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# TOPOGRAPHIC AND ANATOMICAL RELATIONSHIPS BETWEEN THE CRANIAL NERVES AND THE BONY CANALS OF THE SKULL BASE: A COMPARATIVE CHARACTERIZATION

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***Annotation.*** The article presents a literature review of the topographic and anatomical relationships between the twelve pairs of cranial nerves and the bony canals, fissures and foramina of the skull base. The anterior, middle and posterior cranial fossae are compared with respect to the course of the nerves, their bony and dural compartments, and the neurovascular companions that share the same openings. Particular attention is paid to anatomical variability (bony bridges, ossified ligaments, accessory foramina, asymmetry of the jugular foramen and hypoglossal canal), to age-related and sex-related differences, and to the clinical consequences of nerve entrapment. The review is based on published anatomical, radiological and neurosurgical studies and contains no original patient data.

***Keywords:*** cranial nerves, skull base, cranial foramina, optic canal, foramen ovale, jugular foramen, hypoglossal canal, anatomical variability.

# ТОПОГРАФО-АНАТОМИЧЕСКИЕ ВЗАИМООТНОШЕНИЯ ЧЕРЕПНЫХ НЕРВОВ И КОСТНЫХ КАНАЛОВ ОСНОВАНИЯ ЧЕРЕПА: СРАВНИТЕЛЬНАЯ ХАРАКТЕРИСТИКА

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***Аннотация.*** В статье представлен обзор литературы по топографо-анатомическим взаимоотношениям двенадцати пар черепных нервов с костными каналами, щелями и отверстиями основания черепа. Сопоставлены передняя, средняя и задняя черепные ямки по ходу нервов, костным и дуральным компартментам, а также по сопутствующим сосудистым структурам. Особое

внимание уделено анатомической изменчивости (костные мостики, окостеневшие связки, добавочные отверстия, асимметрия яремного отверстия и подъязычного канала), возрастным и половым различиям и клиническим последствиям компрессии нервов. Обзор основан на опубликованных анатомических, лучевых и нейрохирургических исследованиях и не содержит собственных данных о пациентах.

***Ключевые слова:*** черепные нервы, основание черепа, отверстия черепа, зрительный канал, овальное отверстие, яремное отверстие, подъязычный канал, анатомическая изменчивость.

## Introduction

The skull base is the floor of the cranial cavity and, at the same time, the roof of the face, the orbit, the infratemporal fossa and the upper neck. It is formed by the frontal, ethmoid, sphenoid, temporal and occipital bones, and it is perforated by numerous canals and foramina through which the cranial nerves leave the cranial cavity. Each of these openings is a rigid bony tunnel of fixed dimensions, whereas the nerves, arteries and veins that occupy it are soft and may swell, be displaced or be compressed. For this reason, the relationship between a nerve and its canal is one of the central topics of topographic anatomy of the head.

Traditionally, the skull base is divided into the anterior, middle and posterior cranial fossae. The anterior fossa is related mainly to the olfactory apparatus and the orbit; the middle fossa contains the sella turcica, the cavernous sinus and the openings for the optic, oculomotor, trochlear, trigeminal and abducens nerves; the posterior fossa contains the foramen magnum, the internal acoustic meatus, the jugular foramen and the hypoglossal canal. Cranial nerves I–XII do not follow a single pattern: some leave the skull through their own canal, others share a foramen with other nerves, and a number of them pass through dural tunnels before reaching the bone.

## Relevance

Skull base surgery, endoscopic endonasal approaches, stereotactic radiosurgery, and regional anaesthesia of the trigeminal branches all depend on a reliable three-dimensional picture of the cranial foramina. Modern high-resolution computed tomography and magnetic resonance imaging have shown that the bony openings vary considerably in shape, size, symmetry and the presence of additional structures. Not all of these variants are harmless: bony bars, ossified ligaments and narrowed canals have been discussed as causes of neuralgia, cranial neuropathy and difficult needle placement.

In addition, the textbook description of the skull base is frequently presented as a list of foramina and their contents. A comparative approach, in which the foramina are analysed by fossa, by the type of tunnel (osseous canal, fissure, dural cave) and by the degree of sharing with vascular structures, makes the material easier to learn and to apply clinically. This is the reason why the topic deserves a separate literature review.

## Aim

The aim of this review is to summarize and compare published data on the topographic and anatomical relationships between the cranial nerves and the bony canals of the skull base, to outline the main variants of these relationships, and to indicate their clinical significance.

## Main part

### Anterior cranial fossa: olfactory nerve and the cribriform plate

The first cranial nerve is represented not by a single trunk but by 15–20 thin olfactory filaments that pass from the olfactory epithelium of the nasal roof through the openings of the cribriform plate of the ethmoid bone to the olfactory bulb. Here the nerve–bone relationship is exceptionally intimate: the filaments are accompanied by a prolongation of the meninges, and the bone plate is very thin and delicate. This is the reason why trauma of the anterior skull base, or iatrogenic injury during endonasal surgery, may result in anosmia and in cerebrospinal fluid leakage.

