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Magnetic resonance neurography of the head and neck: state of the art, anatomy, pathology and future perspectives

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Corresponding Author:	Fréderic Van der Cruyssen University Hospitals Leuven Leuven, BELGIUM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University Hospitals Leuven
Corresponding Author's Secondary Institution:	
First Author:	Fréderic Van der Cruyssen
First Author Secondary Information:	
Order of Authors:	Fréderic Van der Cruyssen
	Tomas-Marijn Croonenborghs
	Tara Renton
	Robert Hermans
	Constantinus Politis
	Reinhilde Jacobs
	Jan Casselman
Order of Authors Secondary Information:	
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Suggested Reviewers:	Kaan Orhan call53@yahoo.com
	Philippe Demaerel philippe.demaerel@uzleuven.be
	Vincent Vandecaveye vincent.vandecaveye@uzleuven.be
	Egon Burian egon.burian@tum.de
Opposed Reviewers:	

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Invited review

Authors

Dr. Fréderic Van der Cruyssen[1,2]

Dr. Tomas-Marijn Croonenborghs[1, 2]

Prof. Dr. Tara Renton[3]

Prof. Dr. Robert Hermans[4]

Prof. Dr. Constantinus Politis[1,2]

Prof. Dr. Reinhilde Jacobs[2,5,6]

Prof. Dr. Jan Casselman[7,8,9]

Affiliations

[1]Department of Oral & Maxillofacial Surgery, University Hospitals Leuven, Leuven, Belgium

[2]OMFS-IMPATH Research Group, Department of Imaging and Pathology, Faculty of Medicine, University Leuven, Leuven, Belgium

[3]Department of Oral Surgery, King's College London Dental Institute, London, United Kingdom

[4]Department of Radiology, University Hospitals Leuven, Leuven, Belgium

[5]Department of Oral Health Sciences, KU Leuven and Department of Dentistry, University Hospitals Leuven, Leuven, Belgium

[6]Department of Dental Medicine, Karolinska Institutet, Stockholm, Sweden

[7]Department of Radiology, AZ St-Jan Brugge-Oostende, Bruges, Belgium

[8]Department of Radiology, AZ St-Augustinus, Antwerp, Belgium

[9]Department of Radiology, UZ Gent, Gent, Belgium

Corresponding Authors

Fréderic Van der Cruyssen

Department of Oral & Maxillofacial Surgery

University Hospitals Leuven

Kapucijnenvoer 33,

3000 Leuven, Belgium

Email: frederic.vandercruyssen@uzleuven.be

Tel.: +32 16 33 24 62

Jan Casselman

Department of Radiology

AZ Sint-Jan

Ruddershove 10,

8000 Bruges, Belgium

Email: jan.casselman@azsintjan.be

Tel.: +32 50 45 21 01

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Abstract

Magnetic resonance neurography allows for the selective visualization of peripheral nerves and is increasingly being investigated. Whereas in the past the imaging of the extracranial cranial and occipital nerve branches was inadequate, more and more techniques are now available that do allow nerve imaging. This basic review provides an overview of the literature with current state of the art, anatomical landmarks and future perspectives. Furthermore, we illustrate the possibilities by means of a few case studies.

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Abstract

Magnetic resonance neurography allows for the selective visualization of peripheral nerves and is increasingly being investigated. Whereas in the past the imaging of the extracranial cranial and occipital nerve branches was inadequate, more and more techniques are now available that do allow nerve imaging. This basic review provides an overview of the literature with current state of the art, anatomical landmarks and future perspectives. Furthermore, we illustrate the possibilities by means of a few case studies.

Introduction

Magnetic resonance neurography (MRN) refers to dedicated MRI sequences that selectively enhance the visualization of peripheral nerves. Several techniques have been described in the literature including 2D and 3D T2 weighted fat suppressed and diffusion weighted imaging.[1] The first reports on MRN date from 1992 by Howe and Filler and have much evolved since then.[2] At present, MRN is gaining importance due to the introduction of high-field MRI devices and improved imaging techniques.

The skull base course of cranial nerve MRI anatomy has been extensively reviewed.[3–6] In this article we will review the state of the art and relevant MRN anatomy of the extracranial cranial and occipital nerve branches with illustrative pathologic cases. Finally, we will discuss some future directions.

State of the art

Although there is well supported literature on MRN in musculoskeletal imaging, the original research articles are rather limited for the head-neck area. There are several factors why MRN is more difficult to implement in this region. First, the cranial nerves have small calibers and have a complex tortuous course, passing tissues with very different physical properties. The close proximity of fat pads, sinuses and vessels with slow and fast flows require more performant sequences. Ideally a cranial nerve MRN sequence has a large FOV with three-dimensional thin slice thickness, high signal- (SNR) and contrast-to-noise ratios (CNR), with uniform fat, venous and arterial suppression and minimal magic angle artefacts. All these requirements should be met within reasonable acquisition times and minimum chance for motion artefacts. Also, when considering nerve-related pathology we can expect surgical and pathology induced susceptibility artefacts such as edema, increased vascularity and metal particles, which should be accounted for when possible. Previous reports described cranial nerve anatomy using various MRI sequences such as 3D bFFE (3D balanced fast-field echo sequences), T2w TSE (turbo spin echo), STIR (short tau inversion recovery) and CISS (constructive interference in steady state).[3–5,7] Although these sequences nicely demonstrate the anatomy, they are not nerve-specific as surrounding structures are not suppressed. In true MRN sequences we try to obtain a heavily T2 weighted image to achieve high soft tissue contrast with homogenous fat, arterial and venous suppression. Several authors published on available techniques for inferior alveolar, lingual, as well as occipital nerve imaging mainly based on 3D PSIF (reversed fast imaging in steady-state free precession).[8,9] PSIF combines a steady state with a water excitation pulse and fat suppression, selectively enhancing neural anatomy with excellent vascular suppression. A disadvantage of PSIF is the lower SNR and risk for susceptibility artefacts compared to STIR sequences (**Figure 1**). A protocol suggested by Chhabra et al. is further complemented by STIR, CISS, bFFE and DTI (diffusion tensor imaging).[9] By adding multiple sequences, one reduces the risk of non-diagnostic images but loses time and cost efficiency, which are becoming increasingly important in a healthcare environment under financial pressure and with increasing demand for MRI. The authors apply the 3D CRANI (CRAnial Nerve Imaging) sequence which is based on contrast enhanced black blood 3D STIR TSE preceded by an MSDE (motion-sensitized driven equilibrium) pulse in combination with a pseudo steady state sweep and compressed sensing.[10,11] Advantages of 3D CRANI are high SNR and CNR and less susceptibility artefacts. By combining 3D PSIF and 3D CRANI, a cranial MRN examination can be performed in a total acquisition time of 12 minutes. **Table 1** describes in detail the author's MRN protocol including 3D PSIF and 3D CRANI sequences. Routine T1, T2w and 3D FLAIR (fluid attenuated inversion recovery) brain sequences could be added as well to exclude intracranial pathology. DTI is increasingly being used but, for the time being, mostly remains of scientific value.[10,12,13] In order to obtain a diagnostic MRN acquisition, adequate patient positioning and coil selection is necessary.[6] Thorough patient fixation in mild hyperextension using a 32 channel head coil plays an important role in optimization of the SNR (**Figure 2**). Others have advocated the use of a 16 channel head neck spine coil.[14] Finally, post-processing using maximum intensity projection (MIP) and multiplanar reformatting (MPR) renders the necessary viewing windows to evaluate the attenuation-enhanced cranial nerves along their trajectory or in non-axial planes according to the radiologist's discretion (**Figure 3**).[15,16]

In the next paragraphs the cranial and occipital nerve imaging anatomy is described and further illustrated by a supplementary **video**.

Trigeminal Nerve

Anatomy

The trigeminal nerve splits into three main divisions before it leaves the skull: ophthalmic nerve (V_1), maxillary nerve (V_2) and mandibular nerve (V_3). The ophthalmic division (V_1) splits into three branches (lacrimal, frontal and nasociliary nerve) which enter the orbit via the superior orbital fissure. The maxillary division (V_2) leaves the cranial cavity via the foramen rotundum and reaches the pterygopalatine fossa. It innervates the teeth of the upper jaw and part of the nasal mucosa. Its dermal branches, the zygomatic nerves and infraorbital nerve, enter via the inferior orbital fissure. The infraorbital nerve runs over the floor of the orbit, it passes through the infraorbital foramen to the skin of the lower eyelid, the side of the nose and part of the upper lip. Preganglionary parasympathetic fibers originate from the facial nerve. They are conveyed via the greater petrosal nerve. The latter branches off at the knee level of the facial nerve (geniculum), located in the petrosal bone and runs over an intracranial sulcus of the same name on the top of the petrosal bone to the foramen lacerum. The postganglionic (ortho)sympathetic fibers originate from the superior cervical ganglion. They leave the internal carotid plexus as the deep petrosal nerve. In the cartilage of the foramen lacerum they join to form the Vidian nerve in the Vidian canal. Via this canal it reaches the pterygopalatine fossa and its ganglion. Postganglionic nerves leave for the nasal cavity (via the foramen sphenopalatinum), to the palate (via nervus palatinus major and nervus palatini minores through channels of the same name) to the pharynx and also to the orbit. They supply the mucosa and glands of the nose, palate and part of the pharynx (**Figure 4**).

The mandibular nerve (V_3) runs through the foramen ovale from the middle cranial fossa to the infratemporal fossa. Three of its four large branches (buccal nerve, inferior alveolar nerve and auriculotemporal nerve) reach the lower skin of the face and are responsible for the cutaneous innervation of the face but it also carries the smaller motor part (radix motoria) which supplies the muscles of mastication. Approximately one centimeter below the foramen ovale, the trunk of the mandibular nerve splits into an anterior and a posterior division. Its branches are described in three groups (trunk, anterior and posterior division). Branches of the trunk of the mandibular nerve include: the medial pterygoid nerve for the chewing muscle of the same name, meningeal rami which innervate the meninges that runs through the foramen spinosum together with middle meningeal artery.

Branches of the anterior division are all motoric except the buccal nerve which appears between the two heads of lateral pterygoid muscle (**Figure 5**). It innervates a postage stamp large area on the inside and outside of the cheek. The masseteric nerve runs superior from the lateral pterygoid muscle. It passes between the tendon of temporal muscle and the temporomandibular joint (TMJ) and reaches the masseter muscle via the mandibular incisura. On the way, it supplies small branches towards the TMJ. The deep temporal branches, two or three in number, run over the lateral pterygoid muscle to innervate the temporal muscle. The lateral pterygoid nerve innervates the muscle of the same name.

The posterior division of the mandibular nerve constitutes the auriculotemporal, lingual, inferior alveolar and mylohyoid nerve (**Figure 5, 6**). The auriculotemporal nerve innervates most of the temporal region and a small part of the auricle (leading edge) and the outer ear canal. In the classical case it “embraces” the middle meningeal artery. Then, together with the maxillary artery, it runs backwards between the sphenomandibular ligament and the mandibular collum, turns around the condyle of the mandible and ends up in the subcutaneous membrane of the temporal region. Secretomotor fibers originating from the otic ganglion are transported to the parotid gland via this nerve. The lingual nerve appears in the infratemporal fossa between both pterygoid muscles and runs antero-inferiorly over the lateral side of medial pterygoid muscle. It innervates the mucosa of the anterior two thirds of the tongue, the mucosa of the oral floor and of the lingual side of the gums. It also carries the taste fibers from the anterior tongue and parasympathetic preganglionic fibers for the submandibular ganglion (intended for the submandibular and sublingual glands). The preganglionic parasympathetic fibers originate from the facial nerve and reach the lingual nerve via the chorda tympani, which joins high up in the infratemporal fossa. The inferior alveolar nerve also ends up between the two pterygoid muscles in the infratemporal fossa. There, it lies behind the lingual nerve. Together with the artery of the same name it runs between the sphenomandibular ligament towards the inferior alveolar canal or mandibular canal. Just before it enters the mandibular foramen, it releases the mylohyoid nerve that innervates the mylohyoid muscle and anterior belly of the digastric muscle. The inferior alveolar nerve innervates all the teeth of the lower jaw (inferior dental rami, dental plexus), the adjacent gums (inferior gingival rami) and, via its end branch (mental nerve), the skin of the chin (mental rami) and the skin and mucosa of the lower lip (inferior labial rami).[17–19]

Imaging

The brainstem, cisternal and cavernous trigeminal segments can be imaged using conventional brain sequences including CISS and balanced FFE sequences and have been extensively reviewed in the past.[6,20] The peripheral trigeminal nerve branches are best viewed in multiple planes after thick-slab MIP. The first (V_1), second (V_2) and anterior division of the third division (V_3) can be well depicted on axial views whereas the lingual and inferior alveolar nerve are best seen in a coronal oblique direction (**Figure 4, 5, 6**).

In addition to the neurovascular conflict seen in trigeminal neuralgia cases, more and more neurological abnormalities are becoming detectable. The branches that are mostly involved in pathological conditions are the lingual and inferior alveolar nerve. Their course makes these nerves vulnerable to numerous dental and oro-maxillofacial procedures. MRN techniques can aid in grading and clinical decision making if trauma has occurred.[21] Interested readers are referred to a recent systematic review summarizing the available knowledge base on MRN in post-traumatic trigeminal neuropathies.[22] There is also increasing interest for the use of MRN in orofacial pain patients and more specifically in migraine and trigeminal autonomic cephalalgia (**Figure 4**).[23]

Facial Nerve

The facial nerve consists out of motor, sensory and parasympathetic fibers. The sensory fibers innervate a part of the inner ear and the special sensory fibers transport the taste stimuli from the anterior two thirds of the tongue via the chorda tympani. The parasympathetic fibers innervate the submandibular, sublingual and minor salivary glands, as well as the lacrimal glands. The motor fibers innervate the muscles responsible for the facial expression.

The primary or cisternal segment of the facial nerve leaves the brainstem close to the dorsal pons, transverses the cerebellopontine angle and enters the temporal bone by the porus acousticus in proximity to the vestibulocochlear nerve branches: superior to the cochlear nerve and anterior to the superior and inferior vestibular nerves. The trajectory through the temporal bone is subdivided in a meatal, labyrinthine, tympanic and mastoid segment. The sensory fibers, coming from the intermediate nerve, give on the one hand sensibility to the posterior concha and external auditory canal, on the other hand the special sensory fibers will form the chorda tympani.

The main trunk of the facial nerve leaves skull base via the stylomastoid foramen, it immediately releases the smaller posterior auricular r. auricularis. Subsequently, the nerve enters the craniomedial part of the parotid gland. Over the intraglandular course the nerve subdivides into five branches, which appear separately at the upper, front and lower edges of this gland. These end branches spread from here to the facial mimic muscles like the spread fingers of a hand resting on the parotid area (temporal, zygomatic, buccal, marginal mandibular and cervical, **Figure 6**).[24,25]

Imaging

When considering MRI-imaging of the facial nerve, two segments need to be distinguished from each other: the skull base and the extracranial nerve segments. The intracranial and the temporal facial nerve segment is best visualized using 3D CISS, axial T1-weighted and fat-suppressed T2-weighted images.[26] Visualization of the facial nerve within the stylomastoid canal, the extracranial and intraparotid part of the VII cranial nerve can be made using thick-slab MIP/MPR reconstructions of 3D PSIF, and in case of extensive artefacts a black blood 3D-STIR such as 3D CRANI.[9] In case of nerve pathology, an increase of signal intensity and nerve caliber changes can be identified (**Figure 7**). The use of a 3D PSIF sequence in combination with microsurface coils resulted in superior visualization of the peripheral facial nerve branches, in comparison to a standard head and neck coil, as was reported by Chu et al.[27] The 3D-DESS-WE (double-echo steady state with water excitation) sequence is another established option to be considered for peripheral facial nerve neurography.[28–30]

Cranial nerves IX to XII

The trajectory of the IX, X and XII cranial nerves is anatomically closely intercalated, moreover a lot of imaging characteristics are similar and therefore they are discussed together (**Figure 8**).

