Trigeminal nerve: imaging of normal anatomy and pathologic conditions.

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Authors: J. Cabero Moyano¹, A. Carvajał², A. Rovira², S. PEREZ², M. Zauner², M. Prenafeta Moreno³; ¹Reus/ES, ²Sabadell/ES, ³Arenys de Munt-Barcelona/ES
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Learning objectives

- To explain and illustrate trigeminal nerve anatomy.
- To describe the imaging findings for different pathologies involving the trigeminal nerve in its pathway.
Background

Trigeminal nerve is a mixed sensitive-motor cranial nerve, receiving sensory afferent fibers from the face and mouth, and supplying motor branches for muscles of mastication.

Understanding the different pathologies that can affect the trigeminal nerve requires thorough knowledge of the anatomy of this cranial nerve, from its real origin in the brainstem through its apparent origin and along its pathways through the cisterns and parasellar region.

Magnetic resonance is the method of choice for trigeminal nerve imaging due to its anatomy and localization.
Findings and procedure details

ANATOMY (Fig. 1 on page 11 Fig. 2 on page 11)

The gray matter of the brainstem is made up of the segmental formations of the nuclei from which the cranial nerves III to XII originate; these are distributed in longitudinal columns of motor, sensory and vegetative cells. The white matter of the brainstem is comprised of crossing neural pathways, pathways that originate or end in the nuclei of the cranial nerves, and its own interconnecting pathways of association.

The sensory enervation of the face depends on three nerve trunks: ophthalmic nerve (V1), maxillary nerve (V2) and mandibular nerve (V3).

These three sensory nerves come together in the Gasserian ganglion, which occupies a cavity (Meckel's cave) in the dura mater covering the trigeminal impression near the apex of the petrous part of the temporal bone.

This set of structures is lodged in the middle cranial fossa, a small cavity located lateral to the sella turcica and anterointernally to the apex of the petrous part of the temporal bone. Caudal to the Gasserian ganglion are the motor fibers for the muscles used for mastication.

From the Gasserian ganglion impulses are conducted to different nuclei along the brainstem, from the mesencephalon to the spinal cord. It is important to note that sensations of pain and temperature follow a different pathway (medulla-spinal) than sensations of tact (pons), which has implications in the management of trigeminal neuralgia.

From the Gasserian ganglion the trigeminal trunk contains sensory and motor fibers. This bundle crosses the cisternal spaces to the apparent origin at the level of the ventral side of the medial lateral portion of the pons, at the point where the upper third joins the lower two-thirds.

The apparent origin of the motor root is located medially to that of the sensory root. The motor nerve fibers for the muscles of mastication that pass through the pons originate in the pontine motor nucleus of the V pair.

The rest of the non-motor axons course toward their respective nuclei: Chief nucleus at the pontine level (epicritic sensory fibers), spinal tract (protopathic sensor fibers) and mesencephalic tract (protopathic sensory fibers for the muscles of mastication).

The trigeminal nerve is composed by a voluminous sensory root and a small motor root at the level of the junction between the pons and the middle peduncle of the cerebellum.
Ophthalmic nerve (V1) (Fig. 3 on page 12)

Sensory nerve for the upper part of the face, and autonomic fibers for the glands and mucous membranes of the nasal and orbital cavities, and for the eyeball. The ophthalmic nerve divides into three branches:

- Lachrymal nerve: runs to the lachrymal gland and innervates the skin of the external side of the orbit. The lachrymal nerve receives afference from the nerve of the pterygoid canal, which crosses the pterygopalatine ganglion and the maxillary nerve, passing over zygomatic nerve to join the lachrymal nerve.
- Frontal nerve: divides into two branches, the supratrochlear and suborbital (conjunctiva, skin of lower forehead near the midline and of the upper eyelid).
- Nasociliary nerve: passes through the supraorbital foramen, has a nerve bundle that connects with the ciliary ganglion, long ciliary nerves running to the eyeball, and the ethmoidal nerves running to the ethmoidal and sphenoidal sinuses.

