate the lateral wall of the nasal cavity. Frontal to the left. (**a**) Skull from left. Note the pterygomaxillary fissure (pmf) as entrance into the pterygopalatine fossa. (**b**) Lateral wall of a right nasal cavity. Specimen from the historical collection of the Division of Anatomy of the Medical University of Vienna. The mucosa is partly removed. The fila olfactoria emerging from the superior nasal concha (snc) are displayed (compare with Fig. 1.2). The bones parting nasal cavity and pterygopalatine fossa (arrowheads) are removed. The greater and palatine lesser nerves descend toward their eponymous foramina (arrowheads). The lateral posterior superior and lateral posterior inferior nasal nerves are exposed. Note the lateral internal nasal branch of the anterior ethmoidal nerve (arrow)—a branch forming CN V_1. mp, mastoid process; sp., styloid process; lpp, lateral pterygoid plate; at, articular tubercle; zb, zygomatic bone; zff, zygomaticofacial foramen; ma, maxilla; frb, frontal bone; nc, nasal cartilage; nb, nasal bone; sb, sphenoid bone; cg, crista galli; cp, cribriform plate; mnc, medial nasal concha; inc, inferior nasal concha; hp, hard palate

Sphenopalatine nerve: This represents a bundle of nerve fibers, which passes through the sphenopalatine foramen into the nasal cavity. In the majority of individuals, it splits into six lateral posterior superior nasal nerves, three medial posterior superior nasal nerves, and the nasopalatine nerve. The lateral posterior superior nasal nerves innervate the posterior parts of the middle and superior concha (Fig. 1.15b); the medial posterior superior nasal nerves are the septum nasi. The nasopalatine nerve runs anteriorly along the lower parts of the vomer and descends through the incisive (nasopalatine) foramen to the anterior section of the palate.

Nerve for orbital (Müller) muscle: The minority of fibers emerging from the pterygopalatine ganglion ascend toward the inferior orbital fissure. They form several bundles, composed of sympathetic and GSA fibers, which enter the orbital muscle of Müller and the local periosteum, a region which is also reached by fibers emerging from the ganglion located in the pterygopalatine compartment of the PSR [10].

Communicating branch with zygomatic nerve: A single bundle of postganglionic sympathetic and parasympathetic fibers ascends from the ganglion and joins the zygomatic nerve. When splitting into the zygomaticotemporal and zygomaticofrontal nerve, it stays with the zygomaticotemporal before it transits to the lacrimal nerve (Fig. 1.8) to reach and innervate both lobes of the lacrimal gland.

Submandibular Ganglion

The submandibular ganglion rests in the submandibular region, superior to the hilum of the submandibular gland. It is targeted by preganglionic parasympathetic fibers, which emerge from the superior salivatory nucleus. They leave the brain as part of Wrisberg's nerve and branch from the mastoid segment of CN VII as part of the chorda tympani. The chorda tympani also holds GSA and SVA fibers (see above).

As suggested by its name, the chorda tympani enters the tympanic cavity. Running near the tympanic membrane, it passes below the joint linking hamulus and incus in a highly variable distance and then leaves the cavity through the petrotympanic (glaserian) fissure (Fig. 1.14) to enter the infratemporal fossa. Here, it joins the lingual nerve (see CN V_3). The preganglionic parasympathetic fibers and a few GSA fibers leave the nerve near the submandibular fossa of the mandible and descend to the submandibular ganglion. This link between lingual nerve and ganglion is named the "posterior filament."

In addition to the preganglionic parasympathetic and the sensory fibers forming the posterior filament, postganglionic sympathetic fibers enter the submandibular ganglion. They emerge from perikarya located in the superior cervical ganglion and travel to the region as part of the visceral plexus surrounding the facial artery. While the parasympathetic fibers synapse, the sensory and sympathetic fibers merely pass through the ganglion. Five to six fiber bundles (filaments) holding postganglionic parasympathetic, sympathetic, and GSA fibers leave the ganglion to enter and innervate the submandibular gland. In addition, a single filament, the "anterior filament," arises from the ganglion. It holds postganglionic parasympathetic and sympathetic fibers and ascends to join the lingual nerve. Step by step, small fiber bundles leave the nerve to target minor salivary glands. The majority of the fibers however travels with the lingual nerve toward the sublingual fossa of the mandible, where they leave the nerve to innervate the sublingual gland.

Otic Ganglion

The otic ganglion is located in the infratemporal fossa, near the oval foramen. Here, preganglionic parasympathetic fibers stemming from perikarya in the inferior segments of the salivatory nucleus synapse. These fibers leave the brain together with CN IX. They branch off as part of the tympanic nerve and reach the tympanic cavity through the tympanic canal (Fig. 1.14). Inside the tympanic cavity, the tympanic nerve forms the tympanic plexus on the promontorium (cochlear promontorium), which also receives a small amount of fibers from the greater petrosal nerve. Out of this plexus, a portion of fibers converge and form a single nerve, the lesser petrosal nerve. This leaves the tympanic cavity through an osseous canal, which ends with a hiatus at the internal side of the petrous part of the temporal bone. In an eponymous groove, it then runs in middle cranial fossa in the direction of the oval foramen and passes through an osseous canal into the infratemporal fossa, where it terminates in the otic ganglion (see also CN IX).

The lesser petrosal nerve is the only nerve fiber bundle that joins the otic ganglion. Its fibers synapse and the postganglionic parasympathetic fibers pass posteriorly to the middle meningeal artery to join the sensory auriculotemporal nerve, which passes the meningeal artery anteriorly. While passing the artery, postganglionic sympathetic fibers arriving as part of the plexus surrounding the middle meningeal artery also join the auriculotemporal nerve. Hence, when entering the parotid gland, the auriculotemporal nerve carries GSA, postganglionic sympathetic, and postganglionic parasympathetic fibers. Once inside the parotid gland, these fibers leave the nerve and join CN VII. As part of the branches of CN VII, they spread through the parotid gland and innervate it.