Glossopharyngeal nerve anatomy

The glossopharyngeal nerve or IX cranial nerve is composed of a combination of motor, sensory and parasympathetic fibers. Firstly, the sensory, gustatory and visceral stimuli are transported via afferent fibers from the retroauricular region, the posterior third of the tongue, the pharynx wall and the tonsils, the soft palate and the eardrum. Secondly, the motor efferents innervate the stylopharyngeus muscle. Thirdly, the parasympathetic fibers stimulate the production of saliva within the parotid gland.[31]

The origin of the IX cranial nerve is strongly associated with the vagus nerve, sharing three functional nuclei in the upper medulla oblongata. The nerve branches from the medulla oblongata within the cerebellomedullary cistern, slightly superior to the vagus nerve. The 9^{th}, 10^{th} and 11^{th} cranial nerves course in an anterolateral direction through the cistern to the jugular foramen, exiting the foramen anteriorly from the internal jugular vein. Within the foramen the glossopharyngeal nerve is known for two focal expansions: a superior node handling general sensible information and a lower node handling visceral sensory, taste and carotid innervations. The extratemporal course of the IX cranial nerve continues in a caudal direction within the carotid space and disperses in 5 major branches. Firstly, the tympanic nerve branches from the inferior node, carrying sensory information from the external and middle ear and parasympathetic stimuli to the parotid gland via the lesser petrosal nerve. Secondly, the stylopharyngeus branch gives motor input to the stylopharyngeus muscle. Thirdly, the pharyngeal branches associate with branches from the vagus nerve, forming the pharyngeal plexus. Fourthly, the carotid sinus branch mediates parasympathetic information to the carotid body. Finally, the lingual branch conveys general and gustatory sensory input from the posterior third of the tongue.[31,32]

Vagus nerve Anatomy

The n. X forms the pharyngeal plexus and mediates the motor function of the soft palate. The parasympathetic fibers of the dorsal motor core of the n. X innervate pharynx, esophagus, trachea, bronchi, lungs, heart, intestines, liver and pancreas.

Multiple rootlets exiting the ventrolateral sulcus, formed by the olive and interior cerebellar peduncle, fuse together in the vagus nerve. The vagus and glossopharyngeal nerve progress closely intercalated through the cerebellopontine angle. Noteworthy, is the small meningeal branch coming from the vagus nerve, innervating the dura within the posterior cranial fossa. Subsequently, the vagus nerve travels through the center of the jugular foramen: superficial to the internal jugular vein and caudal to the glossopharyngeal nerve. Caudally progressing within the carotid space between, however slightly posterior to the internal carotid artery and internal jugular vein. The internal jugular vein remains lateral and superficial to the vagus nerve; the common carotid artery travels medial and slightly anterior to the nerve.

There are four major extracranial branches leaving the vagus nerve in the head and neck area. Firstly, the auricular branch or Arnold nerve, exiting from the main nerve when passing through the jugular foramen, this nerve receives sensory input coming from the external auditory canal and tympanic membrane. Secondly, the pharyngeal branches leave the vagus nerve below the skull base and form, together with the IX cranial nerve, the pharyngeal plexus innervating the muscles of the soft palate and pharynx. Besides the motor function, the plexus conveys sensory stimuli coming from the epiglottis, trachea and esophagus. Thirdly, the superior laryngeal nerve has a sensory, as well as a motor component. The internal sensory branch conducts sensory input from the hypopharynx, larynx and vocal cords, the external motor branch innervates the cricothyroid and inferior pharyngeal constrictor muscles. And finally, the recurrent laryngeal nerve (RLN) is identified with its renowned asymmetrical anatomical morphology. Bilaterally the RLN branches from the vagus nerve, it loops around the subclavian artery on the right side and on the left side around the aortic arch. The RLN mediates somatic and visceral sensory input coming from below the vocal cords, moreover, conveying motor output to all laryngeal musculature with exception of the cricothyroid muscle. Hereafter, the vagus nerve continues the trajectory into the thorax.[6,33,34]

Accessory nerve Anatomy

The accessory nerve solely contains motor fibers, innervating the sternocleidomastoid as well as the trapezius muscle. The accessory nerve is composed from of both cranial and spinal (C1-5) rootlets. The main trunk of the accessory nerve subsequently travels in a lateral direction, before the nerve leaves the skull via the jugular foramen wherein connections with the vagus nerve can be found. The extracranial accessory nerve runs through the center of the carotid space between the medial internal carotid artery and laterally positioned internal jugular vein (IJV). Subsequently, the nerve divides again in the cranial and spinal roots. The cranial rootlets or internal branches fuse together with the vagus nerve and the spinal rootlets or external branches laterally cross the IJV, passing the transverse process of atlas mostly anteriorly and advancing medially from the styloid process and digastric and stylohyoid muscles. Further progression of the nerve follows an anterolateral direction before reaching the sternocleidomastoid muscle and subsequent formation of a nerve plexus with the ventral rami of C2 to C4, mediating the innervation of the trapezius muscle.[35–37]

Hypoglossal nerve anatomy

The hypoglossal nerve is a purely motor nerve, innervating the extrinsic and intrinsic musculature of the tongue, with exception of the palatoglossus muscle. The XII cranial nerve is formed by two bundles of 10-15 rootlets coming from the ventrolateral sulcus at the medulla oblongata. The bundles pierce through the dura mater separately and fuse together after passing through the hypoglossal canal. The extracranial hypoglossal nerve is joined by efferent C1 motor fibers and progresses laterally and inferiorly to the vagus nerve and internal carotid artery, initially closely associated with the carotid space. Subsequently, after passing the occipital artery the hypoglossal nerve will turn and mostly pass through the space between carotid arteries and internal jugular vein. After progressing medially to the hyoid tendon of the digastric muscle, the nerve will enter the submandibular space medial to the submandibular gland and hyoglossus muscle (**Figure 9**). Some of the C1-fibers branch off more cranially and innervate the superior root of the ansa cervicalis, however other C1 nerve fibers conveying motor input for the geniohyoid and thyrohyoid muscles will remain associated with the XII cranial nerve.[32,38,39]

Glossopharyngeal, vagus, accessory and hypoglossal nerve imaging

Evaluation of the cisternal IX, X and XI cranial nerve segments is preferably performed using heavily T2-weighted steady-state free precession imaging sequences.[26] However, these 2-D sequences have mainly been replaced by 3D CISS and 3D FIESTA.[3] The distinct foraminal nerve segments are identified using conventional 3D FIESTA, or CE-MRA (contrast-enhanced magnetic resonance angiograph) as described by Linn et al.[5,40] The below-skull-base related nerve segments can be nicely differentiated on the MIP/MPR-reformatted 3D CRANI images (**Figure 8,9**). They are conveniently identified on coronal and axial planes. As discussed by Chhabra and colleagues, 3D PSIF is also a valuable technique for neurography of these closely intercalated cranial nerves.[21] The typical nerve trajectories can be distinguished as follows, the extracranial vagus nerve is positioned between the medial IX and lateral XII nerve and has the largest diameter.

Occipital Nerves (C2)

Anatomy

The greater occipital nerve (GON) ensues from the fusion of nerve fibers coming from the medial branch of the dorsal ramus of the second and, to a lesser degree, the third spinal nerve. At the level of the C1-C2 vertebrae the nerve travels in the occipital direction between the medial inferior capitis oblique and lateral semispinal muscles. Important anatomical variation is described concerning the penetration of the trapezius, semispinalis capitis and inferior capitis oblique muscles which are pierced by GON in respectively, 45%, 7,5% and 90% of cases.[41] Next, the nerve loops upwards, joins the occipital artery and subdivides in a medial and lateral branch before terminal branches ensue.[41–44]

The lesser occipital nerve (LON) typically originates from the ventral rami of spinal nerves C2 and C3. The nerve loops around the sternocleidomastoid muscle (SCM). Its trajectory is parallel to the posterior border of the SCM, piercing the superficial lamina of the cervical fascia, in direction of the occipital area. Finally, the LON divides into medial and lateral branches in the middle between the intermastoid line and inion. Interconnections or overlap of GON and LON twigs are frequently present.[43–45]

The third occipital nerve (TON) derives from the superficial medial branch of the dorsal ramus of the third spinal nerve. The nerve courses on top of the dorsolateral surface of the C2-C3 facet joint. The TON travels deeply to the semispinalis capitis muscle in a posterior direction when a communicating branch to GON exits. The overlying musculature will be pierced by TON before progressing subcutaneously.[34,41,43,44]

Functionally, GON, LON and TON receive somatic sensory input from the occipital region. The semispinalis muscle will receive motor output via GON, and to a lesser degree from TON (**Figure 10**).[34,43,44]

Imaging

The occipital nerves are easily visualized on a slightly oblique axial plane using 3D PSIF or 3D CRANI sequences and are of increasing interest to neurologists and pain specialists. Pathological thickening and signal alterations can be noted in cases of occipital neuralgia also referred to as occipital migraine.[23] Occasionally one can also detect pathological changes after trauma or surgery in this region (**Figure 10**).

Future perspectives

MRN performance and applications are evolving rapidly. Where 0.5T systems were available 20 years ago, we are now seeing the arrival of clinical 7T and higher. The introduction of these high-field MRI devices can further improve spatial resolution and soft tissue contrast. However, there is also a risk of increasing susceptibility artefacts as they increase with increasing field strength and thus, they should not be considered the holy grail in MRN imaging. Rather a combination of high-field systems, specialized coils, improved post-processing and contrast agents will likely evolve this field in the next phase.[27,46,47] First, there is a need to further define anatomical benchmarks for the cranial nerves. Several authors have described reference values for the trigeminal nerve or provided classifications to define degree of nerve injury.[14,48] Next, there is a whole field of research left to obtain functional information by means of DTI and diffusion tensor tractography (DTT). These techniques are based on differences in diffusion of protons along nerve tracts and allow quantification of diffusion restriction by means of the apparent diffusion coefficient (ADC) and fractional anisotropy (FA) values. In combination with morphological changes a more detailed description of neural dysfunction and neuroregeneration becomes reality.[49] Additionally, they allow for a multiparametric and standardized approach towards nerve injuries and pathology, which is currently lacking. Several studies described the successful application of DTI and DTT in extraforaminal cranial nerve imaging.[12,50–53] But, most reports only describe DTT of the proximal nerve branches with varying reference values.[51,54] DTT of the small distal cranial nerve branches remains challenging and, for the time being, is mostly of scientific value.[13,55]

In addition to strong diagnostic value, MRN also offers applications for planning of surgical procedures. The surgeon could check in advance where the nerve is located in relation to the neoplasia or when the anatomy deviates from the normal.[51] Panoramic reconstructions can aid in dental surgery planning (**Figure 11**).[56] Fusion with computed tomography images could help with the placement of a temporomandibular joint prosthesis near these peripheral nerve branches (**Figure 12**) and it is only a matter of time before artificial intelligence aids find their way to the clinic.[57,58]

In conclusion, the field of MRN is still in its infancy but a wide range of applications are already under development. It is therefore important that radiologists and anyone involved in cranial nerve pathology become familiar with these techniques and their possibilities.

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Figure captions

Fig 1. Coronal thick slab (5 mm) MIP/MPR images in the same subject comparing two magnetic resonance neurography techniques. Short arrow: lingual nerve (V_3); long arrow: inferior alveolar nerve (V_3); arrowhead: masseteric nerve (V_3). A: 3D CRANI sequence. B: 3D PSIF sequence.

Fig 2. A: patient positioning in a standard 32 channel head coil without additional measures. Note the anterior mandible is located outside the coil. B: patient positioning after fixation by means of an inflatable pillow with the head in slight hyperextension using a towel roll. The mandible is now well positioned within the coil. C: alternative coil, being a 16 channel neck coil. D: imaging output after patient positioning as in example A. Signal loss is seen at the anterior segment. E: imaging output after slight hyperextension and thorough fixation as in example B. F: imaging output using a neck coil after patient positioning as in example C.

Fig 3. A: orthogonal and additional planes constructed in evaluating the cranial and occipital peripheral nerves. B: overall nerve anatomy discussed in this review.

Fig 4. A: ophthalmic division of the trigeminal nerve (V_1) using the 3D CRANI sequence. B: 3D CRANI sequence. Increased caliber of the right infra-orbital nerve (V_2) in a patient with SUNCT (Short lasting Unilateral Neuralgiform headache attacks with Conjunctival injection and Tearing rhinorrhea and forehead sweating). C: 3D CRANI sequence. Increased signal intensity is noted of the Vidian nerve (V_2) in the same patient as seen in B.

Fig 5. A: anatomic relation of the anterior division of the mandibular nerve (V_3) best seen in the axial plane. B: 3D CRANI sequence illustrating the buccal nerve (long arrow), the masseteric nerve (short arrow) and the stem of the auriculotemporal nerve (arrowhead). C: 3D CRANI sequence in a patient with post-traumatic trigeminal neuropathy of the mandibular division after placement of a titanium temporomandibular joint prosthesis. The left masseteric nerve is thickened and shows an increased signal intensity.

Fig 6. A: anatomic overview of the posterior division of the mandibular nerve (V_3) on a coronal oblique plane. B: normal appreciation of the lingual (long arrow) and inferior alveolar (short arrow) nerve running between the pterygoid muscles. C: right sided post-traumatic trigeminal neuropathy of the inferior alveolar nerve after ramus bone grafting. D: patient with neurofibromatosis type 1, showing bilateral neurofibromas of the inferior alveolar nerve at the level of the mandibular foramen.

Fig 7. A: anatomic overview of the facial nerve and its branches which are best seen on a sagittal slightly rotated or coronal plane. B: sagittal view of a normal extracranial facial nerve entering the parotid gland on a 3D CRANI thick-slab MIP/MPR-image. C: coronal image with bilateral visualization of the intratemporal and extraforaminal facial nerve after iatrogenic damage on the right side. A slowly recuperative facial nerve paresis occurred after an infiltration with local anesthesia.

Fig. 8. A: anatomic overview of the facial (VII), hypoglossal (XII), glossopharyngeal (IX), vagus (X) and accessory (XI) nerves which can be seen in close relation to each other on a coronal plane. B: coronal view after a 3D CRANI sequence indicating the aforementioned peripheral nerves without pathological characteristics.

Fig 9. Bilateral normal appreciation of the peripheral hypoglossal nerve (white arrows) on an axial 3D CRANI image after MIP/MPR showing its course around the great vessels before innervating the tongue.

Fig 10. A: anatomic overview of the occipital nerves which are seen together on an oblique axial plane. B: lesser (L), third (T) and greater (G) occipital nerves after MIP/MPR on a 3D CRANI sequence in a healthy subject. C: more distal course of the lesser (L) and greater (G) occipital nerve in a healthy subject.

Fig 11. Panoramic curved reconstruction and MIP of the inferior alveolar nerve using a 3D CRANI sequence allowing a full evaluation at a glance.

Fig 12. 3D fusion of CT and MRN images which can be valuable in planning the placement of a custom made temporomandibular joint prosthesis (blue outline). The inferior alveolar nerve is segmented (red outline) and indicated (white arrows) before entering the mandibular canal.