Maxillary nerve (V2) (Fig. 4 on page 13)

Branches into:

- Zygomatic nerve: postganglionic parasympathetic secretors arising from the sphenopalatine ganglion running to the lachrymal gland.
- Pterygopalatine and alveolar nerves: sensory innervation of the upper portion of the pharynx, the nostrils, palatine velum and hard palate.
- Infraorbital nerve: sensory destination of the skin from the lower eyelid to the upper lip, and molar, premolar and incisor dental alveolar branches.

Mandibular nerve (V3) (Fig. 5 on page 14)

Branches into:

- Meningeal branches
- Auriculotemporal nerve: skin of the temporal region, external auditory canal and eardrum.
- Lingual nerve: sensory innervation of the anterior 2/3 of the tongue and taste fibers that come from the facial nerve through the tympanic membrane filament.
- Inferior alveolar nerve: motor fibers for the mylohyoid muscle and the anterior belly of the digastric muscle; dental sensory fibers that descend in a groove on the deep surface of the ramus of the mandible; and sensitivity of the chin, lower lip, and skin of the ascending maxillary branch.
• Buccinator nerve: internal mucosa of the cheek.
• Motor branches: masseteric, deep temporal nerve, pterygoid, tensor tympani and tensor veli palatini nerves.

**RADIOLOGICAL ANATOMY (Fig. 6 on page 15 Fig. 7 on page 16 Fig. 8 on page 17 Fig. 9 on page 18)**

The trigeminal trunk arising from the Gasserian ganglion (with its motor and sensory bundles) runs through the pontocerebellar cisternal spaces. The apparent origin of the trigeminal nerve is located on the medial lateral portion of the ventral side of the pons.

The cavernous sinus (Fig. 10 on page 19) is situated medial to the cranial middle fossa. It has relationship with the pituitary fossa, superior orbital fissure, Meckel's cave and temporal lobe. It contains venous sinusoids, internal carotid artery and cranial nerves III, IV, VI, V1 and V2.

**PATHOLOGIC CONDITIONS**

**Trigeminal neuralgia** (TN) is a chronic facial pain par excellence classified as a neuropathic pain. It is defined as a sudden, usually unilateral, severe, brief, stabbing and recurrent pain in the distribution of one or more branches of the fifth cranial nerve. It can be triggered by a light cutaneous stimulus on a very localized spot on the face (the so-called "trigger zone").

Knowledge of the topographical and functional anatomy of the V pair is necessary to reach the diagnosis of TN.

Idiopathic TN shows no focal neurological signs at physical examination. Electrophysiologic, analytical and radiological studies cannot diagnose idiopathic neuralgia.

Symptomatic neuralgia or neuralgia secondary to a structural lesion should be suspected when it first presents before the age of 50, or when pain is accompanied by a focal neurological deficit. In these cases, directed imaging studies, especially MRI, help discover the etiology.

The different pathologies that can affect the fifth pair can do so at any level, from the central nuclei to the peripheral branches.
BRAINSTEM LESIONS

Demyelinating diseases. Neuritis (Fig. 11 on page 20 Fig. 12 on page 21 Fig. 13 on page 22 Fig. 14 on page 23)

The incidence of TN in patients with multiple sclerosis (MS) is higher than in the general population. The main theory states that chronic inflammatory processes in the CNS are the cause of the so-called secondary TN. MS trigeminal neuralgia is usually caused by demyelinating lesions affecting the pontine trigeminal pathways. Trigeminal neuralgia may be seen in 1-2% of patients with MS and is often bilateral.

Infection

Listeria monocytogenes (Fig. 15 on page 24 Fig. 16 on page 24) infections can involve the CNS in the form of a rhombencephalitis. This disease has a characteristic biphasic course: a nonspecific prodrome of headache, nausea or vomiting and fever lasting for several days, followed by progressive asymmetrical cranial nerve palsies.

Brainstem tuberculomas (Fig. 17 on page 25) manifest most frequently as oculomotor abnormalities, and are usually accompanied by other focal brainstem signs. CT and MR properties of tuberculomas are indistinguishable from those of nontuberculous bacterial abscess or other space-occupying lesions. Thus, if neuroimaging findings are suggestive of CNS tuberculosis, chest X-ray may further aid diagnosis.

