REVIEW ARTICLE

Magnetic resonance imaging in head and neck radiodiagnosis: An overview

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Keywords
Head and neck, magnetic resonance imaging, pathology, radiodiagnosis

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Received 06 May 2015;
Accepted 13 Jun 2015

doi: 10.15713/ins.jmrps.24

Abstract

"Necessity is the mother of invention"... so goes the age old adage. The insight into the human body has always fascinated man. When diseases and disorders went beyond comprehension, man invented imaging to learn more about the internal architecture of the body. The zeal to gain more information about the underlying disease process compelled researchers, to seek out for the better imaging modalities could help eliminate the drawbacks of conventional imaging and at the same time provide accurate visualization of the internal body structure. With the introduction of high field magnets, advancements in operational procedures through the evolution of hardware and software and the ability to image hyperpolarized nuclei of He^3 and Xe^{129} in addition to H atoms, the arrival of magnetic resonance imaging (MRI) in the early 1970's has been revolutionary. An increased knowledge base over the years has provided a better understanding of how it can best be utilized, either alone or in conjunction with other techniques, in order to maximize diagnostic certainty. Although its application was initially limited to the neuro-axis, it has now widened to cover all the regions of the body including the head and neck. The advantages of being a non-ionizing technique and at the same time providing excellent soft tissue resolution earmarks this imaging technique to particular situations in head and neck radiodiagnosis. Inflammatory and neoplastic pathologies affecting the salivary glands, nasopharynx, paranasal sinuses, lymph nodes, orbits, and intracranial structures are particularly amenable to MRI studies. Furthermore, such pathologies affecting the temporomandibular joint and its soft tissue counterparts are unambiguous candidates for a detailed MRI examination. In this backdrop, this paper aims at reviewing the various applications of MRI in the head and neck region. Actual MRI images of head and neck pathologies shall be presented accompanying the literature.

Introduction

Magnetic resonance imaging (MRI) is a powerful and versatile imaging modality utilized in various medical fields.[1] MRI provides a non-invasive tool to investigate the internal anatomy and physiology of living subjects.

With the emergence of commercial medical MRI in the 1980s, several MRI applications started to evolve in medical diagnostic imaging.[2]

MRI is based on spatially encoding a nuclear MR based signal.[3]

Principles of MRI

T1 is called as "spin-lattice" or "longitudinal relaxation time." It is a measure of the time required for protons to realign themselves with the field of the imaging magnet following a radio frequency (RF) pulse. T1-weighted image is produced by a short repetition time between RF pulses and a short signal recovery time. Since, T1 is an exponential growth time constant; a short T1 will produce an intense MR signal displayed as white in a T1 weighted image. A tissue with a long T1 will produce a low-intensity signal and appear dark on the MRI.

T2 is called as "spin-spin" or "transverse relaxation time." It is the time required for the tissue proton to de-phase following an RF pulse caused by magnetic interactions when they are oriented perpendicular to the external magnetic field. A T2-weighted image is acquired using a long repetition time between RF pulses and a long signal recovery time. A tissue with a long T2 will produce a high-intensity signal and be bright in the image and one with a short T2 will produce a low-intensity signal and be dark in the image.[3]

Indications of MRI

In view of its excellent soft tissue contrast resolution, MRI is used in:

1. Evaluating soft tissue conditions such as the temporomandibular joint (TMJ) disk
2. Evaluating soft tissue disease, especially soft tissues neoplasms
3. Determining malignant lymph node diseases; and determining perineural invasion
4. Visualize edematous changes in the fatty marrow, as well as the surrounding soft tissue
5. Identifying the location of the mandibular nerve
6. Revealing the extent of penetration of carcinoma into the cortex of the mandible
7. The technique of mid-field MRI for pre-surgical dental implant assessment using a one-tesla scanner has been recently described
8. Visualization of dental caries, pulp, and periapical structures in the three spatial dimensions.[1,4,5]