Tables

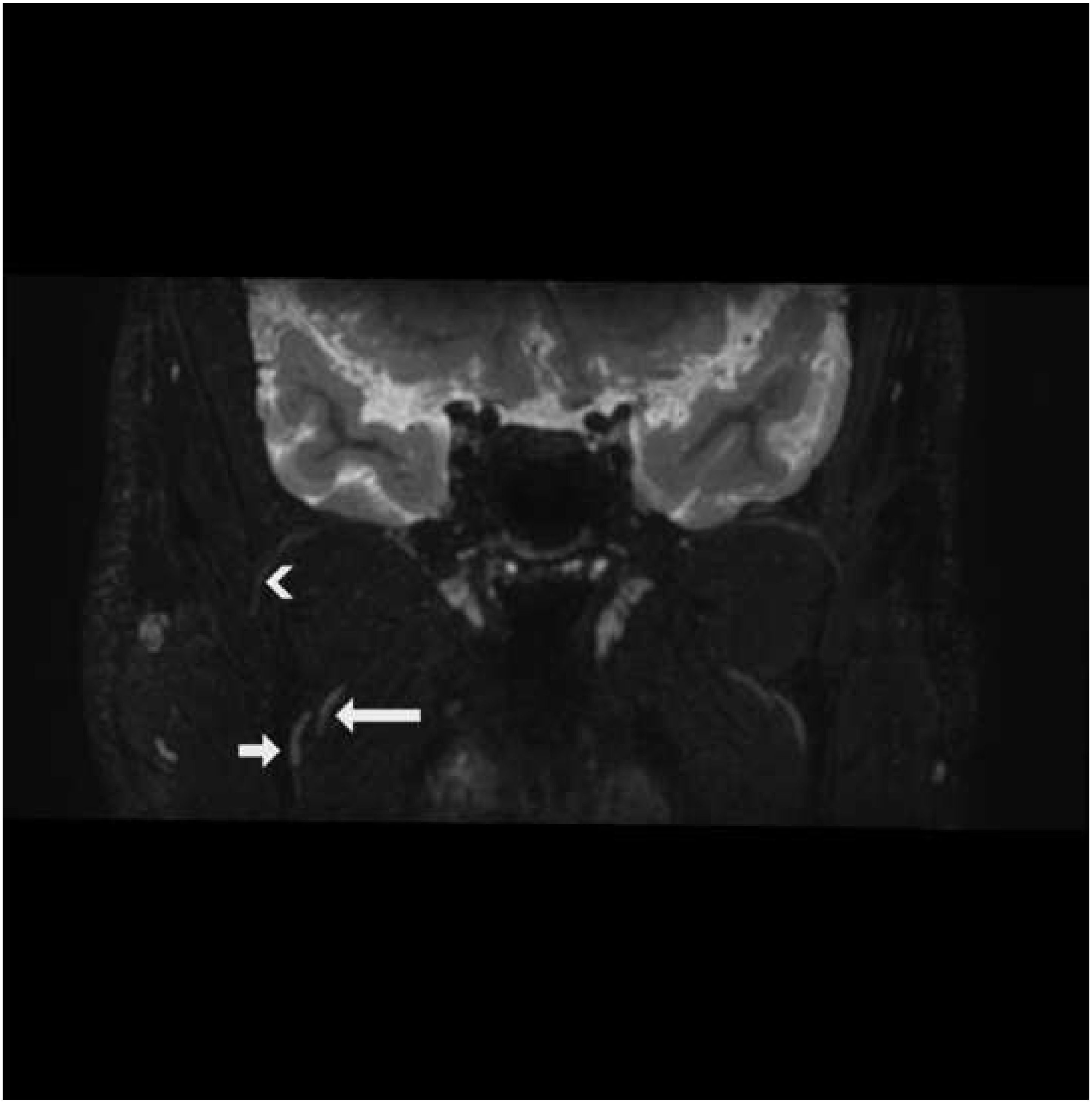
Table 1. Magnetic resonance neurography sequences for a 3T Philips system (Philips, Best, Netherlands). 3D CRANI (CRAnial Nerve Imaging) and 3D PSIF (reversed fast imaging in steady-state free precession) sequences. These can be further supplemented with routine brain T1w, T2w, CISS and FLAIR images. TE: echo time; TR: repetition time, FOV: field-of-view, STIR: short tau inversion recovery; FFE: fast field echo; N/A: not applicable; MSDE: motion-sensitized driven equilibrium.

Video

Illustrative video indicating the peripheral cranial nerve anatomy using the 3D CRANI sequence on a 3T Ingenia system with a 32CH head coil (Philips, Best, Netherlands).

Figure 1a

Click here to access/download;Figure;Fig 1a.tiff



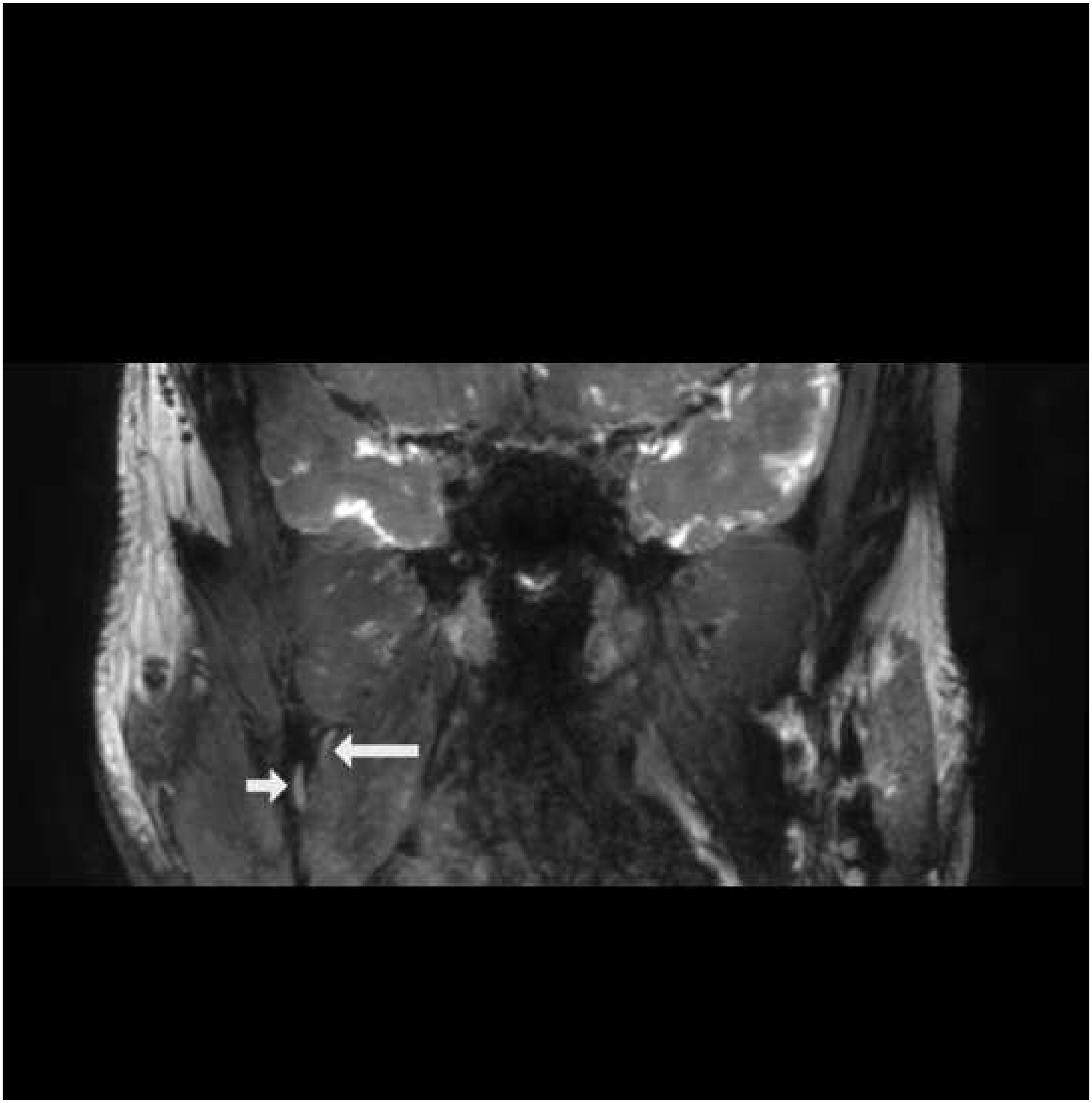


Figure 2a

Click here to access/download;Figure;Fig 2a.tiff

Figure 2b

Figure 2c

Click here to access/download;Figure;Fig 2c.tiff

Figure 2d

Click here to access/download;Figure;Fig 2d normal position 32CH.tif

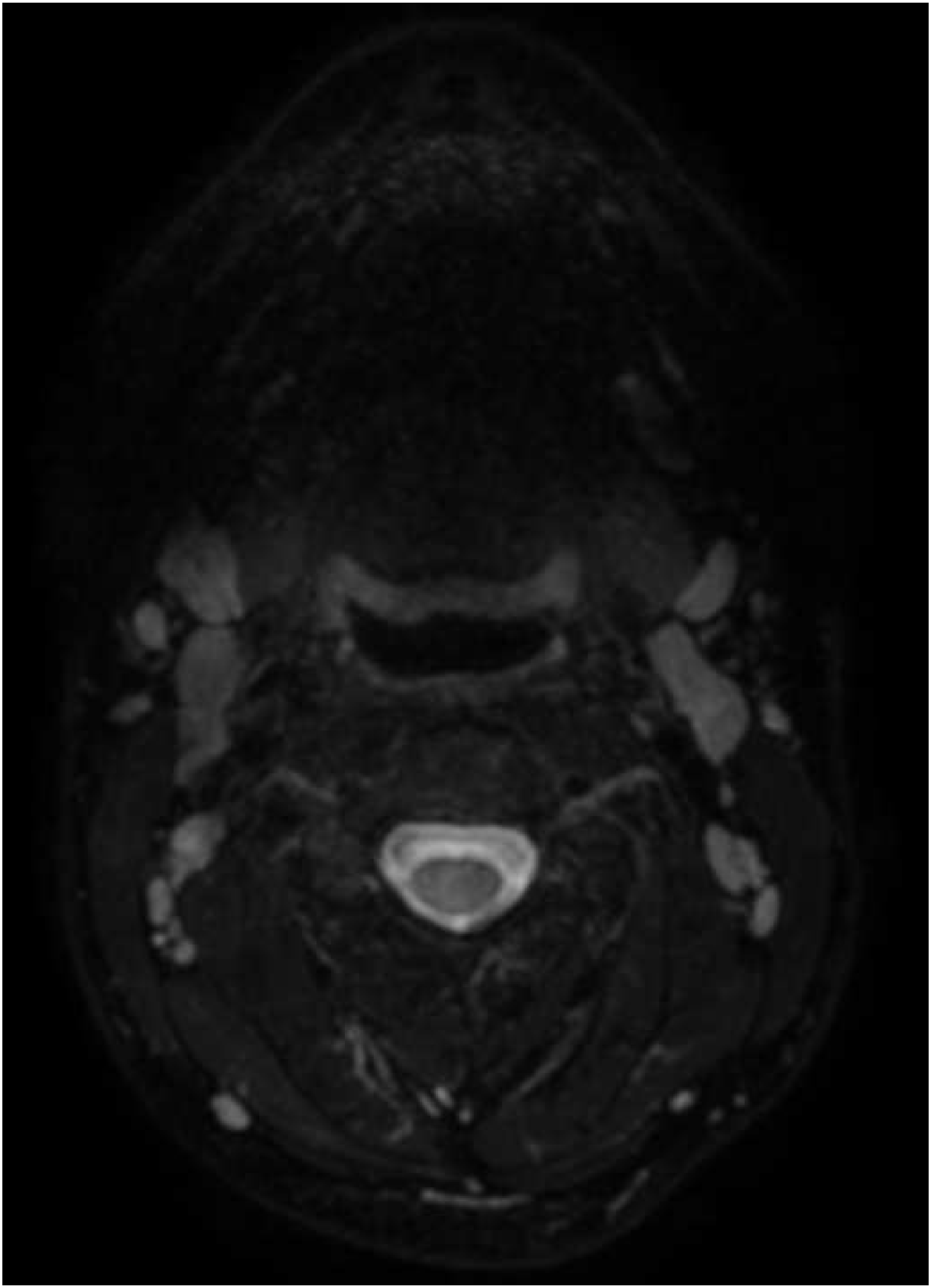


Figure 2e

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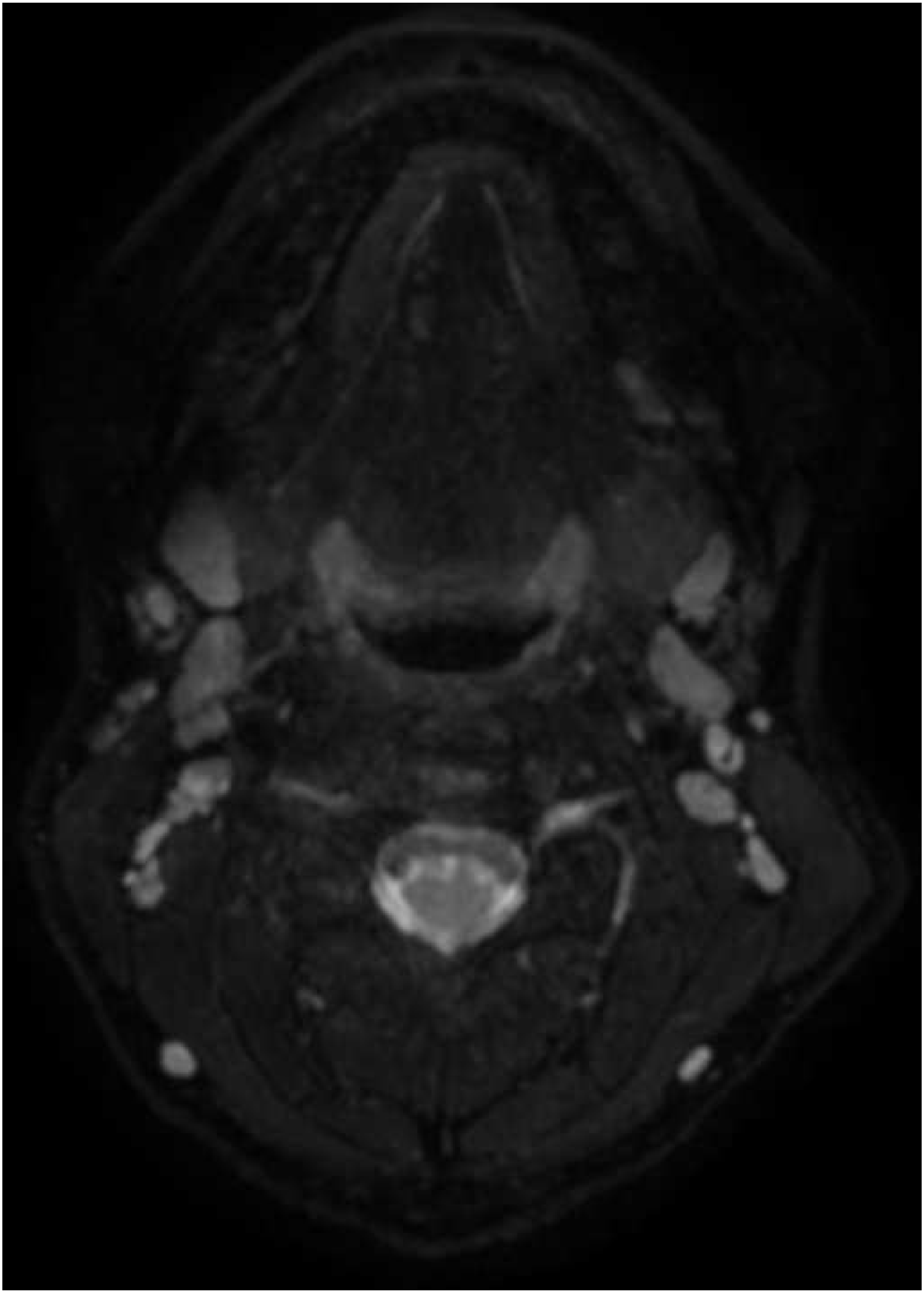