The height of the olfactory groove, the depth of the cribriform plate relative to the roof of the ethmoid and the asymmetry of the lateral lamella are classical variable parameters that are described in radiological classifications and are taken into account during endoscopic surgery. In comparison with the other cranial nerves, the olfactory nerve has no true canal and therefore is not subject to canal-type compression; its main vulnerability is mechanical rupture of the filaments.

### Middle cranial fossa: optic canal, superior orbital fissure and trigeminal openings

The optic nerve (II) enters the orbit through the optic canal, which is formed by the two roots of the lesser wing of the sphenoid bone. In the canal the nerve is surrounded by all three meningeal layers and is accompanied by the ophthalmic artery, which lies in the inferolateral part of the canal. The canal is relatively long and narrow, and its medial wall is in direct contact with the sphenoid and posterior ethmoid sinuses; in some individuals the wall is very thin or even dehiscent. These features explain both the vulnerability of the nerve to indirect traumatic neuropathy and the risk of injury during

sinus surgery.

The superior orbital fissure is a wide communication between the middle cranial fossa and the orbit. The oculomotor (III), trochlear (IV) and abducens (VI) nerves, together with the ophthalmic division of the trigeminal nerve (V1) and the superior ophthalmic vein, pass through it. The nerves are arranged in a regular topographic order: the trochlear, frontal and lacrimal nerves are located above the common tendinous ring, whereas the oculomotor, nasociliary and abducens nerves pass through the ring. This regular arrangement is clinically important because a lesion in the fissure produces a characteristic combination of ophthalmoplegia, ptosis and sensory loss in the forehead.

The maxillary nerve (V2) and the mandibular nerve (V3) have separate bony openings. The foramen rotundum transmits V2 into the pterygopalatine fossa; in the majority of descriptions it is a round or oval canal of a certain length, and in some skulls it is better described as a short tunnel, sometimes continuing as a groove. The foramen ovale, located posterolaterally, transmits the mandibular nerve, the accessory meningeal artery, the lesser petrosal nerve in some individuals, and emissary veins connecting the cavernous sinus with the pterygoid plexus. The foramen spinosum, lying posterolateral to it, transmits the middle meningeal artery and the meningeal branch of V3.

Variability in this region is well documented. The foramen ovale may be oval, round, almond-shaped or slit-like; it may be asymmetric; and its margins may carry spurs. Bony bridges such as the pterygospinous and pterygoalar bars (ligaments of Civinini and Hyrtl, when ossified) may transform the infratemporal opening of the foramen ovale or spinosum into a closed canal and may form additional foramina, such as the foramen of Vesalius for an emissary vein. Authors who discuss percutaneous procedures through the foramen ovale (such as thermocoagulation or glycerol rhizotomy for trigeminal neuralgia) emphasize that the shape and size of the opening influence the ease of cannulation.

**Intradural and petroclival passages: Meckel cave and Dorello canal**

Not every nerve–canal relationship is purely bony. The trigeminal ganglion lies in the Meckel cave, a dural invagination in the middle fossa, from which the three divisions emerge to enter their respective foramina. The abducens nerve, after leaving the pontomedullary junction, travels upward in the prepontine cistern, pierces the dura and enters the Dorello canal, a fibro-osseous tunnel bordered by the petrosphenoidal ligament (Gruber) and the petrous apex. Here the nerve is fixed at two points and has to turn sharply over the petrous apex; this anatomical arrangement is used to explain why the sixth nerve is the cranial nerve most often involved in non-localizing signs of

raised intracranial pressure and in traumatic neuropathies.

**Posterior cranial fossa: internal acoustic meatus, jugular foramen, hypoglossal canal, foramen magnum**

The facial (VII) and vestibulocochlear (VIII) nerves enter the internal acoustic meatus, accompanied by the labyrinthine artery and the nervus intermedius. The meatus is divided by the transverse (falciform) crest into upper and lower compartments: the facial nerve and the superior vestibular nerve lie above the crest, and the cochlear and inferior vestibular nerves lie below it. The facial nerve then enters the fallopian canal, which is the longest bony canal in the human body that is occupied by a nerve and which has three segments (labyrinthine, tympanic and mastoid). The labyrinthine segment is the narrowest, and the nerve in this part is considered to be the most sensitive to oedema, which is the usual explanation of idiopathic peripheral facial palsy and its occurrence in temporal bone fractures.

The jugular foramen is a complex opening between the petrous part of the temporal bone and the occipital bone. It is divided by the jugular spine and the intrajugular processes into the anteromedial pars nervosa, which transmits the glossopharyngeal nerve (IX) and the inferior petrosal sinus, and the posterolateral pars venosa, which transmits the vagus (X) and accessory (XI) nerves together with the sigmoid sinus–jugular bulb system. The foramen is usually larger on the right than on the left, in agreement with the larger calibre of the right sigmoid sinus; the compartments may be separated by bony or fibrous septa of variable completeness. The proximity of the lower cranial nerves to the jugular bulb explains the symptom complexes known as the jugular foramen syndromes (Vernet, Collet–Sicard, Villaret).