Other granulomatous and vasculitic syndromes

Behçet disease (Fig. 18 on page 26) (BD) is a rare multisystem vasculitis characterized by oral and genital aphthous ulcers and uveitis with a fluctuating course. In the absence of history of genital or oral ulcers, the diagnosis of Neuro-Behçet could be extremely difficult. Various MR abnormalities have been described: a) focal lesions within the brainstem (rhombencephalitis). The basal ganglia and cerebral hemispheres are the second most frequent locations, b) images related to venous thrombosis, and c) space-occupying mass mimicking a tumour.
Sarcoidosis (Fig. 19 on page 27) is an idiopathic inflammatory granulomatous multisystem disorder affecting virtually all organs. Sarcoid granulomas can affect any portion of the nervous system, which most commonly affects the cranial nerves, meninges, hypothalamus and pituitary gland. Intracranial involvement is optimally evaluated with MR with contrast and may manifest either a) leptomeningeal disease that may secondarily involve cranial nerves and adjacent brain tissue by infiltration along perivascular spaces with preferential involvement of the optic chiasma and hypothalamus, and b) diffuse parenchymal lesions or a single intracerebral or focal extraxial mass. Isolated cranial nerve's injury is exceptional.

Vascular (Fig. 20 on page 27 Fig. 21 on page 28 Fig. 22 on page 29 Fig. 24 on page 31)

Cerebrovascular disease along the pathway of the trigeminal nerve is a common cause of sensory loss. Isolated vascular trigeminal neuropathy is uncommon, and patients usually have other clinical signs.

Tumoral

Syringomyelia (Fig. 25 on page 32) is a cavitated dilatation of the spinal cord. It can be focal or can extend to longer segments. It's associated to craniocervical junction malformations, especially Chiari malformation, with controversial etiology based on hydrodynamic concepts. Other less common etiologies include trauma, tumours and infections.

Cerebral metastases (Fig. 26 on page 33 Fig. 27 on page 34) represent the most common neurologic manifestation of cancer. In order of decreasing frequency, the primary etiology is lung cancer, breast cancer, and melanoma. All brain regions can be affected by metastases. Metastatic tumours are usually well defined and surrounded by abundant perilesional edema.

Brainstem glioma. (Fig. 28 on page 35) The pons is the most common location, but they also occur in the medulla and midbrain. These tumours infiltrate the brainstem and induce surrounding vasogenic edema.

CISTERNAL ROOT LESIONS
Neurovascular compression (Fig. 29 on page 35 Fig. 30 on page 36 Fig. 31 on page 36 Fig. 32 on page 37)

Tortuous branches of the posterior circulation vessels, particularly the superior cerebellar artery (SCA), may impinge upon the trigeminal nerve. The resultant compression of the nerve leads to intractable trigeminal neuralgia. Neurovascular compression is now accepted as being the most common cause of trigeminal neuralgia unresponsive to medical therapy.

Tumour

Epidermoid tumors (Fig. 33 on page 37). Most develop eccentrically in the region of the CPA. The cyst or tumor contents consist of desquamated epidermal cellular debris, often in concentric layers. CT shows a mass hypodense to CSF. At MRI it's a homogeneous lesions isointense to CSF in T1 and T2, with highly restricted diffusion at DWI.

Arachnoid cysts (Fig. 34 on page 38 Fig. 35 on page 39 Fig. 36 on page 39) in the cerebellopontine angle are well-defined lesions of similar signal intensity to CSF at CT and MRI.

Schwannomas (Fig. 37 on page 40 Fig. 38 on page 41) are usually isolated lesions, except in neurofibromatosis type 2. Schwannomas arise from the nerve sheath and consist of Schwann cells in a collagenous matrix. Histologically they are divided as type A neurilemoma and type B neurilemoma. Type A has elongated spindle cells arranged in irregular streams, and is compact in nature, while type B has a looser organization, often with intermixed cystic spaces within solid tissue.

Meningiomas (Fig. 39 on page 42) are more common in women than in men, with a male-to-female ratio of 1:2. They are the most common extra axial tumors in the brain. Typically have a definite dural attachment with the "dural tail" sign often present, and may show calcifications.

