

REVIEW

Anatomy of the Olfactory Nerve: A Comprehensive Review with Cadaveric Dissection

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Because of their anatomical situation, the olfactory nerves constitute a natural obstacle to exploring the anterior cranial fossa, making them vulnerable to traumatic, tumor, or iatrogenic lesions. Consequently, accurate knowledge of their microsurgical anatomy is of particular importance for surgeons to ensure the correct execution of surgical procedures with minimal sequelae, the least functional deterioration, and better therapeutic results. This review describes the functional and microsurgical anatomy of the olfactory nerves, illustrated with pictures of simulations based on cadaveric dissections and original illustrations of the central connections of the olfactory pathway. *Clin. Anat.* 31:109–117, 2018. © 2017 Wiley Periodicals, Inc.

Key words: olfactory nerve; neuroanatomy; olfactory pathways; anatomy; cranial nerves; dissection

INTRODUCTION

Phylogenetically, olfaction is the oldest of the senses. It is effected via a special visceral afferent nerve that has some peculiarities; for example, it is the only cranial nerve lacking a precortical connection to the thalamus (Milardi et al., 2017), and along with those of taste, it is the only sensory nerve lacking decussation. The olfactory impulse transmission pathway, despite comprising only two neurons (Walker, 1990), is a sophisticated sensory system that maintains complex neural relationships that allow smell to be integrated with memory, emotions, and taste (Damodaran et al., 2014). From the anatomical and surgical points of view, the location of the olfactory bulbs and tracts in the anterior cranial fossa renders them vulnerable to injury from traumatic or tumor lesions (Fig. 1A). They are especially important in anterior and middle cranial fossa approaches, where some measure of olfactory injury is a common sequela (Favre et al., 1995; Cardali et al., 2005; Wang et al., 2008; Cömert et al., 2011).

NASAL CAVITY

The nose is designed, among its other functions, to direct inspired air toward the olfactory epithelium. This epithelium is situated in the posterosuperior portion of each nasal cavity and covers the septum and lateral surface in both, including the upper portion of the superior turbinate. The cells of the nasal

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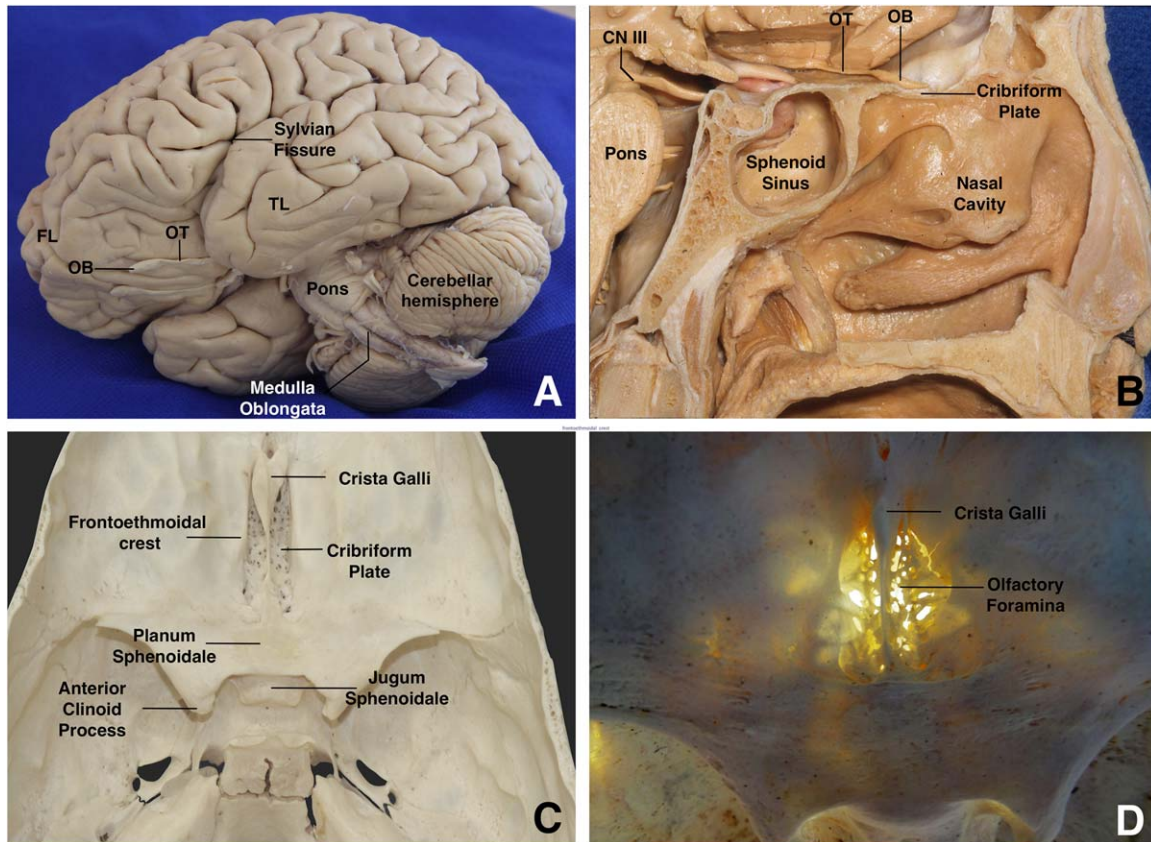