The hypoglossal canal runs through the occipital bone above the occipital condyle and transmits the hypoglossal nerve (XII) accompanied by a venous plexus. In a number of skulls the canal is divided by a bony or fibrous septum into two parts, and the nerve rootlets may travel separately; the shape and orientation of the canal are of interest in surgical approaches to the craniovertebral junction because drilling of the occipital condyle may jeopardize the nerve. The foramen magnum transmits the medulla oblongata, the vertebral arteries and the spinal roots of the accessory nerve; its morphology has clinical value for the understanding of craniocervical compression syndromes.

**Comparative characteristic of the nerve–canal relationships**

Comparison of the above data allows several types of relationship to be distinguished. (1) A true bony canal with a single dominant nerve (optic canal, foramen rotundum,

hypoglossal canal). Here the nerve has little room to move, and compression is mainly caused by a decrease in canal diameter, as occurs in bony dysplasias or by tumours of the sphenoid. (2) A shared fissure with a strict internal order (superior orbital fissure), in which the topographic sequence of nerves explains the syndromes. (3) A compartmentalized foramen with nerves and a venous sinus (jugular foramen, internal acoustic meatus), where the vascular component determines the size of the opening. (4) Fibro-osseous or dural tunnels (Dorello canal, Meckel cave), in which ligaments and dura rather than bone determine the nerve course. (5) Multiple small openings (cribriform plate), in which the vulnerability is related to the thinness of the bone.

The degree of bony protection also differs. The optic, facial and hypoglossal nerves are surrounded by thick bone over most of their canal length, while the nerves in the sphenoid sinus region (the optic and maxillary nerves, and the vidian nerve in the pterygoid canal) may be separated from the sinus lumen only by a thin lamina. This explains why the same inflammatory or neoplastic process in the paranasal sinuses may cause optic or maxillary neuropathy in one patient and not in another: the outcome depends on the individual degree of pneumatization and the thickness of the bony wall.

**Age, sex and side differences**

The skull base undergoes remodelling throughout postnatal life. In the newborn, several foramina are incomplete or occupy a different position; the stylomastoid foramen, for example, is located more superficially, which makes the facial nerve vulnerable during forceps delivery and surgery. The cranial foramina increase in size with growth of the skull, and the sphenoid and temporal pneumatization progresses during childhood and adolescence. In adults, several studies of dry skulls and CT scans report differences in the dimensions of the foramen ovale, foramen spinosum and jugular foramen between sexes and between the right and left sides, but the results vary between populations and methods, and the differences are in general modest and overlapping. Therefore, population-specific reference data are needed, and their absence for Central Asian populations can be seen as a gap in the literature.

**Clinical aspects**

The most frequently discussed clinical situations include trigeminal neuralgia in which vascular and bony factors interact; entrapment of V3 by ossified pterygospinous ligaments; compression of the optic nerve in fibrous dysplasia, in meningioma of the sphenoid wing and after trauma; jugular foramen syndromes caused by glomus tumours, schwannomas and metastases; and hypoglossal palsy associated with lesions of the occipital condyle. In all of these cases the clinical picture is determined not only

by the pathological process but also by the particular configuration of the bony canal. A radiologist or surgeon who knows the normal variants is less likely to interpret them as pathology and, conversely, is better able to recognize true narrowing.

## Discussion

The reviewed literature allows several conclusions. First, the major nerve–foramen relationships are constant and well described, but the shape and the dimensions of the openings are variable, and this variability has been investigated in most detail for the foramina of the middle fossa, for which both anatomical and imaging data are abundant. Second, data on the posterior fossa (especially on the intrajugular compartments and the hypoglossal canal) are less uniform, and measurements are frequently obtained by different techniques, which makes direct comparison problematic.

A further limitation is that many publications are based on dry skulls of relatively small samples, in which soft tissues cannot be evaluated, while CT-based studies, although more representative, evaluate mostly the bony outline and not the real fit between nerve and canal. For this reason, statements about nerve compression derived from morphometry alone should be treated as hypotheses. The comparative classification offered here is a didactic scheme and does not replace original measurements. Further studies, combining cadaveric dissection, multiplanar CT and high-resolution MRI in local populations, are desirable.

## Conclusion

The cranial nerves and the bony canals of the skull base form a system in which the type of tunnel (canal, fissure, compartmentalized foramen, fibro-osseous or dural tunnel) determines the topography of the nerve, its vulnerability and the characteristic clinical syndromes. Anatomical variants—bony bridges, septa of the hypoglossal canal, asymmetry of the jugular foramen, thin walls adjacent to the paranasal sinuses—are common and must be distinguished from pathology. A comparative, fossa-by-fossa approach is useful for teaching and for clinical planning, but its practical value will increase when it is supplemented by population-specific morphometric reference data.

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