Hi-Resolution Imaging of Trigeminal Nerve, Microanatomy and Common Pathologies: A Journey through the Cave

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Learning Objectives

1. Understanding embryology and microanatomy of the trigeminal nerve from nuclei within the brainstem to neural exit foramina of the skull base
2. Identification of Trigeminal nerve segments and its branches (V1, V2, V3) on high resolution MRI and CT
3. Correlation with common pathologies involving CN V and its divisions
Background

The largest and most widely distributed within the suprahyoid neck, the Trigeminal nerve has complex relationships to the skull base and neural exit foramina. Consisting of general somatic sensory and special visceral motor fibres, the Trigeminal nerve is entirely sensory to the face with motor innervation to muscles of mastication, whilst the Facial nerve is motor to intrinsic muscles of the facial expression.

An understanding of the complex anatomy of CN V is required to comprehend and identify the pathologies related to the convoluted course of the nerve. Hi Resolution MR imaging is able to demonstrate the path of CN V and its branches, and is crucial in identification of associated pathologies.
EMBRYOLOGY

Whilst questions remain over the exact details of cranial nerve embryological development, understanding the embryological relationships of Trigeminal nerve nuclei in comparison with other cranial nerves, serves to aid the understanding of sensory and motor distribution to the head and neck in later life.

By week 5 in utero, the neural tube has developed a primitive brain, divided into segments, later to be the main divisions of the mature brain. The rhombencephalon, or hindbrain, is the most caudal of these segments and a precursor for the pons, medulla and cerebellum. Rhombencephalon is divided into a rostral metencephalon and a caudal myelencephalon, divided by the pontine flexure.

The mantle layer (grey matter) of the neuroepithelial cells of the neural tube thicken to form an alar plate and a basal plate. The alar plate is the precursor for afferent neurons involved in sensory processing and the basal plate provides a precursor for all spinal cord and brainstem efferent motor neurons. Fig 1. Neuroblasts within the alar and basal plates of the rhombencephalon develop into nuclei, whereas in the spinal cord these develop into tracts.

CN V contains both general somatic afferent and special visceral efferent neurons. General somatic afferent neurons of CN V develop within the alar plate of the myelencephalon of the hindbrain and special visceral efferent neurons develop within the basal plate of the metencephalon. Fig 2. Efferent nuclei of CN V are located within the basal plate, adjacent to those of CNVII. These neurones, together with those of the adjacent CN VII innervate muscles derived from the 1st and 2nd pharyngeal arches. CN V afferent neurons provide sensation to the face.

ANATOMY

The complex course of the trigeminal nerve can be divided into segments; brainstem, cisternal, ganglionic and divisions which traverse the neural exit foramina. Detail of these segments is demonstrated with MR and CT images obtained via the following parameters:

- Hi Resolution MR cranial nerve imaging performed using 1.5T (SIEMENS Magnetom Symphony) and 3T (SIEMENS Skyra).
• Thin slice T2 SPACE provided superior delineation of neural anatomical segments. Imaging parameters as follows:

- 1.5T
  - FoV 200mm
  - SL 0.6mm
  - TR 1200ms TE 263ms
  - Base Resolution 320

- 3T
  - FoV 200mm
  - SL 0.3mm
  - TR 1000ms TE 133ms
  - Base Resolution 512
  - CT skull base performed on 128 slice MDCT (SIEMENS Definition AS Plus) with slice thickness of 0.6-0.8mm with multiplanar reformats

**Brainstem and root entry zone**

As CN V functions as both motor and sensory, it contains both motor and sensory roots. The principal sensory root lies within the dorsolateral pontine tegmentum at entry level of sensory fibres exiting the trigeminal ganglion. Mesencephalic sensory root lie within superior pons, lateral to cerebral aqueduct and the spinal sensory root is largely located in the pons, however extends into the medullar, terminating at the upper substantia gelatinosa of Rolando. The single motor root lies within the pons, ventrolateral to the cerebral adqueduct and medial to the main sensory nucleus. Fig 3. Sensory roots: principal (3), mesencephalic (1) and spinal (4). Motor root (2). CN V emerges from the brainstem via the ventrolateral pons at the root entry zone as a large sensory and small motor root.

**Preganglionic cisternal segment**

CN V traverses the prepontine cistern from the root entry zone, to enter Meckel's cave via the porus trigeminus. Whilst within the prepontine cistern, CN V may come into contact with vascular structures also within this cistern, such as the superior cerebellar artery or the posterior inferior cerebellar artery. Neurovascular contact in this region can give rise to symptoms of trigeminal neuralgia. Examples of this are provided under pathology. Fig 4. Axial T2 SPACE demonstrating region of nuclei, root entry zone and cisternal segment of CN V

**Ganglionic segment within Meckel's cave**
Meckel's cave is a CSF filled space formed by dural layers, anteromedial to the petrous apex and posterior to the cavernous sinus. Nuclei of three sensory roots within cave, join to form the semilunar/trigeminal ganglion. The motor root remains separate and inferior to the ganglion within Meckel's cave. **Fig 5. Axial T2 SPACE and coronal T2 images demonstrating the sensory and motor nerve rootlets within Meckel's cave.**

**Divisions and neural exit foramina**

The trigeminal ganglion divides into three exiting sensory branches. **Fig 6. Cadaveric specimen demonstrating CN V divisions exiting Meckel's cave through skull base foramina and associated sensory distribution of the three divisions.**