Fig. 1. **A.** Oblique view of the brain, where the ventral face of the frontal lobe is seen with both olfactory nerves attached to its surface in anatomical position. In each olfactory nerve, the olfactory bulb and the olfactory tract can be seen. **B.** Parasagittal view of the nasal region and adjacent structures, where the relationship of the olfactory bulb and tract to the nasal cavity and the anterior skull base can be appreciated. **C.** Superior view of the anterior and middle cranial fossa, where the cribriform

plate can be appreciated, as along with the bone references to be considered during surgical approaches to this region. **D.** Enlarged view of the cribriform plate with a trans-illumination effect that allows the olfactory foramina distribution to be visualized. Abbreviations: CN III, cranial nerve III; FL, frontal lobe; ON, olfactory nerve; OT, olfactory tract; TL, temporal lobe. [Color figure can be viewed at wileyonlinelibrary.com]

respiratory epithelium include the somas of bipolar olfactory neurons (Patel and Pinto, 2014). These specialized sensory neurons comprise the origin of the olfactory nerve fibers. It is estimated that humans have approximately 6–10 million olfactory sensory neurons in the nasal mucosa, distributed on a surface of 2.5 cm² in each nostril (Fig. 1B) (Hendrix et al., 2014). These cells are both receptors and neurons of the first order in the olfactory pathway. Their half-life is 30–40 days, and their regeneration depends on stem cells situated within the basal portion of the epithelium. They have dendrites in their apical portion that project to the epithelial surface, which makes them accessible to odoriferous particles (Walker, 1990). This exposure of the olfactory dendrites to the external environment is exploited by herpes virus, poliovirus, paramyxoviruses, and other viruses as a path of entry into the central nervous system by trans-synaptic transport and microfusion (van Riel et al., 2015).

A wide range of molecules meet the chemical and size requirements to be potentially odoriferous particles (Ache and Young, 2005; Yeshurun and Sobel, 2010). To achieve recognition, the odorant molecules must bind to G protein-coupled receptors on the dendrites of the sensory neurons in the respiratory epithelium. Humans possess a repertoire of approximately 400 functional receptors (Ache and Young, 2005). It is currently understood that each nerve cell expresses a specific type of odoriferous receptor. Likewise, each receptor type can bind to a number of different odorants at different junction sites, and each odorant can be attached to different receptors. It follows that there are many possible combinations. Until a few years ago, it was thought that humans can distinguish about 10,000 distinct odors (Buck and Axel, 1991); some have even claimed that the combinations amount to one trillion different olfactory stimuli (Bushdid et al., 2014). However, when the information is analyzed, the precise number of olfactory stimuli that humans can