Infection

Meningitis (Fig. 40 on page 43) involving basal cisterns or localized abscesses (Fig. 41 on page 43) may affect the fifth nerve.
PERIPHERAL LESIONS

Neoplasms (Fig. 42 on page 44 Fig. 43 on page 45 Fig. 44 on page 45 Fig. 45 on page 46 Fig. 46 on page 47 Fig. 47 on page 48 Fig. 48 on page 48) within Meckel's cave may cause trigeminal nerve symptoms, as do tumors arising from the pituitary gland or the skull. Carotid aneurysm (Fig. 49 on page 49 Fig. 50 on page 50) may involve the trigeminal nerve, particularly cavernous aneurysms. In this situations nerve symptoms are most often found in association with other clinical features. (Fig. 51 on page 51)
Fig. 1: Brainstem. Cranial nerves nuclei distribution.

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Fig. 2: Brainstem. Trigeminal nuclei and nerve pathway diagram.

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**Fig. 6:** Trigeminal nerve. Apparent origin (white arrows) and pontocerebellar trajectory (red arrows) 1. Internal auditory canal 2. Pontocerebellar cistern 3. Cochlea 4. Vestibule 5. External semicircular canal 6. Superior semicircular canal.

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Fig. 7: Sphenoidal cranial base forams in relation to V nerve. 1. Optic canal (ophthalmic artery, cranial nerve II) 2. Superior orbital fissure (cranial nerves III, IV, VI and V1) 3. Foramen rotundum (V2) 4. Foramen ovale (V3, accessory meningeal artery, emissary vein) 5. Foramen spinosum (meningeal branches from V3, meningeal artery).

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Fig. 8: Sphenoidal cranial base foramen in relation to V nerve. 1. Optic canal (ophthalmic artery, cranial nerve II) 2. Superior orbital fissure (cranial nerves III, IV, VI and V1) 3. Foramen rotundum (V2) 4. Foramen ovale (V3, accessory meningeal artery, emissary vein) 5. Foramen spinosum (meningeal branches from V3, meningeal artery).

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Fig. 9: Sphenoidal cranial base foramens in relation to V nerve. 1. Optic canal (ophthalmic artery, cranial nerve II) 2. Superior orbital fissure (cranial nerves III, IV, VI and V1) 3. Foramen rotundum (V2) 4. Foramen ovale (V3, accessory meningeal artery, emissary vein) 5. Foramen spinosum (meningeal branches from V3, meningeal artery).
Fig. 10: Cavernous sinus

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Fig. 11: Patient with multiple sclerosis and right facial paresthesias. T2W, T1W, DWI and FLAIR images showing multiple focal lesions in the pons, along the pathway of the cranial nerve V.

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**Fig. 12:** Neuritis in a patient with chronic trigeminal neuralgia. Right pontine linear image with T2 and FLAIR hyperintensity, following the intraparenchymal trigeminal pathway.

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Fig. 13: Multiple sclerosis. T1W, T2W, FLAIR and DW showing a left pontine focal lesion in the trigeminal sensitive nucleus (red arrows).
**Fig. 14:** Trigeminal neuritis with denervation and atrophy of masticatory muscles (arrows in e, f). T2 and FLAIR images show hyperintense lesion in intrapontine pathway of the fifth cranial nerve.

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**Fig. 15:** Listerial rhombencephalitis in a patient with fever and multiple cranial nerves involvement. T1W, T2W and DW MR images show a focal right pontine and middle cerebellar peduncle lesion (red arrows) with enhancement after gadolinium administration. Right trigeminal (blue arrows), vestibular (yellow arrows) and Luschka foramen margins (yellow circle) are also enhanced after gadolinium administration.

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**Fig. 16:** Listerial rhombencephalitis. T2W images show patchy hyperintense signals throughout the medulla, pons and the cerebellar peduncles (red arrows). Annular image (blue arrows) in T2W and gadolinium enhanced T1W images, evidence of microabscesses in the rhomboencephalon.

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**Fig. 17:** Brainstem tuberculomas. Irregular brainstem lesions with long T1 and short T2 relaxation times. MRI T1 axial images using gadolinium show frontal, temporal and pontine ring-enhancing lesions with mass effect on the fourth ventricle.