Figure 2f

Click here to access/download;Figure;Fig 2f normal position neck coil.tif

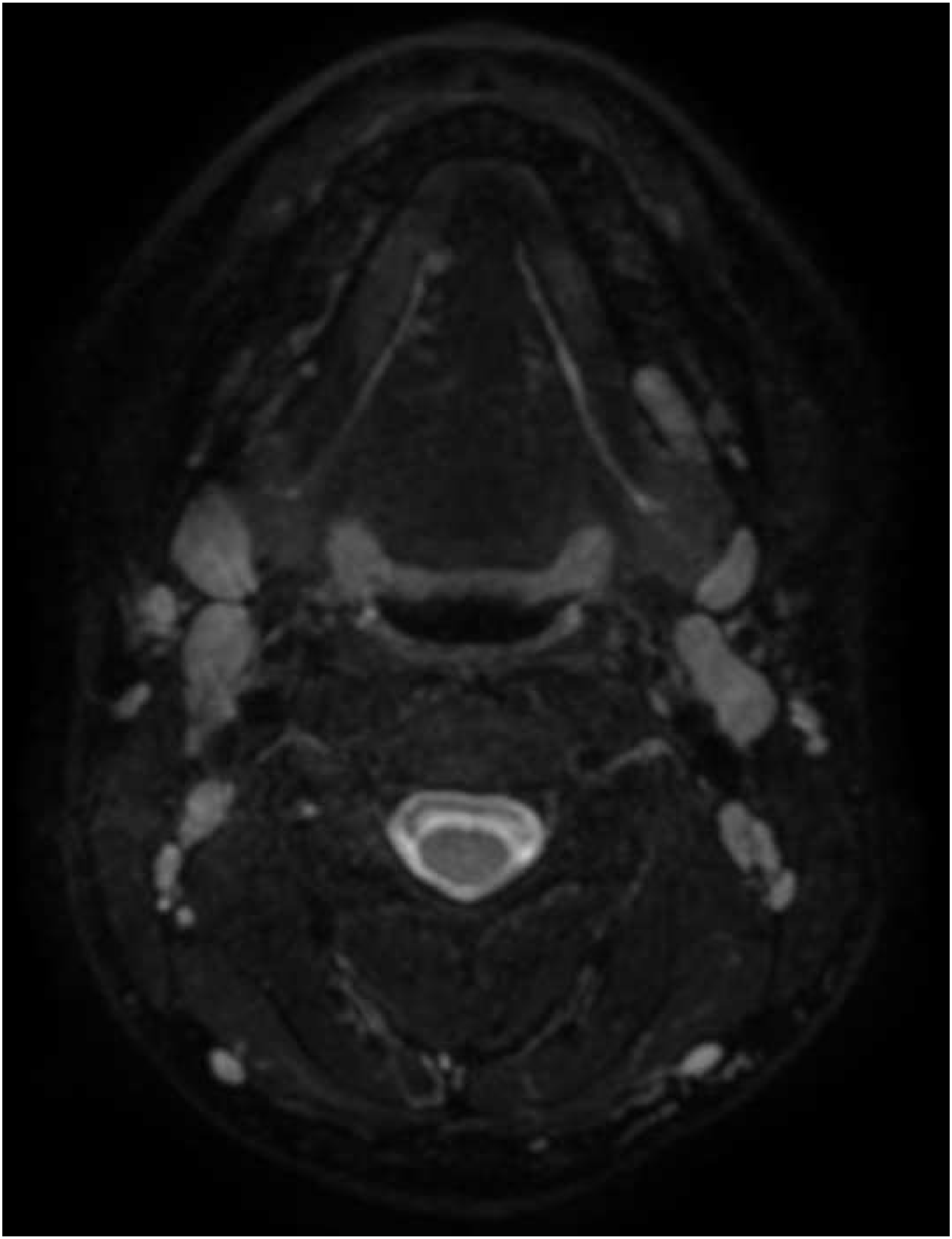

Figure 3a

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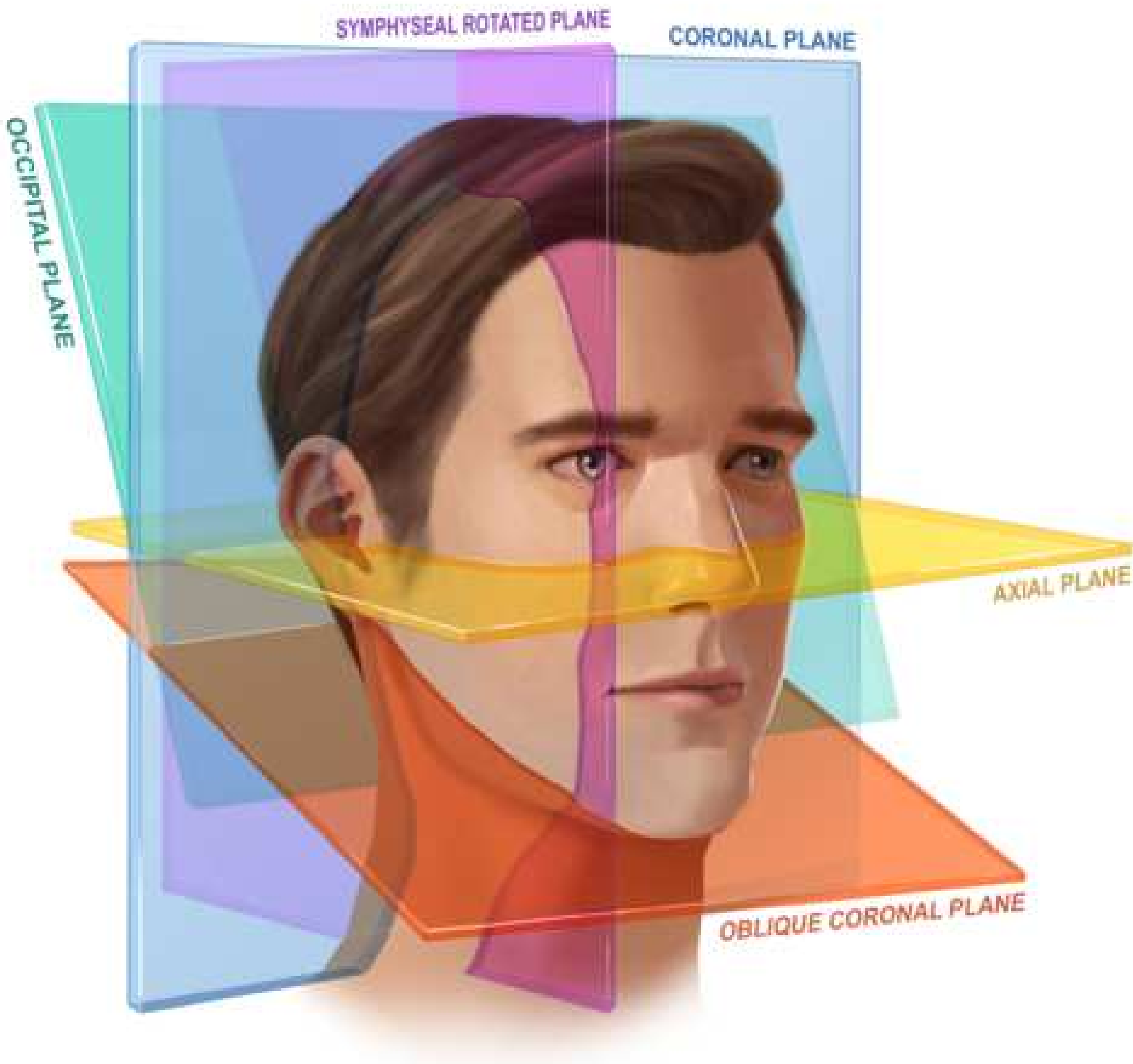

Figure 3b

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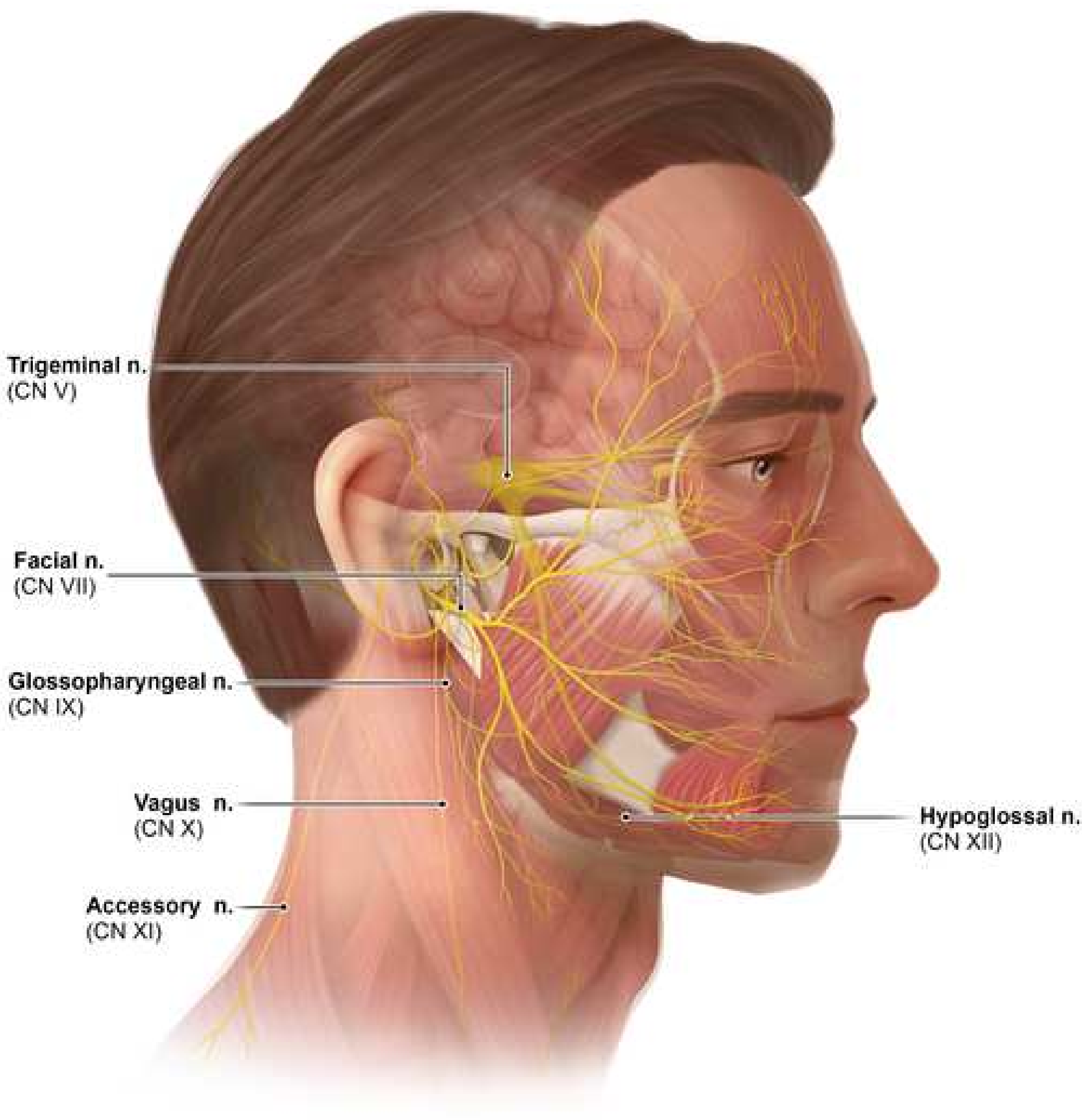