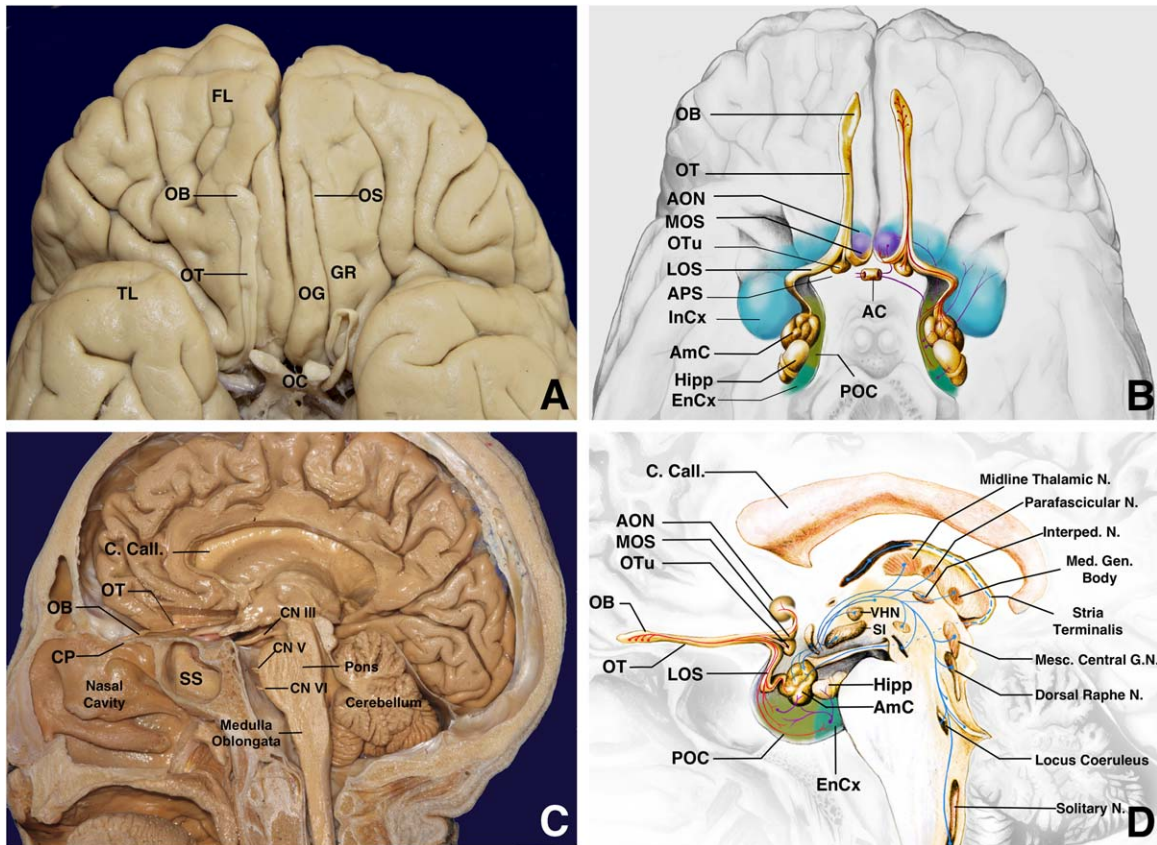


Fig. 2. **A.** Basal view of the brain, where the ventral aspect of the frontal lobes is seen. The right olfactory bulb and tract are attached to the frontal lobe, in anatomical position. The left olfactory (nerve) bulb and tract have been retracted in order to observe the olfactory sulcus located between the orbital gyri and the gyrus rectus, and then the optic chiasm. **B.** Schematic drawing of olfactory centers and pathways, projected on to the same view as **A.** Red lines indicate first-order neurons; purple lines indicate second-order neurons. **C.** Parasagittal view of the brain and facial region, showing the olfactory nerve and its anatomical relationships. **D.** Scheme of olfactory centers and pathways, projected on the same view as **C.** Red lines indicate first-order neurons; blue lines indicate second-order neurons. The interneurons are represented

in purple (See the text for a more detailed description). Abbreviations: AmC, amygdaloid complex; AC, anterior commissure; AON, anterior olfactory nucleus; APS, anterior perforated substance; C. call., corpus callosum; CN III, cranial nerve III; CN V, cranial nerve V; CN IV, cranial nerve IV; CP, cribriform plate; EnCx, entorhinal cortex; FL, frontal lobe; Hipp, hippocampal formation; InCx, insular cortex; LOS, lateral olfactory stria; Med. Gen. Body, medial geniculate body; MOS, medial olfactory stria; Mesc. Central G. N., mesencephalic central gray nucleus; OB, olfactory bulb; ON, olfactory nerve; OT, olfactory tract; OTu, olfactory tubercle; Interped. N., interpeduncular nucleus; POC, primary olfactory cortex; SI, substantia innominata; SS, sphenoid sinus; TL, temporal lobe; VHN, ventromedial hypothalamic nucleus.

discriminate remains unknown (Araneda et al., 2000; Yeshurun and Sobel, 2010; Gerkin and Castro, 2015).

Basal projections ascend as unmyelinated axons, traversing the cribriform plate (Fig. 1C, D) of the ethmoid through their openings, grouped in the form of small nerve bundles or fila olfactoria. There are approximately 15–20 of these bundles on each side of the nasal cavity, each forming the olfactory nerves that pass through the cribriform plate (Leboucq et al., 2013). They penetrate the cranial cavity, pass through the subarachnoid space, and immediately enter the olfactory bulbs through its ventral surface; there they synapse with the second-order bulbar neurons

(Walker, 1990; Levine and Marcillo, 2008; Giessel and Datta, 2014). The fila olfactoria emerge from the cribriform plate surrounded by a meningeal covering (arachnoid) (Favre et al., 1995). They also acquire a Schwann cell hedge approximately 0.5 mm beyond the olfactory bulb (Figueiredo et al., 2011).

OLFACTORY BULB

Each olfactory nerve comprises the olfactory bulb and the olfactory tract and is actually an extension of the telencephalon, lacking Schwann cells (Fig. 2)

(Favre et al., 1995; Figueiredo et al., 2011). The olfactory bulb is the primary center of the system and serves as a relay station for all impulses that pass between the olfactory mucosa and upper olfactory centers (Walker, 1990; Shipley and Ennis, 1996; Levine and Marcillo, 2008).

The olfactory bulb is a bilateral, elliptical, ventrodorsally-oriented structure averaging 11–15 mm in length and 4–5 mm in thickness, with a convex medial edge and flat lateral edge (Cardali et al., 2005; Wang et al., 2008; Cömert et al., 2011). It has an average volume of 125 mm³ (Abolmaali et al., 2008). Its rostral edge is located approximately 22 mm from the frontomarginal sulcus and 26 mm from the anterior wall of the frontal sinus (Favre et al., 1995; Shipley and Ennis, 1996; Cömert et al., 2011). Its dorsal surface is in contact with the orbital and rectus gyri (the inferior surface of the frontal lobes), separated by a double layer of arachnoid membrane. This arachnoid cover results in the olfactory cistern and envelops the olfactory bulb and tract along its entire length (Wang et al., 2008).