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**Fig. 18:** Behçet disease. T2W MR images show a heterogeneous lesion with extensive edema in the pons, superior cerebellar peduncle, midbrain and mesodiencephalic junction. The parenchymal pontomesencephalic contrast enhancement distribution supports the hypothesis of small vessel vasculitis, with mainly venular involvement.
Fig. 19: Neurosarcoïd encephalopathy. T2W images show a large area of signal abnormality in the brainstem (asterisk), indicating an encephalopathy or vasculopathy, resembling a demyelinating disease. The positive imaging findings in neurosarcoïd encephalopathy are divided into categories as follows: pachymeningeal, leptomeningeal, nonenhancing brain parenchymal, enhancing brain parenchymal, cranial nerve and spinal nerve and nerve roots involvement.
Fig. 20: Right hemimedullary infarct. a) axial and b) sagittal T2W MR images.

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**Fig. 21:** Left pons lateral infarct. a) coronal FLAIR and b) axial T2W MR images.

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Fig. 22: Right pons infarct. a) axial and b) sagittal T2W MR images.

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Fig. 23: Right pons lateral infarct. a) coronal and b) axial T2W MR images.

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Fig. 24: Cavernoma in a patient presenting with vague facial sensory disturbance and ataxia. a) CT axial show a typical hyperdense posterior pontine lesion without edema. b) T2W MR image shows a central high signal intensity (methaemoglobin) surrounded by a rim of very low signal intensity (hemosiderin deposits). c) T2* weighted MR image shows typical signal dropout around the cavernous hemangioma.

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**Fig. 25:** Syringomyelia. MR cervical sagittal T1W image showing a large syrinx extending cranially through the foramen magnum, which is stenosed with a Chiari I malformation.

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Fig. 26: Breast cancer brainstem metastases. T1W (left) and T1W C+ (right) MR images showing intense enhancement of the cystic-necrotic metastatic lesion in the pons (asterisk), which extends into the left cerebellopontine angle. Note the presence of contralateral cranial nerve V distortion (red arrow).

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Fig. 27: Lung cancer brainstem metastases. Sagittal, axial and coronal T1W C+ MRI. Intense enhancement of two nodular solid metastatic lesions (red arrows) in the cerebellum and cerebellar right peduncle.

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Fig. 28: Brainstem glioma. MR T1W axial (a), T1W C+ sagittal (b) and T2W coronal (c) images at mid pontine level, in a patient with recent onset of facial pain. There is an ill defined mass within the pons (asterisk). T2W images confirm the diffuse stem affection. Brainstem gliomas are relatively homogeneous masses without much cystic change, necrosis, vascularity nor calcification. About 50% of cases will show mild enhancement.

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**Fig. 29:** Arterial variants. Coronal T2W MRI. Asymmetric morphological variant of vertebral arteries (blue arrows). Tortuosity of the superior cerebellar artery displaces up and left the fifth cranial nerve (red arrow).

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**Fig. 30:** Aneurysm. Postcontrast axial CT, CISS 3D and angiography MR images. Left vertebrobasilar aneurysm (asterisk) with cranial nerve V distortion (arrow).

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Fig. 31: Trigeminal neuralgia caused by the superior cerebellar artery. Axial 3D CISS MR image shows a superior cerebellar artery (green arrow) compressing the root of the trigeminal nerve.

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Fig. 32: Arterial kink. T1W and T2W MR images. Elongated vertebral arteries (red arrows) involving cranial nerve V cisternal portion (green arrow).

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**Fig. 33:** Epidermoid tumour in the left cerebellopontine angle. Apparent widening of the left cistern due to the presence of an epidermoid cyst (blue asterisk), homogeneously isointense to CSF in T1W and T2W MR images, with hyperintensity at DW images. The left trigeminal nerve is displaced (red arrow).

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**Fig. 34:** Arachnoid Cyst in the cerebellopontine angle. Axial and coronal T2W images showing a well defined lesion of similar signal intensity to CSF within the cerebellopontine angle. The pons is compressed and the fifth cranial nerve is shifted (red arrow).

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Fig. 35: Acoustic schwannomas. MR images of two different patients show tumoral cystic (blue asterisk) or solid (red asterisk) cisternal extension with pons distortion and mass effect on the fifth cranial nerve (red arrows) and its entrance into Meckel's cave (teal arrows). Note the normal right V nerve (yellow arrow). Solid portions of the tumour show intense homogeneous enhancement after gadolinium contrast administration.