Ophthalmic: V1, exits Meckel's cave and courses anteriorly through the cavernous sinus to exit the skull base via the superior orbital fissure. This branch then traverses the supraorbital foramen of the orbit and exits to provide sensation to the forehead. **Fig 7. CT and MR images demonstrating V1 as it exits the skull base via the superior orbital fissure and courses through the supraorbital foramen**

Maxillary: V2, exits Meckel's cave and like V1, courses anteriorly through the cavernous sinus, however exits the skull base via the foramen rotundum to enter the pterygopalatine fossa. Traversing the inferior orbital foramen, this nerve exits to provide sensation to the maxilla. **Fig 8. CT and MR images demonstrating V2 as it exits the skull base via the foramen rotundum, courses through the pterygopalatine fossa and into the inferior orbital foramen.**

Mandibular: V3, exits Meckel's cave and joins with the main motor root. This mixed motor and sensory nerve exits the skull base via the foramen ovale to enter the infratemporal fossa. From here the nerve provides sensation to the mandible and motor innervation to the muscles of mastication. **Fig 9. CT and MR images demonstrating V3 as it exits the skull base via the foramen ovale, coursing from the infratemporal fossa through the mandibular canal.**

**PATHOLOGY**

**Trigeminal Neuralgia**

Trigeminal neuralgia can be caused by direct compression of the nerve by vascular structures or tumour (Type 1) or abnormal signal impulses through the trigeminal nerve.
causing pain (Type 2). MR imaging in trigeminal neuralgia aims to identify a reversible aetiology for the pain. The most common reversible cause of trigeminal neuralgia is compression of the root entry zone or cisternal segment by the superior cerebellar artery within the prepontine cistern. **Fig 10. Artists depiction of most common patterns of neurovascular conflict involving CN V.**

Following axial imaging through the posterior and middle cranial fossae and identification of possible neurovascular conflict, TOF sequences are required to confirm contact vessels as arteries. **Fig 11.**

**Axial T2 SPACE demonstrating regions of neurovascular contact, confirmed on TOF. Fig 12. Axial T2 SPACE, MinIP and TOF images demonstrating contact of the left superior cerebellar artery with the REZ of CN V within the prepontine cistern.**

Another common cause of facial pain is the formation of plaques within the pons and medulla with multiple sclerosis. **Fig 13. Axial Flair MR demonstrating region of high signal intensity within right pons, extending into root entry zone of the trigeminal nerve in a patient with facial pain and multiple sclerosis.**

**Primary nerve tumours: Trigeminal Schwannoma/neuroma**

The most common primary tumour of the trigeminal nerve, schwannomas most commonly involve the cavernous or cisternal segments. **Fig 14. Axial T2 demonstrating widening of right Meckel’s cave by schwannoma of trigeminal ganglion.**

Nerve sheath tumours of the trigeminal peripheral branches can be particularly subtle, as in the case provided where a V2 neuroma was initially diagnosed as a mucus retention cyst, however later diagnosed as neuroma on MRI. **Fig 15. Axial CT of the orbits demonstrating small rounded lesion within left maxillary sinus, initially diagnosed as mucus retention cyst. Coronal projection shows subtle, but relative widening of the inferior orbital foramen. MR images show region of concern is not mucus, but a V2 neuroma.**

**Perineural spread of malignancy**

The extensive distribution of the trigeminal nerve within the head and neck, in particular cutaneous sensation, enables perineural spread of head and neck malignancies via trigeminal nerve to central structures such as the cavernous sinus and Meckel's cave.
**Fig 16.** Sagittal CT and coronal T1 FS MR demonstrating perineural spread of periorbital cutaneous SCC along ophthalmic/V1 branch of CN V. MR images presented anterior to posterior, upper right to lower left.

**Fig 17.** Axial and coronal T1 FS demonstrating perineural spread of right cheek cutaneous malignancy along V2 through inferior orbital foramen and V3 through the foramen ovale, into Meckel's cave.

**Fig 18.** Axial T2, axial FLAIR and coronal T1 FS demonstrating perineural invasion cavernous sinus and Meckel's cave from adenoid cystic carcinoma of the left pinna.

**Fig 19.** Axial FLAIR and coronal T1 FS demonstrating loss of fat within medullary bone from invasion of nasopharyngeal carcinoma into central skull base, and invasion via V3 into Meckel's cave and cavernous sinus.

**Wallenberg/lateral medullary Syndrome**

Dissection or thrombus of the vertebral or PICA arteries can result in infarction of brainstem regions containing trigeminal nuclei and result in facial pain, a symptom of lateral medullary syndrome.

**Fig 20.** T1 FS and DWI images demonstrating right vertebral artery dissection with associated right brainstem infarction and absence of right vertebral artery on MRA in patient with lateral medullary syndrome and ipsilateral facial pain.
Fig. 1: Neuroblasts within the alar and basal plates of the rhombencephalon develop into nuclei, whereas in the spinal cord these develop into tracts.

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Right vertebral artery dissection with brainstem ischaemia

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Conclusion

Trigeminal nerve is the largest and most complex of the twelve cranial nerves. It has a long course and its 3 branches have a very important function. The nerve and its branches can be well demonstrated on high resolution imaging.

Understanding embryology, osseous-neural microanatomy and its relationship to the arteries of the Circle of Willis and orbit can overcome pitfalls in diagnosis of common pathologies of the Trigeminal nerve.
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