The ventral surface of the olfactory bulb covers the posterior third of the cribriform plate (Fig. 1C, D), which is also the horizontal plate of the ethmoid bone. It constitutes the middle portion of the anterior skull base and is located in the ethmoid notch of the frontal bone. It is divided medially by the crista galli, a vertical bony prominence located in the anterior segment of the ethmoid. Two grooves called the “olfactory ethmoidal canals” are formed on each side of the crista galli, where the olfactory tract is housed. The cribriform plate gives rise to the roof of the nasal cavity, with which it communicates through 18–22 foramina on each side (Walker, 1990; Favre et al., 1995; Levine and Marcillo, 2008). Each perforation has a diameter <1 mm (Vasvári et al., 2005).

The fila olfactoria from the nasal olfactory epithelium pass through the olfactory bulb to form synapses. The dura mater that covers the intracranial surface of the cribriform plate is continuous with the basal membrane of the olfactory epithelium through the foramina (Favre et al., 1995). In the anterior segment of the cribriform plate, on each side of the crista galli, two indentations are found. These lateral grooves allow passage for the anterior ethmoidal nerve and artery, while the medial recesses are occupied by dura mater (Vasvári et al., 2005).

The olfactory bulb has a microscopic laminar organization consisting of seven layers. Fila olfactoria synapse with second-order neurons on the glomerular stratum, which constitutes the second of these histological layers. It owes its name to the presence of the so-called glomeruli, specialized aggregates of dendritic and neuropil projections responsible for the first relay of olfactory sensory information. The most important neurons in the bulbar region and those considered the second-order neurons in the olfactory pathway are mitral cells, tufted cells, and periglomerular cells (Walker, 1990; Shipley and Ennis, 1996; Levine and Marcillo, 2008). All axons that reach a particular glomerulus have the same odiferous receptor on the mucosal surface (Ache and Young, 2005). All second-order neurons that synapse in that glomerulus

process the same odor stimulus. In consequence, it is held that each glomerulus, and all of the neurons that synapse in it, constitute the basic functional unit of perception of odor stimuli (Giessel and Datta, 2014).

Eventually, the axonal projections of the mitral and tufted cells form bundles that traverse the olfactory bulb and run dorsally, merging together as the secondary olfactory projection or olfactory tract. Previously, the fibers from the tufted cells have sent projections into the olfactory bulb to create intrabulbar feedback systems (Walker, 1990; Shipley and Ennis, 1996; Levine and Marcillo, 2008).

OLFACTORY TRACT

The olfactory tract is a thin, triangular, myelinated nervous projection that averages 28–30 mm in length and 5 mm in thickness in its anterior portion, with gradual narrowing of up to 2 mm in the posterior segment. It originates in the anterior cranial fossa and ends in the middle fossa to give rise to the olfactory trigone. Running parallel to the midline, it extends from an anteromedial position (relative to the olfactory bulb) at its origin to a posteromedial one at its terminal end (Abolmaali et al., 2008). Its path is composed of the olfactory sulcus, a 5–10 mm deep cleft formed between the orbital gyrus laterally and the rectus gyrus medially (Cardali et al., 2005; Cömert et al., 2011). In its course, the olfactory tract passes over the optic nerves, which in turn pass over the oculomotor nerves. These nerves and the caudal segment of the olfactory tract pass through the suprasellar region and the anterior incisural space (Fig. 2) (Wang et al., 2008).

Like the olfactory bulb, the olfactory tract lacks Schwann cells. Instead there are singular glial-type cells known as olfactory ensheathing cells, which share phenotypic characteristics with astrocytes and Schwann cells. Among other functions, they promote axonal regeneration and facilitate the formation of the olfactory bulb glia limitans in the transition zone between the central and peripheral nervous system (Fairless and Barnett, 2005). Olfactory ensheathing cells have only been described in the olfactory nerves (Ekberg and St John, 2015). Hence, some authors (Yasuda et al., 2006; Yamaguchi et al., 2010; Figueiredo et al., 2011) suggest that olfactory-groove schwannomas are derived from Schwann cells that briefly overlap the fila olfactoria, or from meningeal branches (from the trigeminal nerve or anterior ethmoidal nerves), but not from the olfactory nerve.

The olfactory cistern is formed in the olfactory sulcus and represents a dilation of the subarachnoid space aligned in the anteroposterior direction. It contains the olfactory nerves through its entire extent from the fila olfactoria to the olfactory tracts. It is important because it establishes the anatomical relationships of the olfactory nerve to the frontal lobe and the skull base, and also constitutes a plane of surgical dissection (Favre et al., 1995). The ventral surface of the olfactory cistern is rostrally delimited by the arachnoid membrane (Fig. 3A). The arachnoid membrane comes into direct contact with the floor of the