Figure 4a

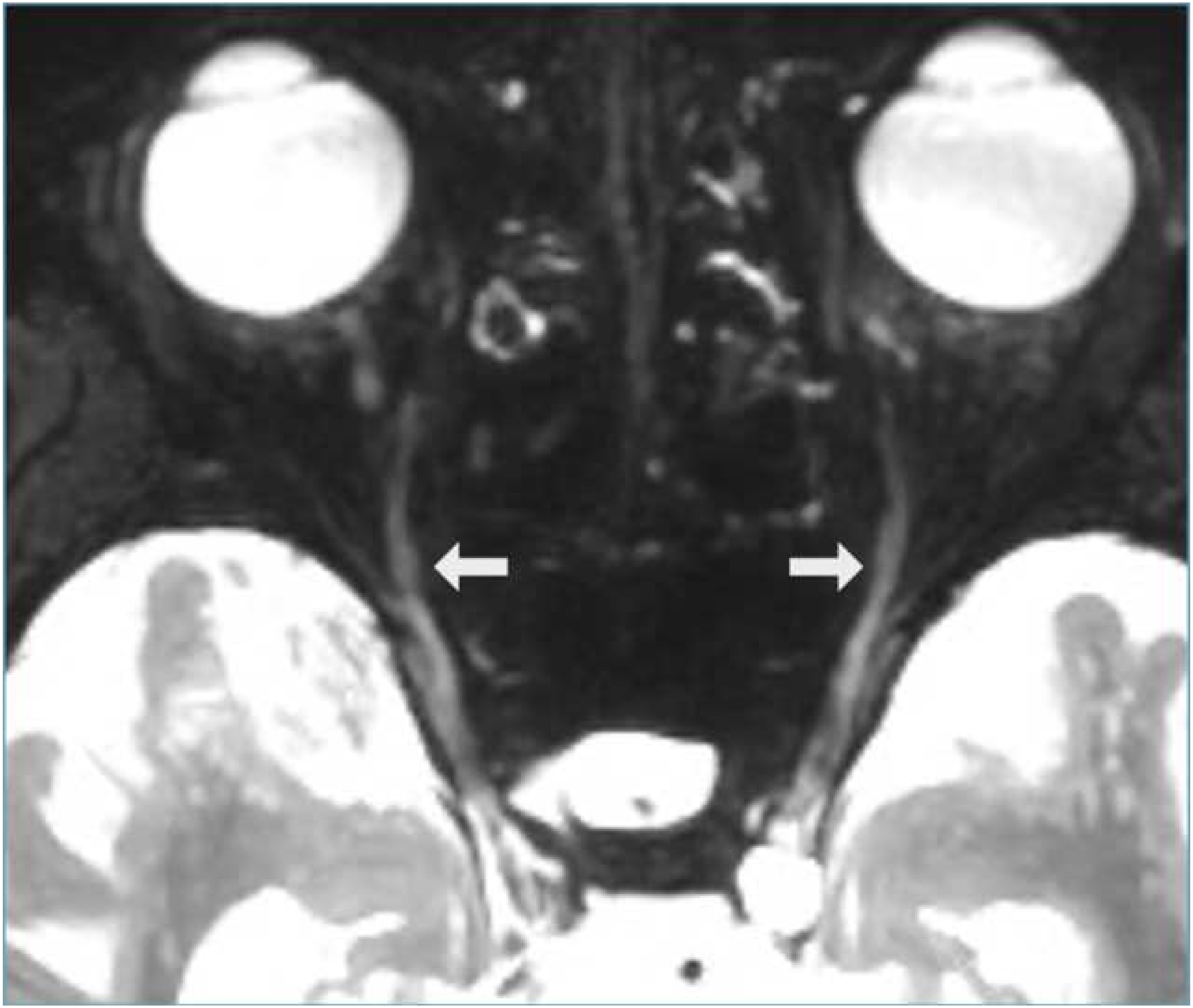

Figure 4b

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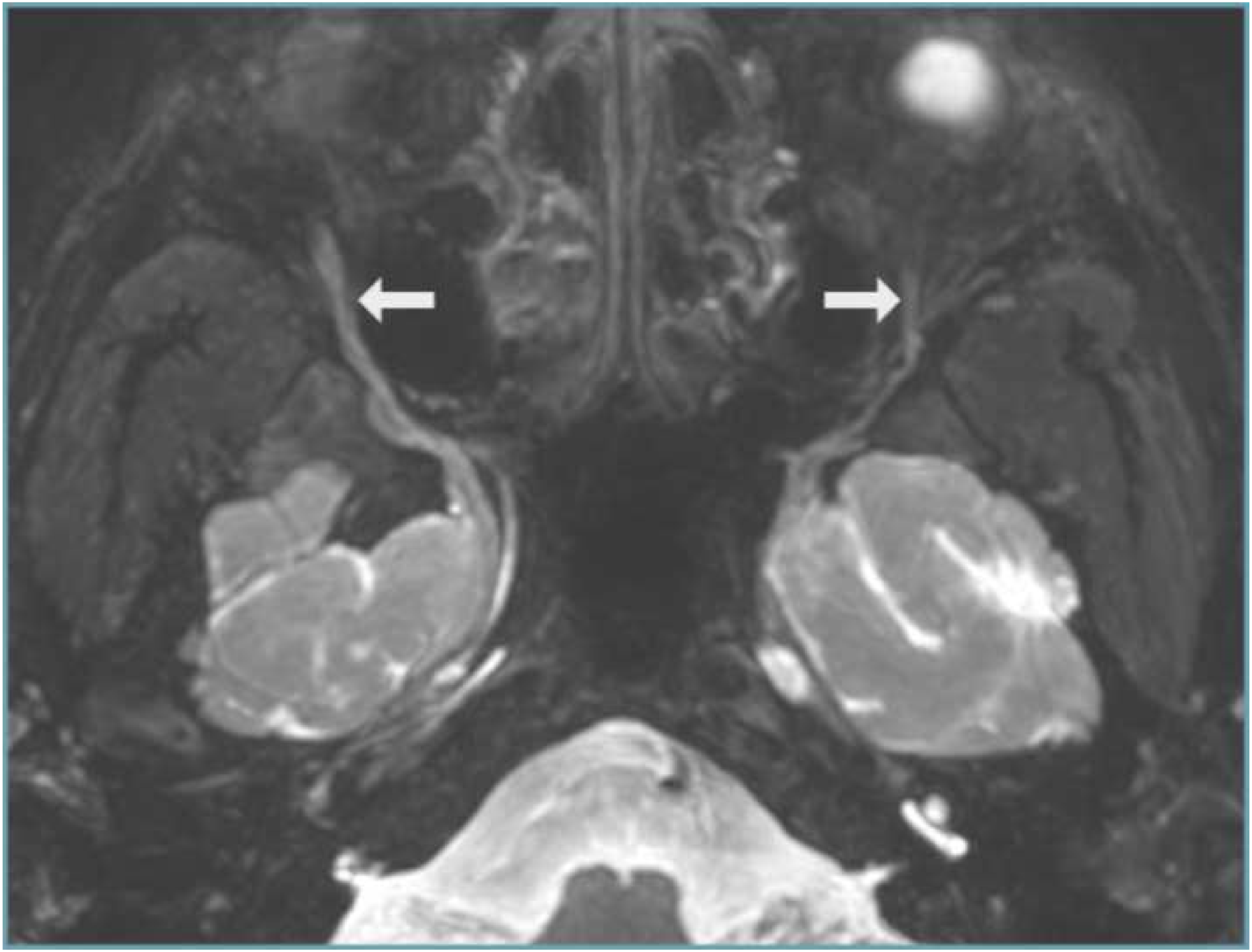

Figure 4c

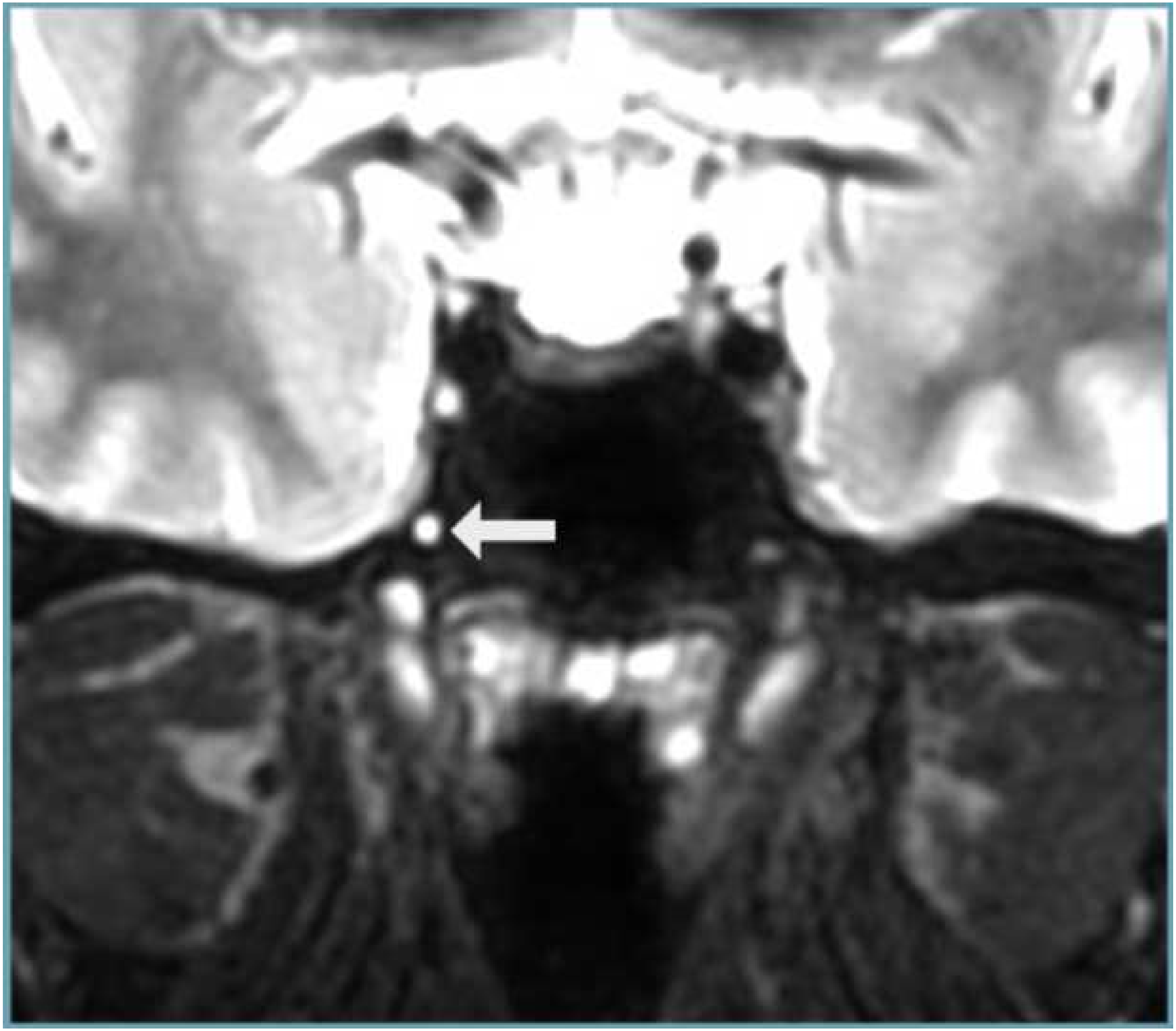

Figure 5a

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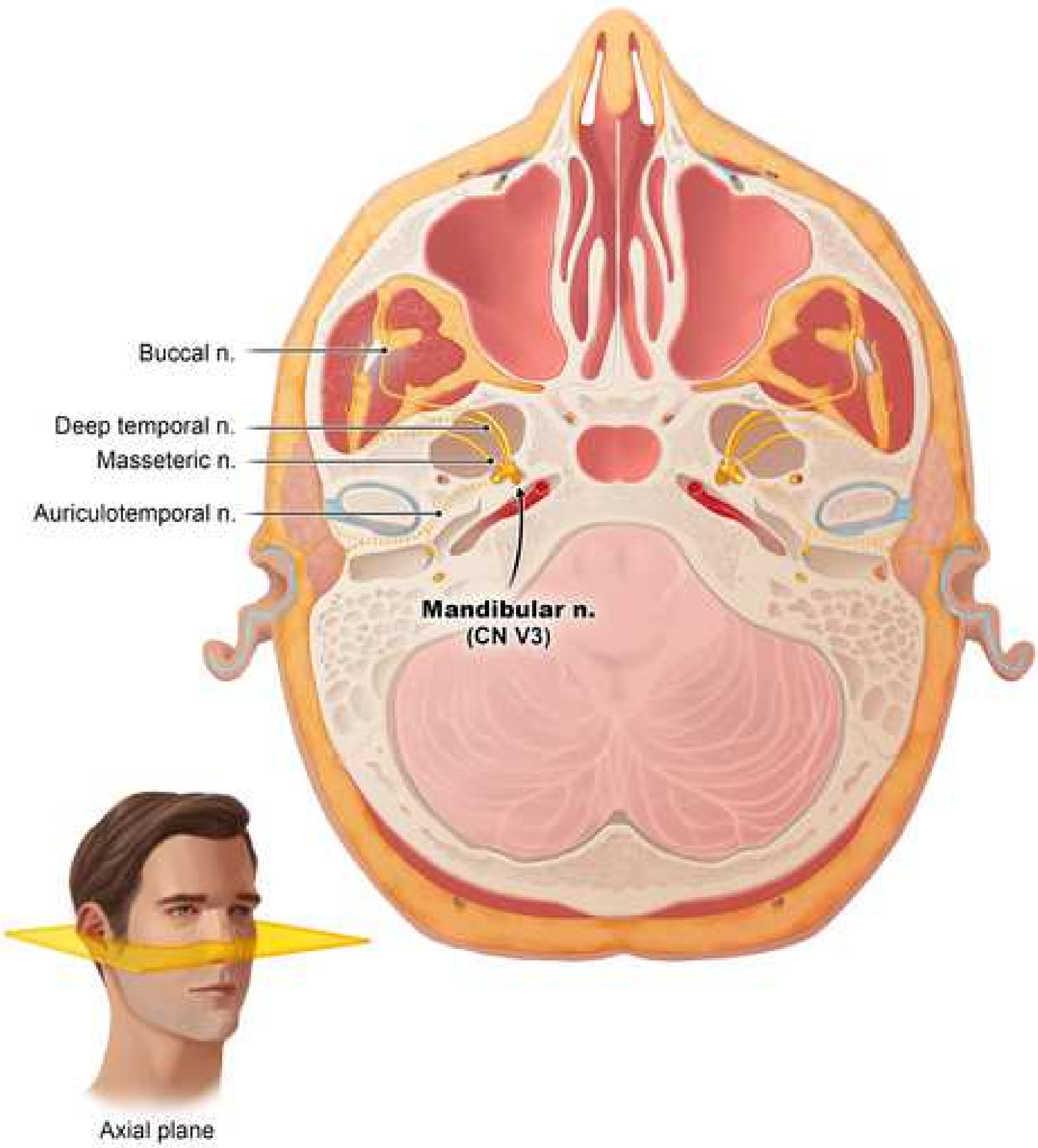

Figure 5b

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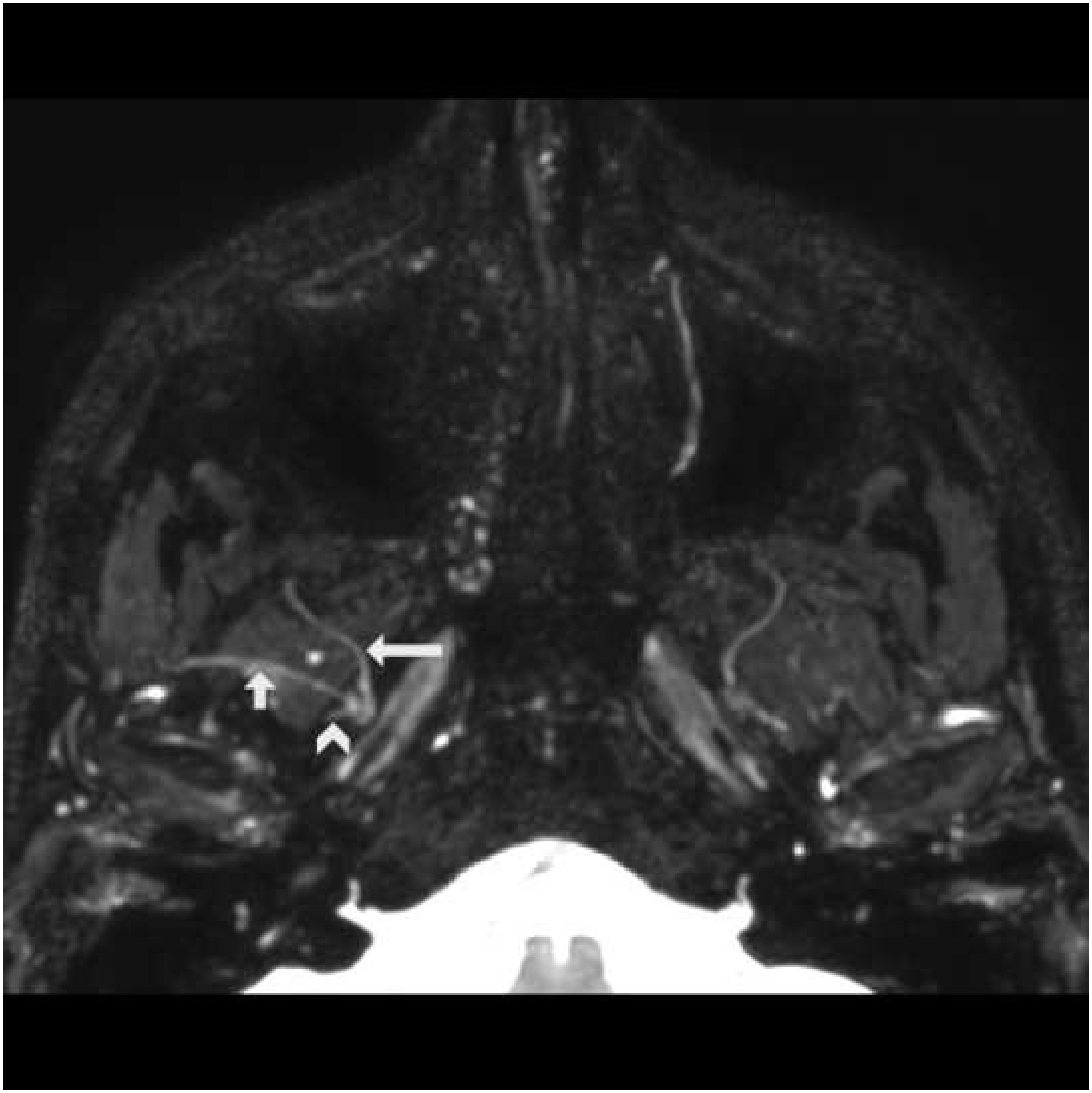