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**Fig. 36:** Acoustic schwannomas. MR images of two different patients show tumoral cystic (blue asterisk) or solid (red asterisk) cisternal extension with pons distortion and mass effect on the fifth cranial nerve (red arrows) and its entrance into Meckel's cave (teal arrows). Note the normal right V nerve (yellow arrow). Solid portions of the tumour show intense homogeneous enhancement after gadolinium contrast administration.

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Fig. 37: Neurofibromatosis type 2. Axial CISS 3D (top) and coronal T1W C+ (bottom) images show bilateral vestibular schwannomas (blue arrows) and multiple parietal and falcine meningiomas (red arrows), with typical homogeneous contrast enhancement.

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Fig. 38: Trigeminal schwannoma. T1 and T2 weighted MR images show a bilobulated mass in right Meckel's cave and cerebellopontine cistern, with homogeneous intense post-contrast enhancement.

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**Fig. 39:** CPA meningiomas. MRI shows an extra axial lesion (blue asterisk) that compresses the pons and all CPA structures including the fifth cranial nerve, with distortion of the left trigeminal nerve (red arrows). Intense and homogeneous contrast enhancement (right images).

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![MRI images of CPA meningiomas]

**Fig. 40:** Meningitis. T1W C+ MRI. Diffuse basal cisterns and brainstem meningeal enhancement (red arrows), with right fifth cranial nerve enlargement (yellow arrow).

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Fig. 41: CPA epidural abscess secondary to an otomastoiditis. Coronal T1W (left) and T1 C+ (right) MR images. Epidural collection (red asterisks) in the right cerebellopontine angle with important meningeal enhancement. Right cranial nerve V is involved in the abscess. Left trigeminal nerve (green arrow) in its normal position.

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**Fig. 42:** Meningioma. T1W C+ sagittal and coronal MR images showing a middle cranial fossa meningioma (asterisks) involving the sellar region, cavernous sinus and pontocerebellar angle. The tumour extends extracranially through the foramen ovale (red arrows).

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**Fig. 43:** Meningioma. Axial T1W C+ MR images show a middle cranial fossa meningiomas (asterisks) involving the right cavernous sinus and pontocerebellar angle cisterns. Note the mass effect on the right carotid artery (black arrows) and the brainstem (red arrow).

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Fig. 44: Dermoid cyst. T1W MR images show. Hyperintense lesion in the right petrous apex and parasellar region (asterisks) with disseminated cisternal lipid droplets. Meckel's cave and fifth cranial nerve cisternal portion (purple arrows) are affected.

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**Fig. 45:** Invasive prolactinoma. Coronal post contrast T1W MR image demonstrates the presence of a left sided adenoma (asterisk) extending superiorly into the suprasellar cistern and laterally toward the cavernous sinus (red arrow).

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Fig. 46: Chordoma in a patient with right trigeminal neuralgia. Axial and coronal T1W C+ MR images show a chordoma (red asterisk) with slight contrast enhancement in the right sphenoidal region, cavernous sinus, Meckel's cave, pituitary fossa and clivus. Chordomas usually appear as lobulated, large masses with septa of low signal intensity.

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Fig. 47: Nasopharyngeal carcinoma. Axial and sagittal T1W C+ MR images show an erosive and invasive heterogeneous mass involving the cranial basis and sellar and parasellar regions.

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**Fig. 48:** Metastasis. Coronal CT shows a soft tissue mass in the orbito-sphenoidal junction (arrows), and helps to define its relationship with adjacent bony and neuromuscular structures.

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Fig. 49: Aneurysm. CT and MR images before and after intravenous contrast administration show a nodular, homogenously enhancing mass (blue arrow) in the right cavernous carotid artery with marginal calcification. Note the adjacent meningioma (red arrow).

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Fig. 50: Internal carotid artery aneurysm arising within the cavernous sinus. Plain film and CT axial images show a characteristic arc-like or ring marginal calcification (blue arrows).

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Fig. 51: Traumatic fracture. CT axial image shows a complex cranial base fracture involving the left great sphenoid wing (red arrows) and the left foramen ovale (blue asterisk).

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Conclusion

Knowledge of the anatomy and pathological states of the trigeminal nerve is essential to understand imaging findings in the different pathologies that affect this cranial nerve and enables a correct differential diagnosis among the different pathological entities. MR is the method of choice for evaluating the trigeminal nerve.
References