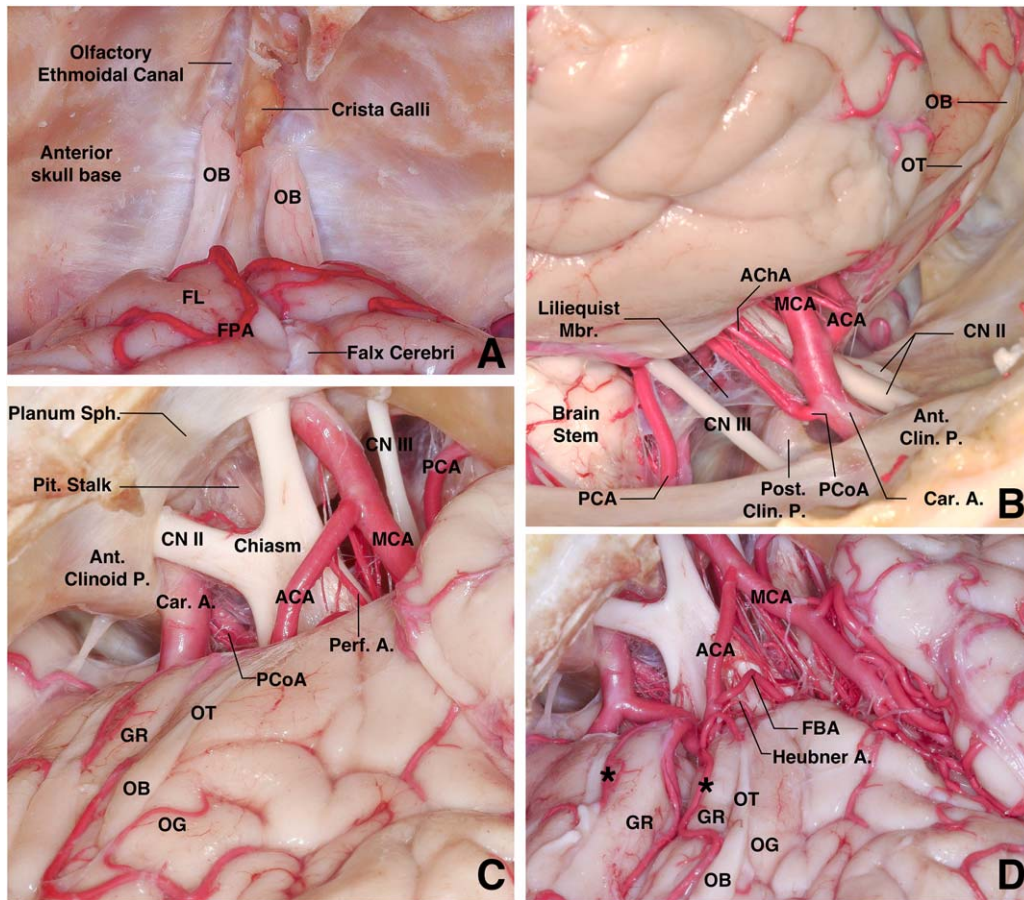


Fig. 3. Vascular relationships of the olfactory nerve. **A.** Superior view of the anterior cranial fossa where the frontal lobes are retracted posteriorly. The olfactory tracts course anteriorly up to the olfactory bulbs lying on the olfactory ethmoidal canal, divided medially by the crista galli. The frontopolar artery courses on the polar surface of the frontal lobe. **B.** Lateral view of the frontal lobe in a simulation of an orbito-zygomatic access. The olfactory nerves were detached from the cribriform plate and remained in the olfactory sulcus, attached to the frontal lobe to provide for greater brain retraction. This approach gives access to neurovascular structures located in the anterior cranial fossa. **C.** Superior view as seen on a subfrontal approach where the frontal lobes are retracted along with the olfactory nerves. A postfixed optic chiasm is positioned above the dorsum sellae. The carotid arteries course along the lateral margin of the chiasmatic cistern. The right anterior cerebral artery crosses the optic tracts and lamina terminalis. The oculomotor nerve is seen

below the carotid artery. **D.** Extended view from **C** where the temporal lobe, the carotid bifurcation, and the middle cerebral artery are lateral to the optic chiasm. The Sylvian fissure is opened to expose the course of the middle cerebral artery. Both olfactory arteries (*) originate from the ipsilateral anterior cerebral arteries, beyond the origin of the frontobasal artery, and the recurrent artery of Heubner. Abbreviations: ACA, anterior cerebral artery; AChA, anterior choroidal artery; Ant. Clin. P., anterior clinoid process; Car. A., carotid artery; CN II, cranial nerve II; CN III, cranial nerve III; FL, frontal lobe; FBA, frontobasal artery; FPA, frontopolar artery; GR, gyrus rectus; Heubner A., recurrent artery of Heubner; MCA, middle cerebral artery; OB, olfactory bulb; OG, orbital gyri; ON, olfactory nerve; OT, olfactory tract; PCA, posterior cerebral artery; PCoA, posterior communicating artery; Perf. A., perforating arteries; Pit. Stalk, pituitary stalk; Planum Sph., planum sphenoidale; Post. Clin. P., posterior clinoid process. [Color figure can be viewed at wileyonlinelibrary.com]

anterior cranial fossa, including the cribriform plate and the fila olfactoria. Caudally, the limit of the olfactory cistern comprises the chiasmatic and pericallous cisterns, while laterally it is delimited by the pia mater of the orbital and rectus gyri (Cardali et al., 2005; Wang et al., 2008; Cömert et al., 2011).

The olfactory cistern contains not only the olfactory bulb and tract but also part of the fronto-orbital and

olfactory arteries, along with branches of these and several frontobasal veins. The fronto-orbital artery is characteristically located deep within the cistern in its lateral path through the orbital surface of the frontal lobe (Yaşargil and Yaşargil, 1984; Favre et al., 1995; Cardali et al., 2005; Wang et al., 2008; Cömert et al., 2011).