Figure 5c

Figure 6a

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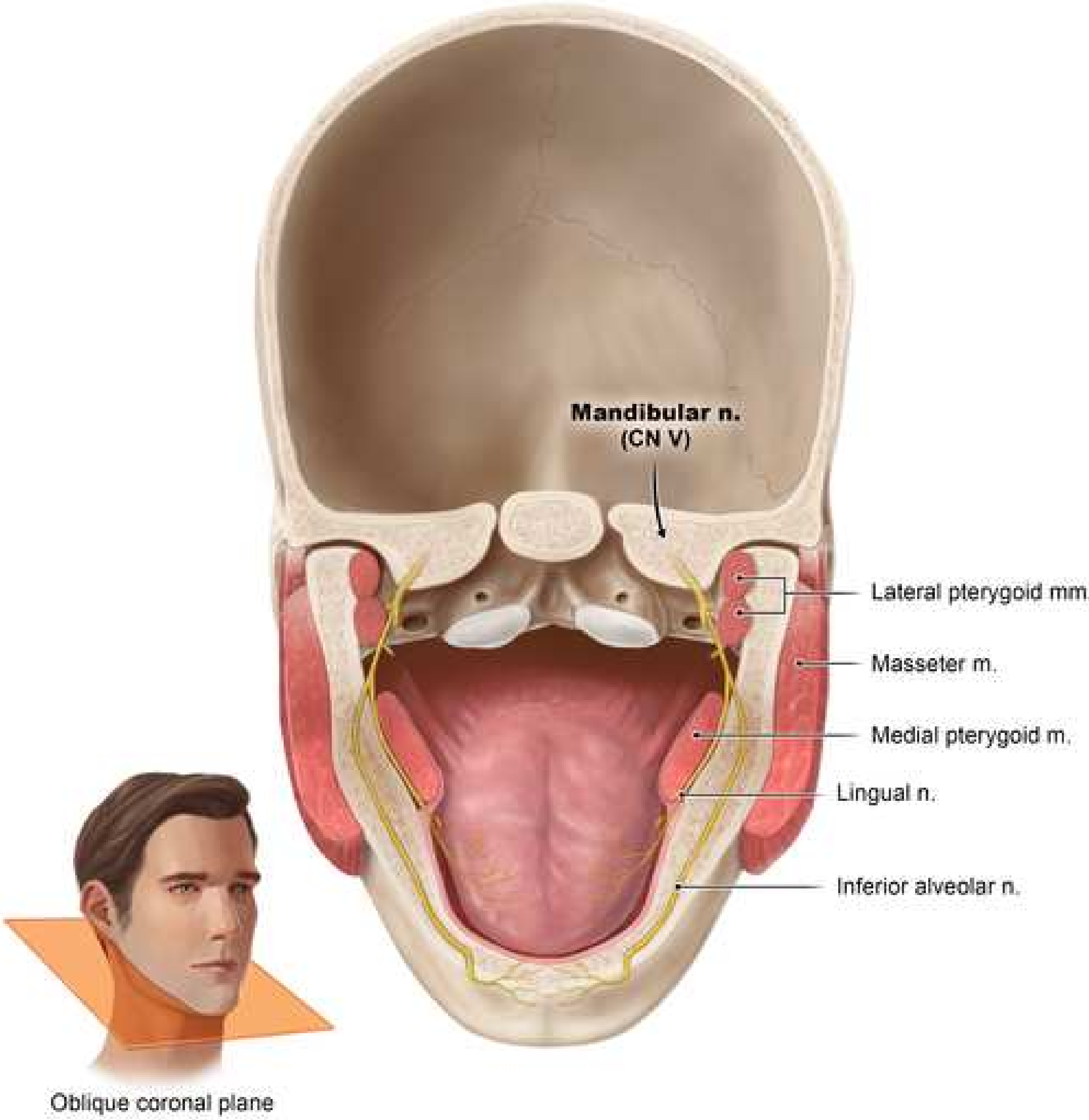

Figure 6b

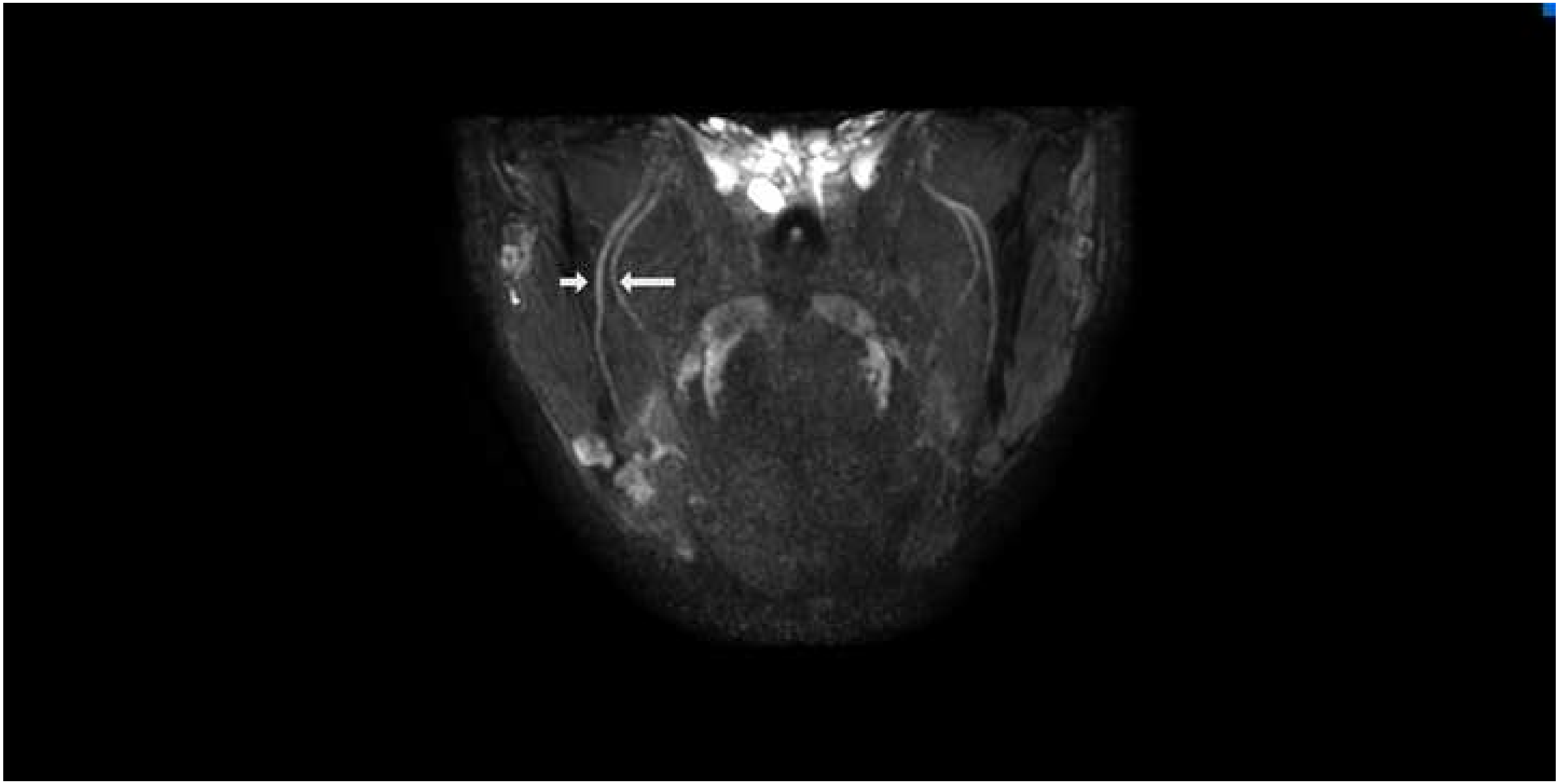

Figure 6c

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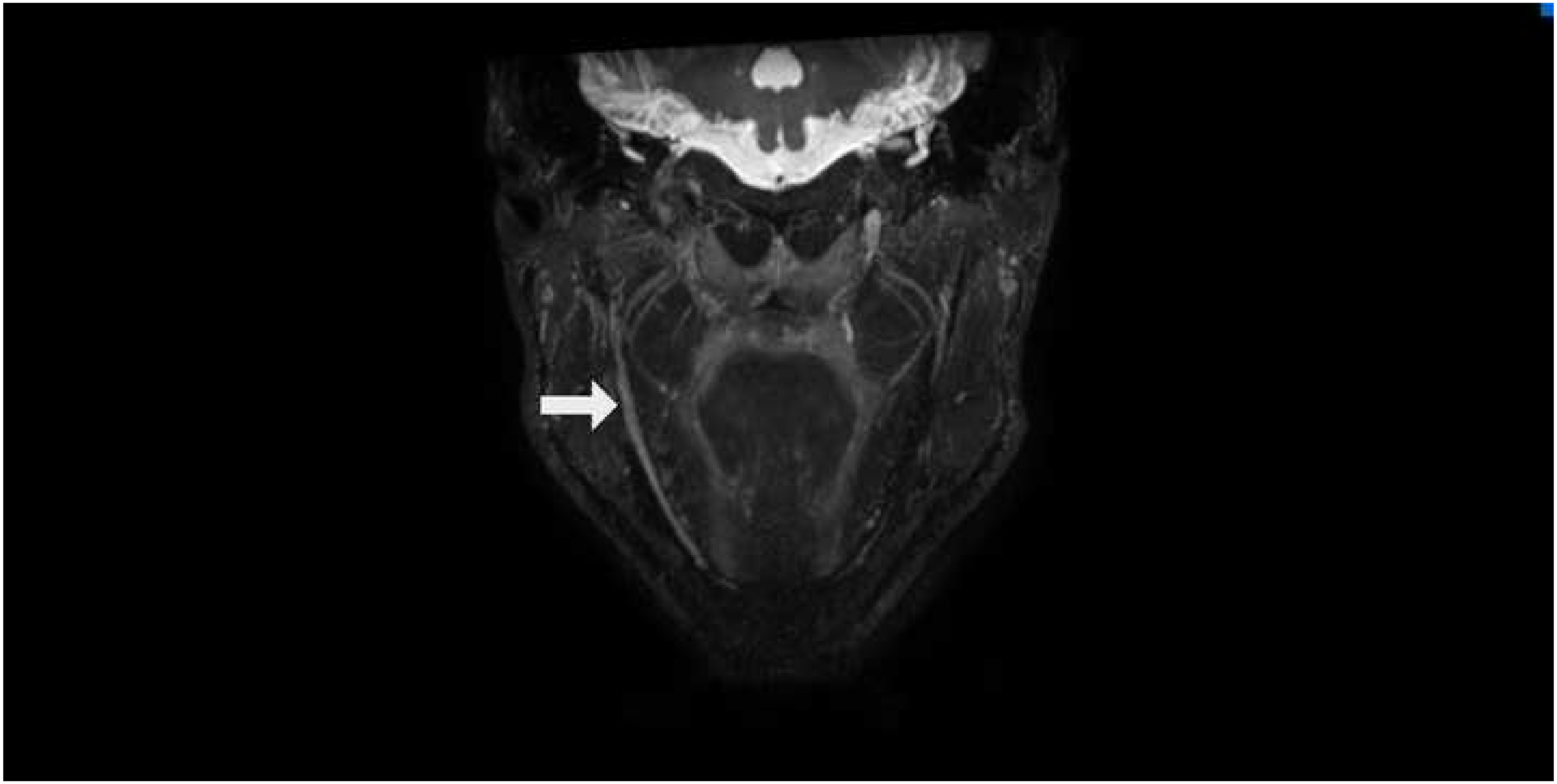

Figure 6d

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Figure 7a

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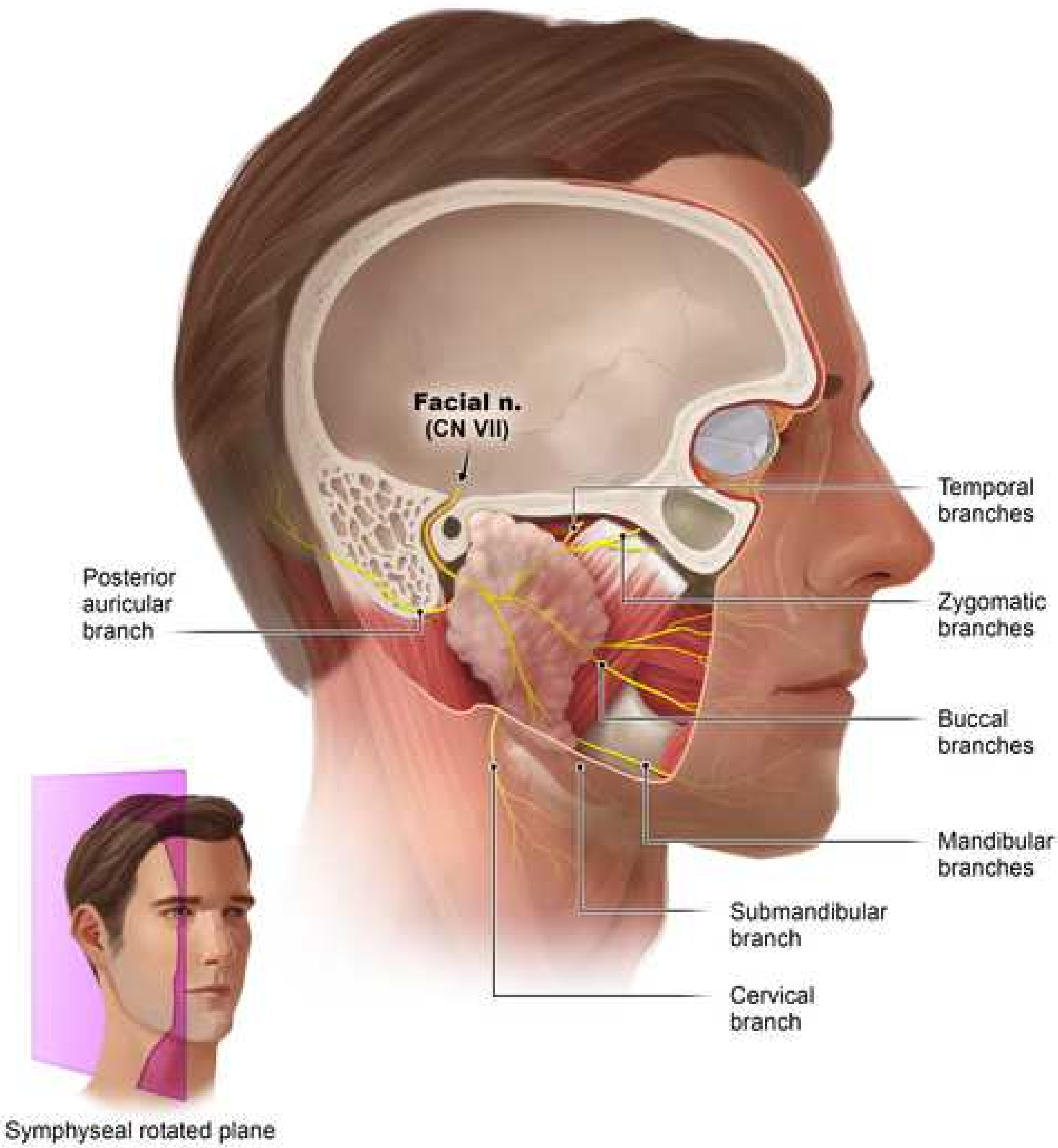