References

1. Williams PL, Gray H. Gray's anatomy. 37th ed. Edinburgh: Churchill Livingstone; 1989.
2. Apaydin N, Kendir S, Karahan ST. The anatomical relationships of the ocular motor nerves with an emphasis on surgical anatomy of the orbit. Anat Rec (Hoboken). 2019;302(4):568–74.
3. Porras-Gallo MI, Pena-Meliaan A, Viejo F, Hernaandez T, Puelles E, Echevarria D, et al. Overview of the history of the cranial nerves: from galen to the 21st century. Anat Rec (Hoboken). 2019;302(3):381–93.
4. Martinez-Marcos A, Sanudo JR. Cranial nerves: phylogeny and ontogeny. Anat Rec (Hoboken). 2019;302(3):378–80.
5. Fuller GN, Burger PC. Nervus terminalis (cranial nerve zero) in the adult human. Clin Neuropathol. 1990;9(6):279–83.
6. Pineda AG, Leon-Sarmiento FE, Doty RL. Cranial nerve 13. Handb Clin Neurol. 2019;164:135–44.
7. Vilensky JA. The neglected cranial nerve: nervus terminalis (cranial nerve N). Clin Anat. 2014;27(1):46–53.
8. Pena-Melian A, Cabello-de la Rosa JP, Gallardo-Alcaniz MJ, Vaamonde-Gamo J, Relea-Calatayud F, Gonzalez-Lopez L, et al. Cranial pair 0: the nervus terminalis. Anat Rec (Hoboken). 2019;302(3):394–404.
9. Benninger B, McNeil J. Transitional nerve: a new and original classification of a peripheral nerve supported by the nature of the accessory nerve (CN XI). Neurol Res Int. 2010;2010:476018.
10. Weninger WJ, Müller GB. The sympathetic nerves of the parasellar region: pathways to the orbit and the brain. Acta Anat (Basel). 1997;160(4):254–60.
11. Weninger WJ, Streicher J, Müller GB. Anatomical compartments of the parasellar region: adipose tissue bodies represent intracranial continuations of extracranial spaces. J Anat. 1997;191(Pt 2):269–75.
12. Weninger WJ, Müller GB. The parasellar region of human infants: cavernous sinus topography and surgical approaches. J Neurosurg. 1999;90(3):484–90.
13. Weninger WJ, Pramhas D. Compartments of the adult parasellar region. J Anat. 2000;197(Pt 4):681–6.
14. Weninger WJ, Prokop M. In vivo 3D analysis of the adipose tissue in the orbital apex and the compartments of the parasellar region. Clin Anat. 2004;17(2):112–7.
15. Parkinson D. Lateral sellar compartment: history and anatomy. J Craniofac Surg. 1995;6(1):55–68.
16. Meng S, Geyer SH, Costa Lda F, Viana MP, Weninger WJ. Objective characterization of the course of the parasellar internal carotid artery using mathematical tools. Surg Radiol Anat. 2008;30(6):519–26.
17. Parkinson D. Collateral circulation of cavernous carotid artery: anatomy. Can J Surg. 1964;7:251–68.
18. Lasjaunias PL. Anatomy of the tentorial arteries. J Neurosurg. 1984;61(6):1159–60.
19. Parkinson D. A surgical approach to the cavernous portion of the carotid artery. Anatomical studies and case report. J Neurosurg. 1965;23(5):474–83.
20. Gyori E, Tzou CH, Weninger WJ, Reissig L, Schmidt-Erfurth U, Radtke C, et al. Axon numbers and landmarks of trigeminal donor nerves for corneal neurotization. PLoS One. 2018;13(10):e0206642.
21. Tv L, Wachsmuth W. Praktische anatomie. Erster Band, erster Teil: Kopf. Berlin: Springer Verlag; 1985.
22. Heber UM, Weninger WJ. In: Tzou CJ, Rodriguez-Lorenzo A, editors. Anatomy of the facial nerve. Facial palsy: Springer Cham; 2021. p. 71–8.

23. Jensson D, Weninger WJ, Schmid M, Meng S, Jonsson L, Tzou CJ, et al. Oculo-zygomatic nerve transfer for facial synkinesis: an anatomical feasibility study. Microsurgery. 2019;39(7):629–33.
24. Lopez-Poveda EA. Olivocochlear efferents in animals and humans: from anatomy to clinical relevance. Front Neurol. 2018;9:197.
25. Mathews MA, Camp AJ, Murray AJ. Reviewing the role of the efferent vestibular system in motor and vestibular circuits. Front Physiol. 2017;8:552.
26. Raghu V, Salvi R, Sadeghi SG. Efferent inputs are required for normal function of vestibular nerve afferents. J Neurosci. 2019;39(35):6922–35.
27. Banneheka S, Tokita K, Kumaki K. Nerve fiber analysis of ansa cervicalis-vagus communications. Anat Sci Int. 2008;83(3):145–51.
28. Rabl H. Notiz zur Morphologie der Geschmacksknospen auf der Epiglottis. Anat Anz. 1895;11:153–6.
29. Geyer SH, Weninger WJ. Some mice feature 5th pharyngeal arch arteries and double-lumen aortic arch malformations. Cells Tissues Organs. 2012;196(1):90–8.
30. Placheta E, Tinhofer I, Schmid M, Reissig LF, Pona I, Weninger W, et al. The spinal accessory nerve for functional muscle innervation in facial reanimation surgery: an anatomical and histomorphometric study. Ann Plast Surg. 2016;77(6):640–4.