Each olfactory tract runs posteriorly and ends in the olfactory trigone, located above the anterior clinoid

process, immediately rostral to the anterior perforated substance (Milardi et al., 2017). The olfactory trigone is a widening of the olfactory tract that tends to become triangular, dividing and giving rise to two main olfactory striata (lateral and medial) and a small central olfactory stria (Cardali et al., 2005; Rhoton, 2007; Duque Parra et al., 2016), which eventually target higher brain regions (Fig. 2C, D).

CENTRAL PATHWAYS

The main central cortical structures of olfaction include the primary olfactory cortex, the anterior olfactory nucleus, the olfactory tubercle, the amygdaloid complex, and the entorhinal cortex (Giessel and Datta, 2014). Secondary central structures of olfaction include the hippocampus, hypothalamus, thalamus, orbitofrontal cortex, and cerebellum (Patel and Pinto, 2014).

The axons of the olfactory tracts pass backward and are distributed to central olfactory areas. The axons of the medial olfactory stria belong mainly to bulbar tufted cells (Walker, 1990; Levine and Marcillo, 2008). Their interactions are primarily responsible for the autonomic responses associated with olfaction. They send projections to the ipsilateral anterior olfactory nucleus and the olfactory tubercle, and also to the contralateral olfactory bulb through the anterior commissure (Milardi et al., 2017), ending in the septal nuclei of the subcallosa area surrounding the paraterminal gyrus (Shipley and Ennis, 1996; Levine and Marcillo, 2008; Duque Parra et al., 2016). Two fiber bundles split from the septal nuclei: (1) the medullary stria, which reaches the habenular nuclei, which is in turn projected toward the tegmentum, achieving autonomic centers such as the superior and inferior salivatory nuclei, responsible for salivation in response to pleasant cooking odors; and (2) the olfacto-hypothalamo-tegmental bundle, which attains the dorsal vagal nucleus (responsible for accelerating peristalsis in the intestinal tract and increasing gastric secretion) (Nieuwenhuys et al., 1988; Leboucq et al., 2013).

In turn, the anterior olfactory nucleus is projected massively and bilaterally toward the olfactory bulb and the primary olfactory cortex, forming part of a feedback system of odoriferous information. The central olfactory stria, in its short path, crosses the olfactory tubercle and sends its projections to the anterior perforated substance (where it ends) in order to establish olfactory synapsis (Giessel and Datta, 2014; Duque Parra et al., 2016). The olfactory tubercle is situated immediately behind the bifurcation of the olfactory stria and is fused with the anterior perforated substance. This area is a thin layer of gray matter extending from the central olfactory stria to the optic tract. It owes its name to the obvious perforations that allow the lenticulostriate arteries to penetrate into the cerebral parenchyma (Fig. 2B, D) (Nieuwenhuys et al., 1988).

The lateral olfactory stria groups the largest number of fibers in the olfactory tract; therefore, it is the stria with the greatest functional transcendence. It follows the lateral margin of the anterior perforated substance, projecting itself into the temporal lobe that is immersed in the temporal stem, and passing during

its trajectory through the insular limen toward the parahippocampal gyrus, entorhinal cortex, and amygdaloid nuclei (Fig. 2B–D).

The temporal stem is described as a white matter tract comprising a dense network of bidirectional long and short association fibers that communicate between the temporal lobe (amygdala, uncus, and entorhinal cortex), thalamus, insula, striatum, and orbitofrontal cortex (Choi et al., 2010; Peltier et al., 2010; Wang et al., 2011). Several of these structures are part of the olfactory sensory pathway. The temporal stem consists mainly of the uncinate fasciculus, inferior occipitofrontal fasciculus, Meyer's loop of optic radiations, the anterior commissure, and the inferior thalamic fibers (Ebeling and von Cramon, 1992; Ribas et al., 2015). Injury to this tract could be responsible for severe cognitive and visual deficits (Wang et al., 2011). It is also important in numerous disorders such as tumor spread, infections and seizures (Peltier et al., 2010).

The primary olfactory cortex is the area of the brain specializing in the interpretation of olfactory sensory stimuli. It is located near the uncus, in the temporal lobe. It includes the pyriform (periamygdaline) and prepyriform areas. It maintains a close relationship with the entorhinal cortex (which in turn sends projections to the hippocampus), and with the amygdala, especially the cortical nucleus, which is an extension of the pyriform cortex that covers the inner parts. This cortex connects with the frontal lobe for the conscious discrimination of odors. It also sends projections to other areas such as the hypothalamus, dorsal thalamus, mesencephalic nuclei, and brainstem nuclei, giving rise to a system of association fibers related to olfaction and its complex conductual reactions (Fig. 2B, D) (Nieuwenhuys et al., 1988; Shipley and Ennis, 1996; Giessel and Datta, 2014).