Figure 7b

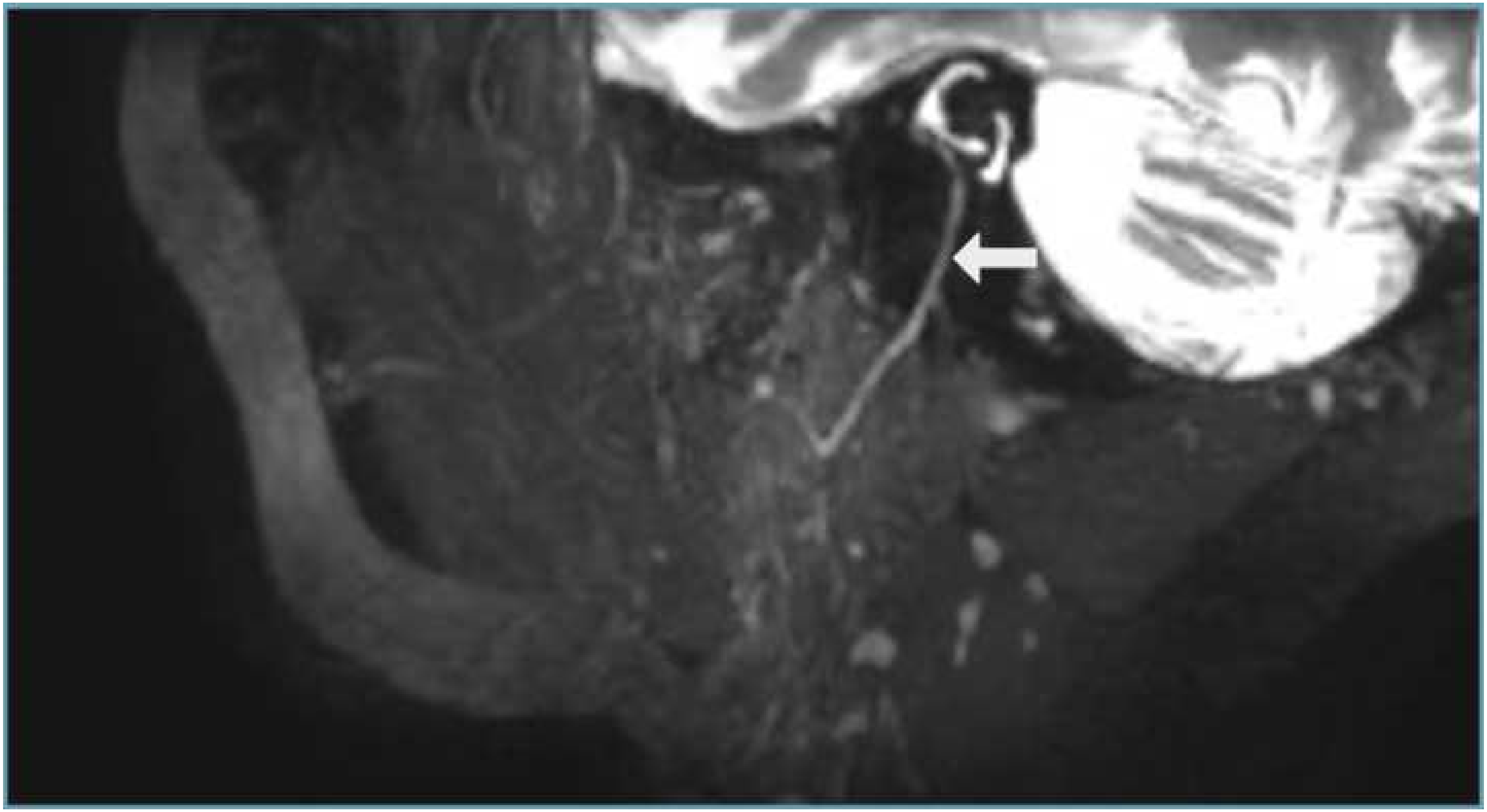

Figure 7c

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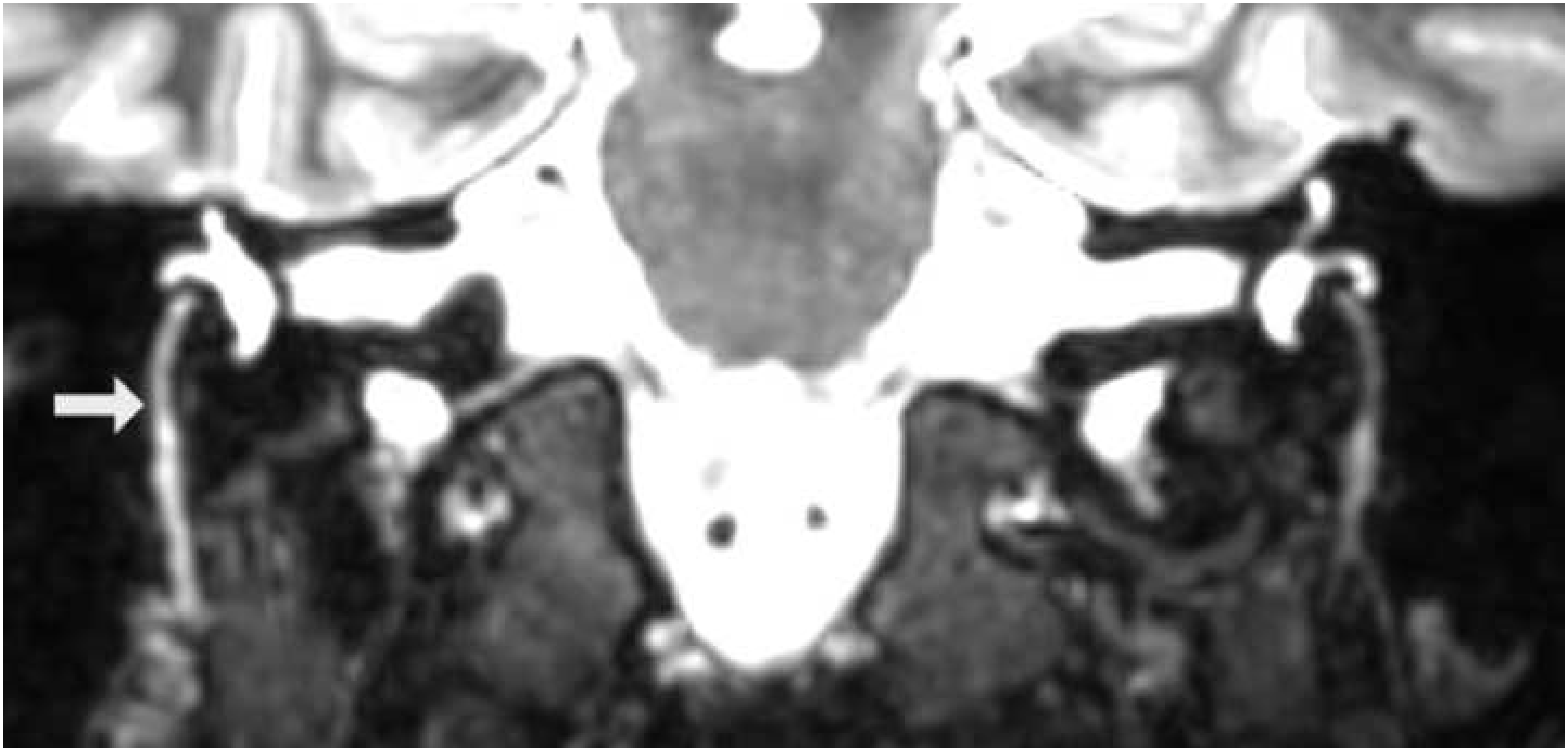

Figure 8a

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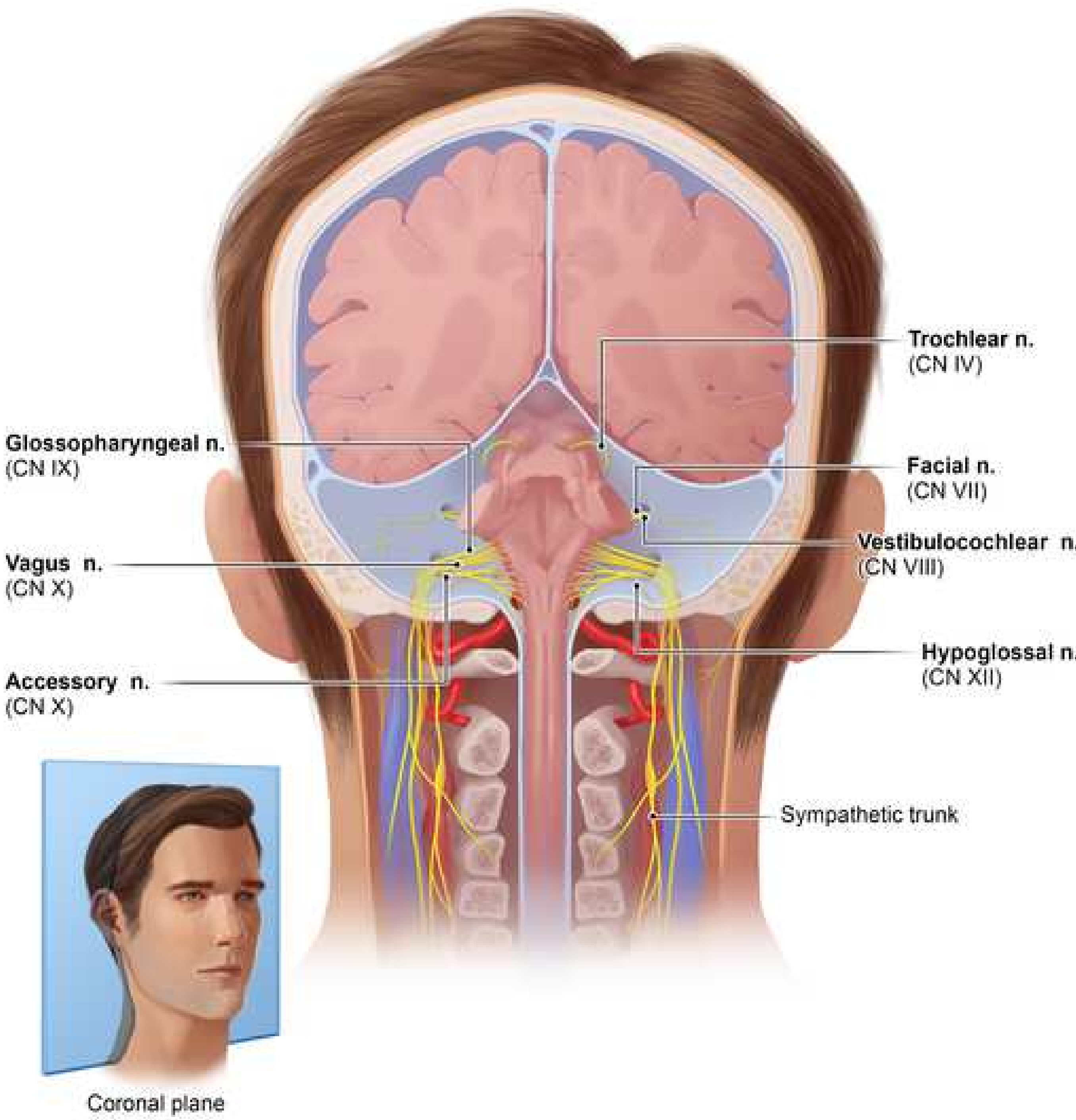

Figure 8b

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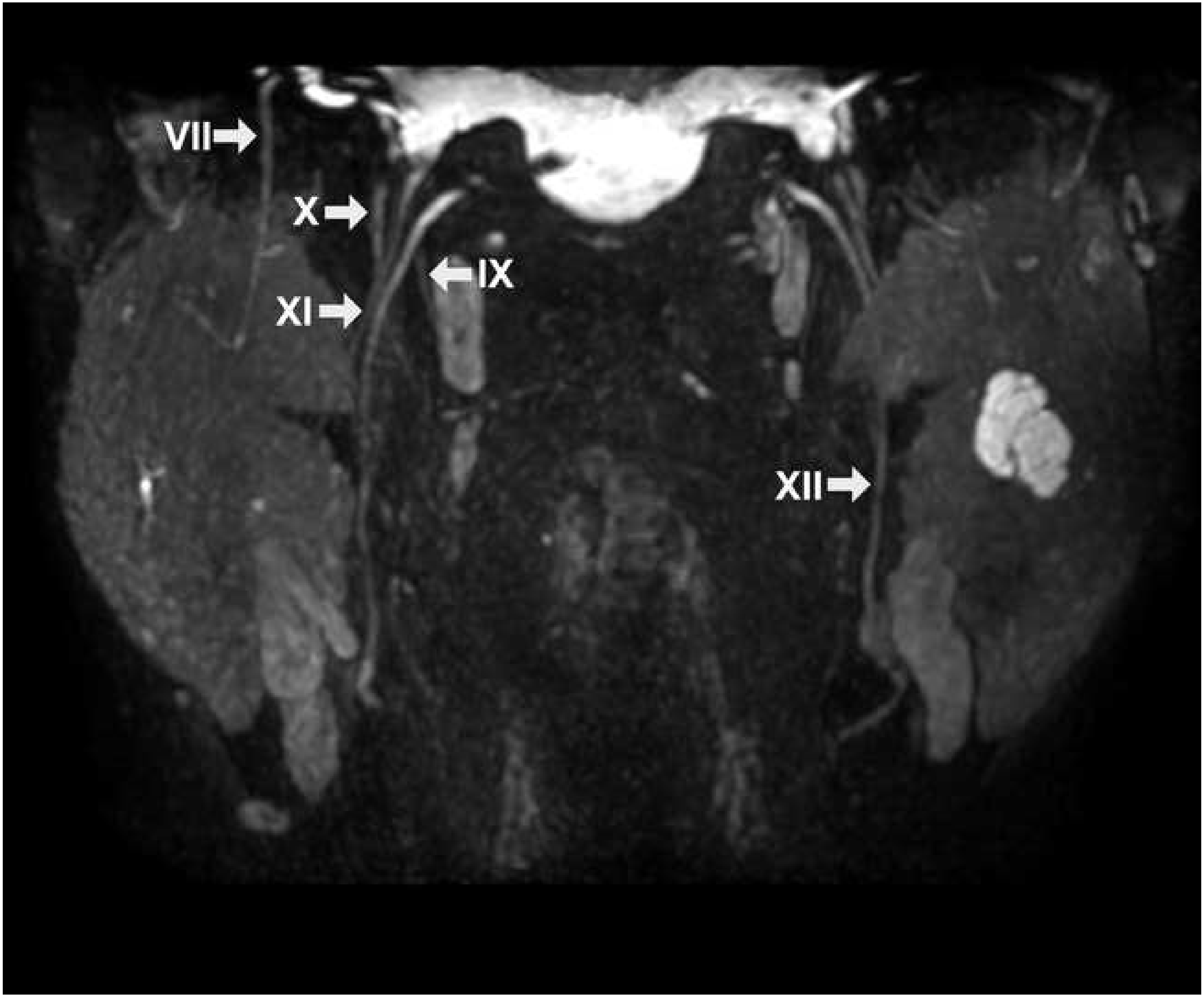