BLOOD SUPPLY OF THE OLFACTORY NERVE

The olfactory artery has been described as a branch of the anterior cerebral artery, which supplies the entire course of the olfactory tract and bulb. In a cadaver study, Favre et al. (1995) reported that in just over half the specimens the olfactory artery emerged from the lateral border of the anterior cerebral artery (segment A2), immediately beyond the origin of the anterior communicating artery, between the origins of the frontobasal artery and the distal medial striate artery (also known as the recurrent artery of Heubner). In the remaining cases, the olfactory artery originated as a collateral branch of the medial frontobasal artery, which in turn is a branch of the anterior cerebral artery (Favre et al., 1995). From its origin, the olfactory artery runs above the optic nerve and is later incorporated into the olfactory sulcus and adheres to the ventral surface of the olfactory tract by arachnoid. This vessel provides a maximum of three terminal branches to the olfactory tract and bulb, along with others that irrigate the adjacent gyrus and, occasionally, the perforated substance (Fig. 3A–D) (Yaşargil and Yaşargil, 1984; Favre et al., 1995; Hendrix et al., 2014).

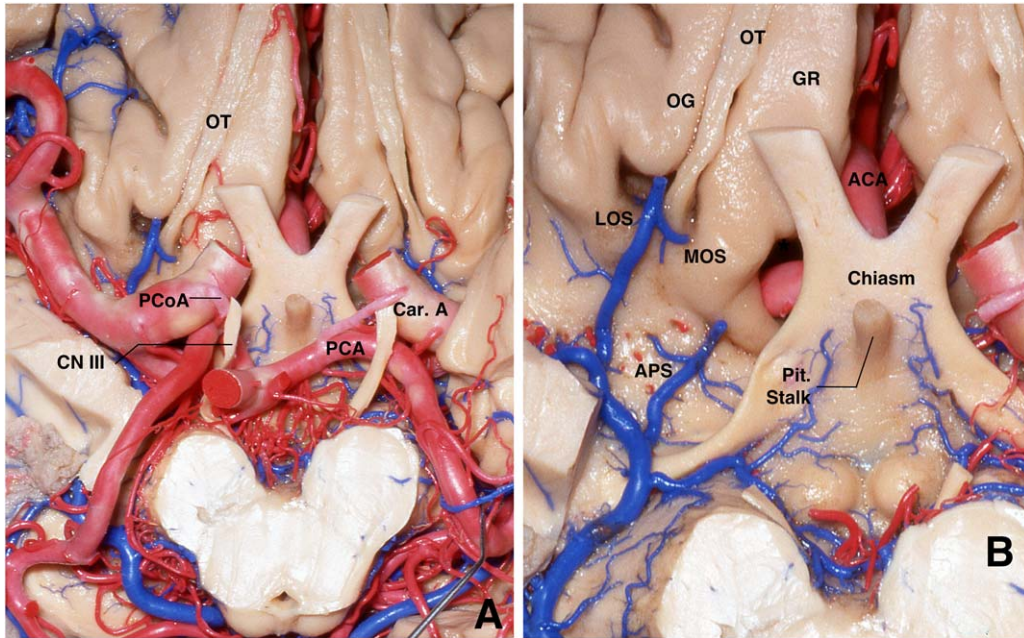


Fig. 4. Vascular relationships of the olfactory nerve. **A.** Inferior view of the basal surface of the frontal lobes, and the mesencephalon, where the oculomotor nerves pass below the posterior cerebral arteries. **B.** Enlarged view of the olfactory nerve, anterior perforated substance and surrounding structures. Abbreviations: ACA, anterior

cerebral artery; APS, anterior perforated substance; CN III, cranial nerve III; LOS, lateral olfactory stria; MOS, medial olfactory stria; OT, olfactory tract; OG, orbital gyri; Pit. Stalk, pituitary stalk; GR, gyrus rectus. [Color figure can be viewed at wileyonlinelibrary.com]

Other arteries involved in olfactory nerve blood supply are the anterior and posterior orbital arteries, which penetrate the olfactory cistern at the level of the anterior and posterior half, respectively. They form 2–3 vascular loops that lie in the olfactory groove. They are also known as the anterior and posterior ethmoidal arteries or accessory olfactory arteries (Hendrix et al., 2014). The frontopolar artery often constitutes a third artery that also penetrates the olfactory cistern to supply the olfactory bulb with blood. In some individuals, the recurrent artery of Heubner emits branches that also penetrate the cistern and contribute to olfactory bulb irrigation (Cardali et al., 2005; Wang et al., 2008; Cömert et al., 2011). The microvasculature is located mainly on the ventral surface of the nerve, and its presence limits the possibility of microdissecting the olfactory bulb and olfactory cistern (Figs. 3A, C and 4C).

To our knowledge, no distinctive pattern of venous circulation has been described. Wang et al. (2008) documented branches of the olfactory vein, the frontopolar vein, the orbital vein, and small affluent branches of the sagittal sinus (Wang et al., 2008).

MICROSURGICAL RELEVANCE OF OLFACTORY NERVE ANATOMY

Because of its anatomical situation, the olfactory nerve represents a natural obstacle to exploring the anterior cranial fossa, so there is potentially a risk of

injury. Therefore, in pathologies proper to that area (such as the olfactory groove, the third ventricle, the anterior circulation, or the sellar region), anatomical and vascular relationships must be taken into account. This is undertaken in order to release the olfactory cistern to prevent detachment of the olfactory bulb when the frontal lobe is retracted during different surgical techniques. The most commonly used are the subfrontal, pterional, and supraorbital approaches (Rhoton, 2007).

During surgical procedures, according to Cardali et al. (2005), there are three main mechanisms of olfactory nerve injury: (1) detachment of the cribriform plate and section of the fila olfactoria during retraction of the frontal lobe; (2) partial or total section of the olfactory tract during dissection; and (3) ischemic injury (Cardali et al., 2005). To our knowledge, no therapy restores olfaction, so prognosis in this regard is nearly always poor. This risk should be taken into consideration in surgical planning.

The main approach to frontotemporal lesions of the anterior and middle cranial fossa is the pterional-trans-Sylvian. Its execution requires some degree of frontal lobe retraction, which can injure the olfactory bulb or tract by ischemia or traction. Anosmia or hyposmia are two of the most frequent complications of this approach. Even so, the olfactory bulb can become completely detached from the cribriform plate (Cömert et al., 2011). In this approach, after accessing through the Sylvian fissure and gently retracting the frontal lobe, the distal portion of the ipsilateral

olfactory tract can be observed on the surface of the orbital gyri. Once the olfactory tract is accessed, dissection of the arachnoid cover from the olfactory bulb and tract will prevent inadvertent tearing and enable it to be freely mobilized. It is important always to maintain the olfactory bulb in close contact with the cribriform plate. This procedure should be performed proximally to distally and, beginning on its dorsal side, parallel to the olfactory tract direction to avoid nerve injury during dissection (Cardali et al., 2005; Cömert et al., 2011).

Careful dissection of the olfactory tract allows the frontal lobe to be retracted further, avoiding laceration of the fila olfactoria that cross the cribriform plate, thus precluding postoperative complications. Particular attention should be paid to the olfactory arteries and to the anterior orbital, posterior orbital, and frontopolar arteries during olfactory bulb and olfactory tract dissection. As previously described, these run immediately below the arachnoid cover in the olfactory sulcus and can be injured during dissection, or can be injured ischemically owing to the pressure exerted with the brain retractors. Minor branches of these arteries also supply the cortex of the rectus and orbital gyri with blood; thus, dissection must be meticulous. Early identification of the olfactory bulb and tract and detailed arachnoid and vascular dissection reduces the index of postoperative olfactory compromise (Wang et al., 2008; Cömert et al., 2011).

The unilateral subfrontal approach is preferred when the lesion, be it of vascular, tumor, or traumatic origin, predominates on one side. In lesions such as meningiomas of the anterior cranial fossa, which provides an interface between the tumor and the parenchyma, the tumor can be gently retracted for stepwise resection, devascularizing it and dissecting it from its dural plane. The surgeon must be aware that the arteries will be pushed upward and that, along with the contralateral olfactory tract, these are the last structures to be visualized. The contralateral bulb and tract are usually found on the skull base, with a dense subarachnoid layer that must be preserved. Centralized debulking is performed in another technique, in which the rigid subarachnoid and hard adhesions mentioned previously prevent the lesion from shrinking (Yaşargil and Yaşargil, 1984; Rhoton, 2007). This preparation should be intended to preserve the olfactory nerve and segment A2 of the anterior cerebral artery. Thus, early visualization and early release of the olfactory tract from its arachnoid coverage is needed before it is directed toward the dural matrix of the tumor. This maneuver is simpler with a gradual lateral approach for maintaining its integrity. The olfactory nerve is particularly sensitive to cauterization with bipolar and inadvertent aspiration; thus, it is preferable to cover it. Some authors prefer gelfoam to cottonoids (Aydin et al., 1996; Bassiouni et al., 2007; Rhoton, 2007).

In bilateral subfrontal approaches to midline injuries, once the frontal lobes have been gently retracted, cautious simultaneous dissection of both olfactory tracts is required, alternating gradually between one and the other to reduce the risk of laceration and detachment of the olfactory bulb. Care must

also be taken with the pressure exerted on the arteries by cerebral retractors or other instruments, since ischemia is another possible consequence (Cardali et al., 2005). If this fails to protect the olfactory bulbs adequately, anosmia by section of the fila olfactoria or by ischemia will frequently ensue (Sepehrnia and Knopp, 1999).

The transclivary supraorbital approach (eyebrow approach) is a keyhole craniotomy with very important space limitations, commonly used for treating aneurysms. As in the previously described techniques, some degree of frontal lobe retraction is required when it is necessary to expose the skull base. During this maneuver, the surgeon must ensure that excessive displacement is avoided and be aware that the tension exerted can completely separate the olfactory filaments from the olfactory bulb, causing severe and permanent nerve injury (Rhoton, 2007).

CONCLUSIONS

Injury to the olfactory nerve is often underestimated as a sequela to surgical approaches into the anterior and middle cranial fossa. However, permanent or significant loss of olfactory capacity can considerably affect the patient's quality of life. Therefore, precise knowledge of its anatomical details, including its neurovascular hallmarks, is important for obtaining a better postoperative result without affecting the execution of the surgical procedure.

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