Figure 9

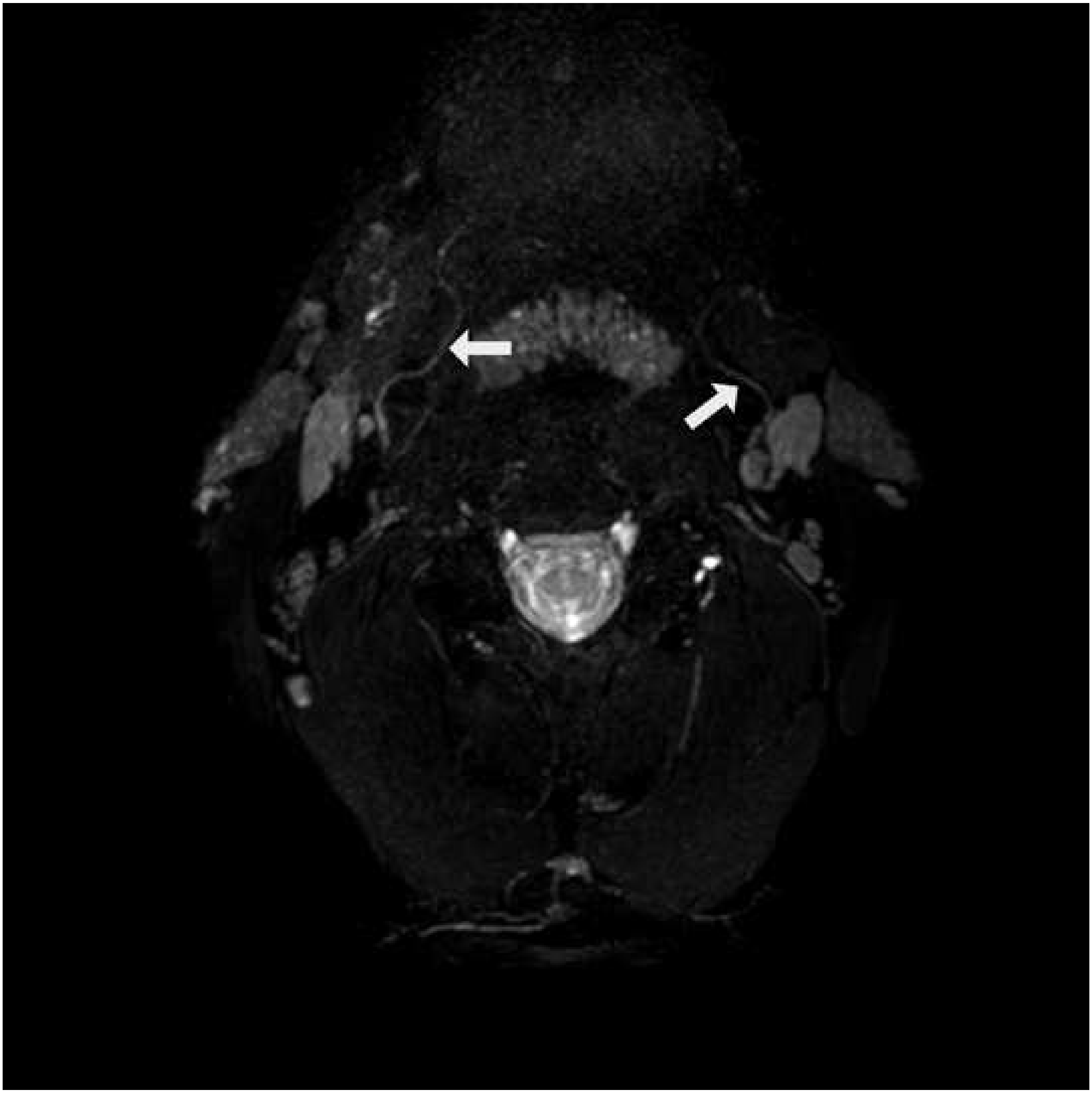

Figure 10a

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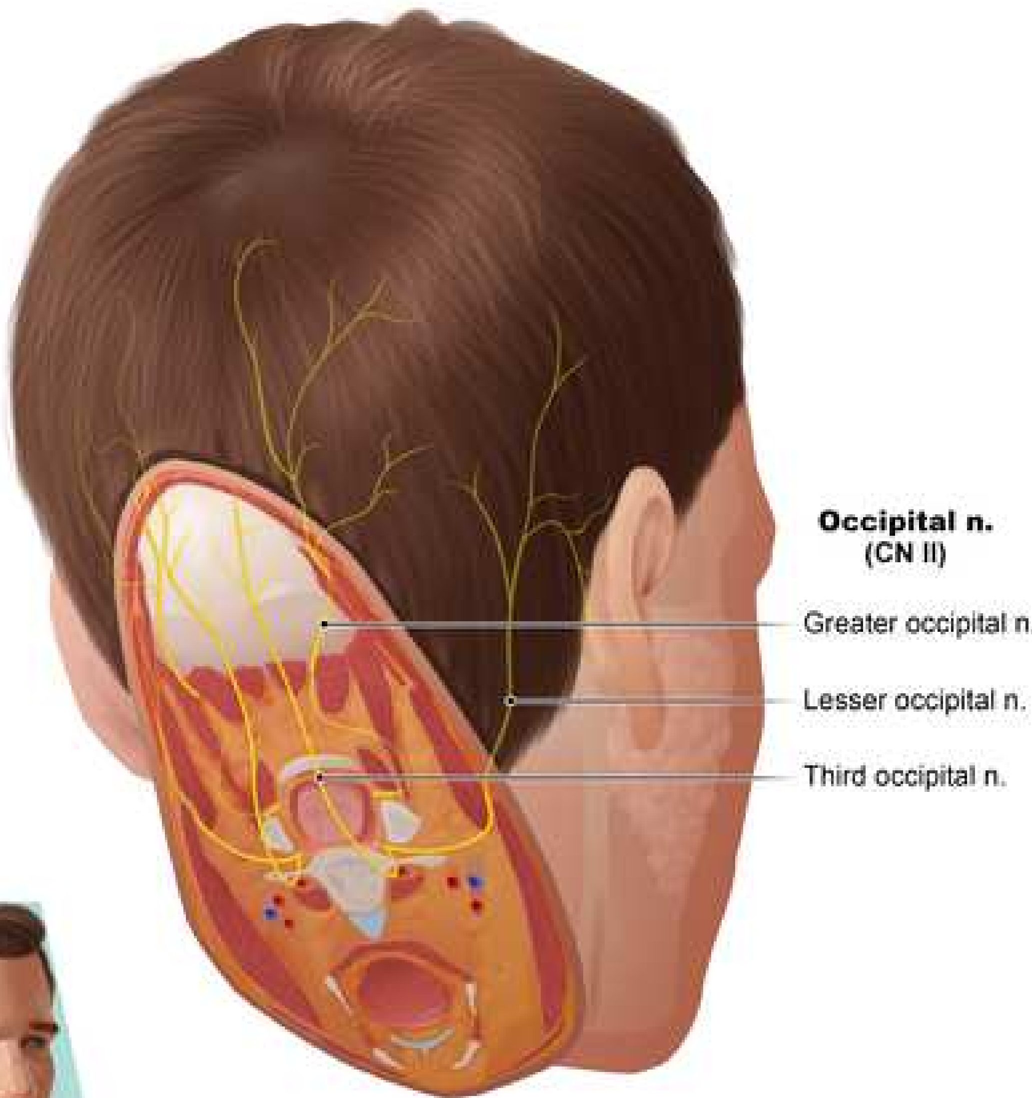
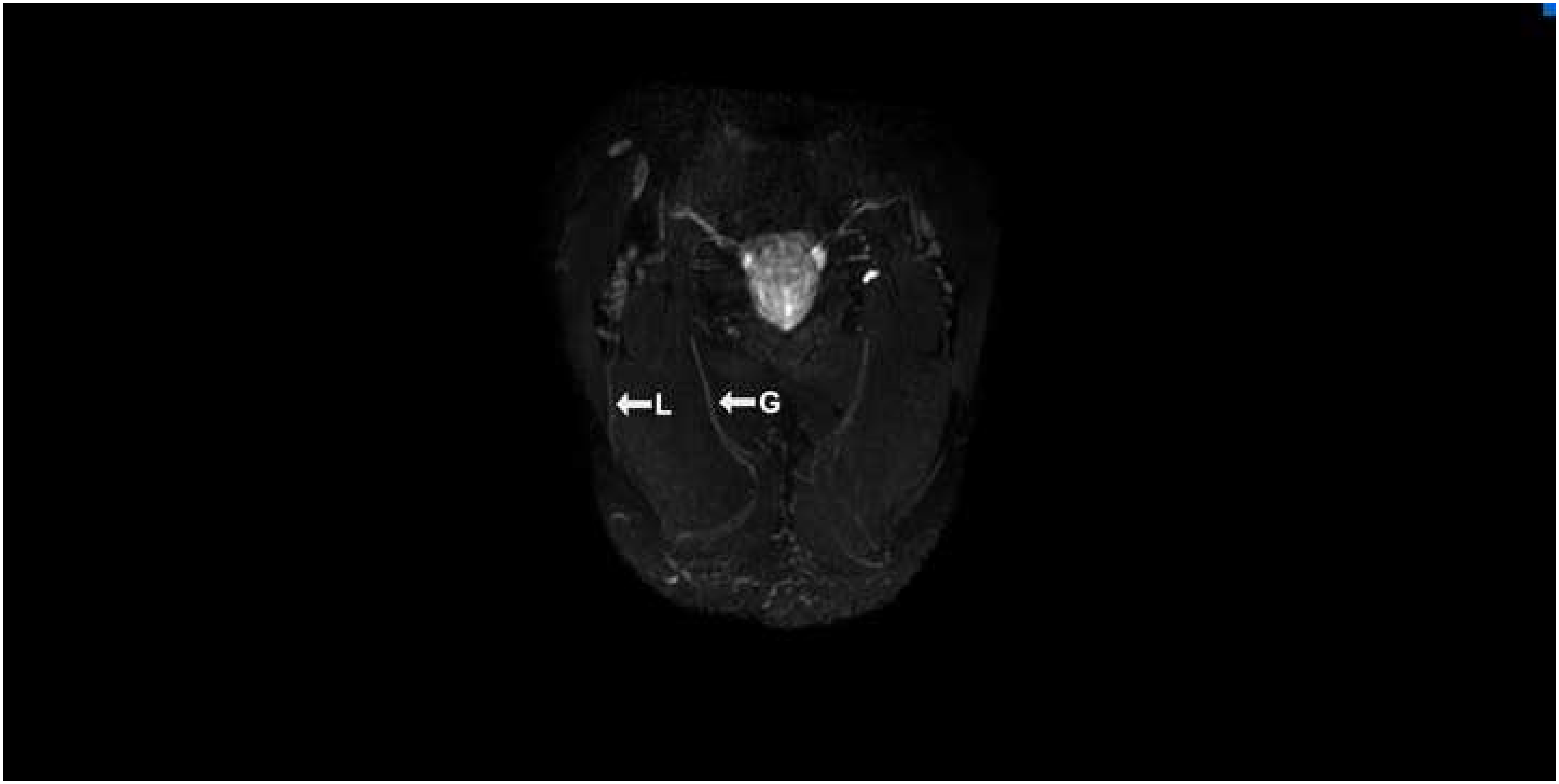


Occipital cross section

Figure 10b

Click here to access/download;Figure;Fig 10b Occipital All.tiff

Figure 10c



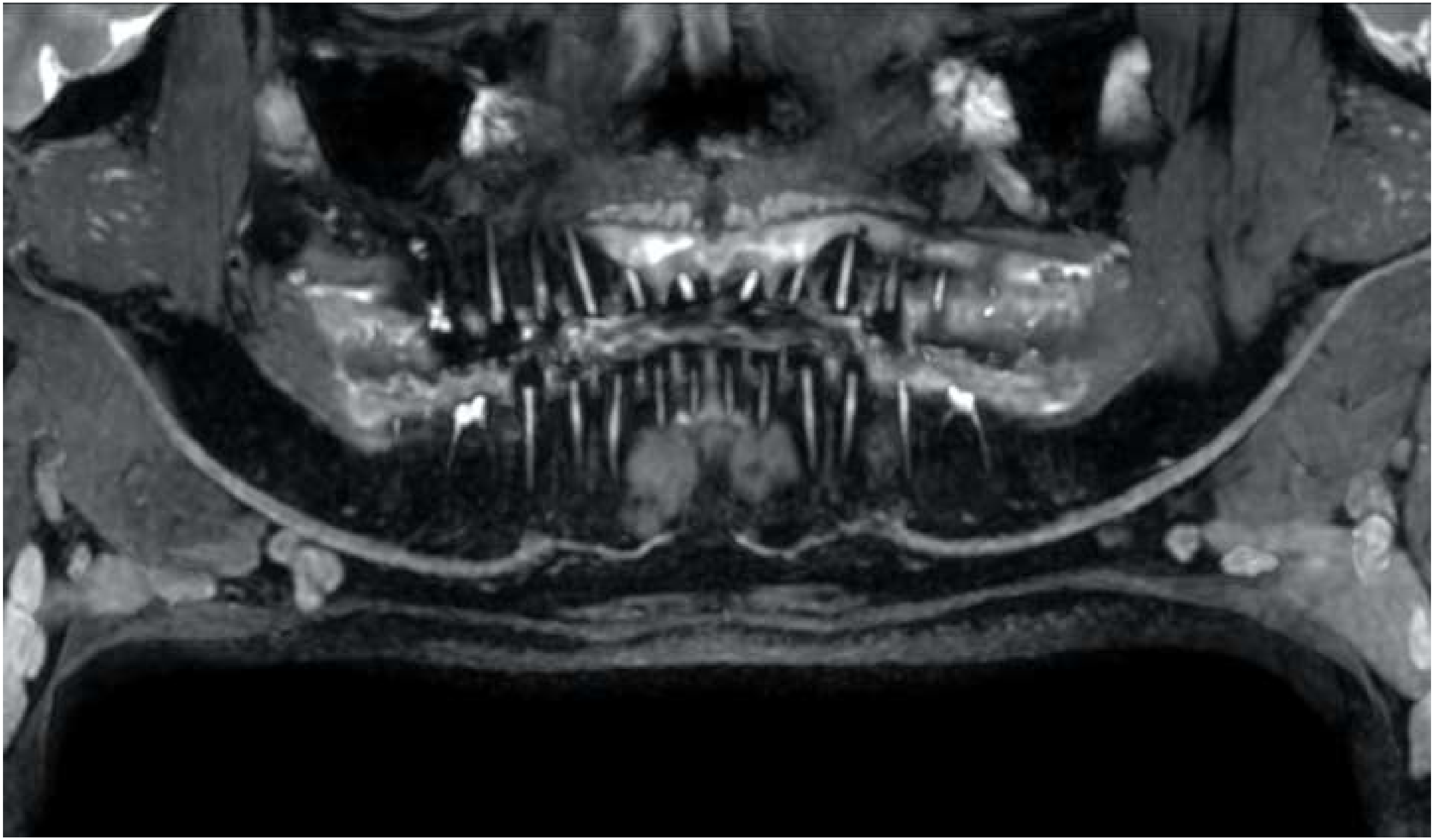


Figure 12

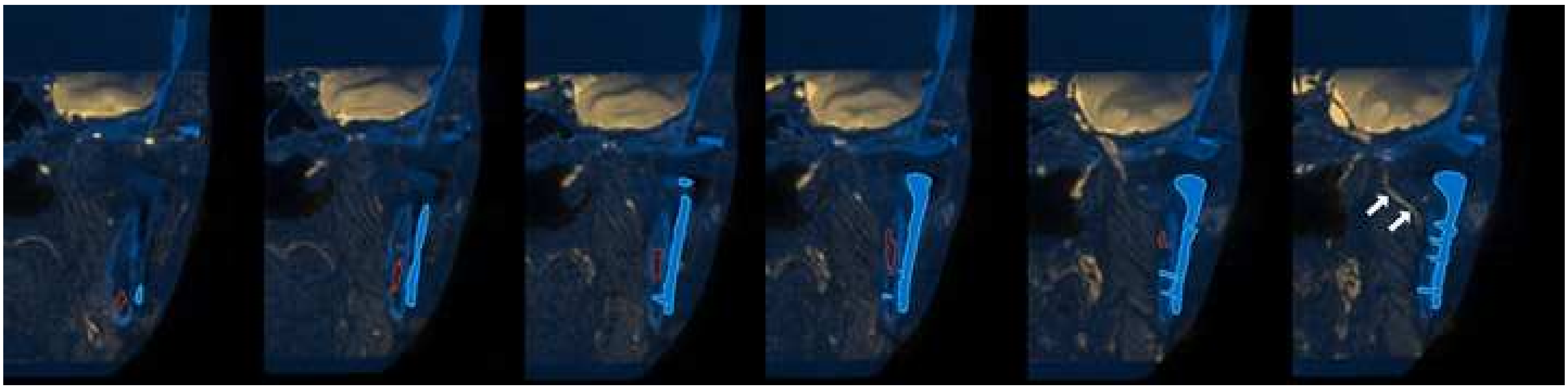


Table 1

	3D CRANI	**3D PSIF**
Basic MRI technique	3D STIR	3D FFE
TR/TE (msec)	2300/188	12/2.5
Slice thickness (mm)	0.5	0.45
FOV (mm)	200	200
Voxel size (mm)	0.9 isotropic	0.9 isotropic
Acquisition time (min:sec)	5:17	6:45
Compressed sensing	Yes	No
Flip angle	N/A	35°
Fat suppression technique	MSDE	Proset

Video

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