Contraindications of MRI

1. Vascular clips: A ferromagnetic vascular clip can have concerns with MR-associated heating
2. Foreign bodies: Shifting of metal foreign bodies under the influence of the magnetic field could damage vital structures and can induce artifacts
3. Coronary and peripheral artery stents/aortic stent grafts: The effect of heating induced by the RF field might cause artifacts, which can impair the evaluation of stent itself
4. Prosthetic heart valves and annuloplasty rings: There are some minor interactions with the magnetic field. Sternal wires are usually made of stainless steel or alloy and are not a contraindication to MRI
5. Cardiac occluder devices/vena cava filters and embolization coils: They may induce occlusion of vessels when subjected to MRI. Therefore, MRI examination should be deferred until 6 weeks after implantation
6. Hemodynamic monitoring/support devices and temporary pacing devices: During an MRI examination RF pulses might induce currents that could lead to thermal injuries
7. Permanent cardiac pacemakers and implantable defibrillators and retained transvenous pacemaker: Are contraindicated because of the potential for device dislodgement, programing changes, asynchronous pacing, activation of anti-tachycardiac therapies, as well as due to heating and cardiac stimulation
8. Permanent contraceptive devices: Intrauterine contraceptive devices are made of either non-ferromagnetic material (plastic) or weak ferromagnetic material metal components, typically with copper. Therefore, heating and displacement might be the consequence of MRI
9. Cochlear implants: Contraindicated as the force and torque induced by the magnetic field of the MRI represent a hazard for the implant.[6,7]

Advantages of MRI

1. It offers the best resolution of tissue of low inherent contrast. The X-ray attenuation co-efficient may vary by no more than 1% between soft tissue, the MR parameters spin intensity and T1 and T2 relaxation times may vary by up to 40%
2. Non-ionizing radiation: RF pulses in MRI will not cause ionization and has no harmful effects, hence can be used in females and children
3. Non-invasive: MRI is non-invasive
4. The main advantage of MRI is contrast resolution, wherein image process will differentiate adjacent soft tissue from one another. Contrast resolution of different tissues can be manipulated by altering the pattern of radiofrequency pulses
5. Multiplanar image: With MRI, we can obtain direct, sagittal, coronal, and oblique image
6. The histopathological phases of acute, chronic, and the transit to the fibrous phases can be simultaneously differentiated
7. Artifact associated with dental filling is absent
8. The high contrast level available in MRI make the use of contrast agents unnecessary in most cases
9. No adverse effects have been reported
10. Manipulation of the image is possible
11. Useful in determining the intramedullary spread.[3,4,8]

Disadvantages of MRI

1. Claustrophobia, i.e., fear of closed places since the patients are within the large magnet
2. MRI apparatus are expensive to purchase, maintain, and operate
3. As the strong magnetic field used for imaging the patient are electrically and mechanically activated, patients with implants, cardiac pacemakers, implanted defibrillators, and prosthetic cardiac valves are not safe for MRI
4. The presence of metals such as surgical clips, aneurysm stents, etc., becomes distorted due to the magnetic field, so MRI image becomes distorted
5. Signals are obtained only from the bone marrow, but bone does not give MR signal
6. Strong magnets used in MRI can be a serious threat to the placement of equipment even with advanced shielding
7. The scanners used in MRI create loud noise
8. MRI fails to differentiate between benign and malignant tumors or disease process
9. Bone, teeth, air, and metallic objects all appear black, making differentiation difficult.[3,4,8]

MRI Imaging of the Head and Neck

Lymph nodes

The evaluation of cervical nodes is important for diagnosis and staging of malignant diseases, differentiating from infectious diseases and treatment planning.[9] According to several studies, the use of lymph node characteristics such as homogeneity, margins, and shape, as diagnostic criteria do not improve the accuracy of conventional MRI to discriminate between benign and metastatic lymph nodes. MRI, because of its high contrast resolution and multiplanar capacity, has advantages over computed tomography (CT) for tumor staging. The reported sensitivity of MRI for detecting lymph node metastases is 36-94% and specificity is 50-98%. Central nodal necrosis is the most reliable radiologic criterion. This area may represent true necrosis, residual lymphoid elements, or tumor deposits. On T2-weighted MRI, a focal area of both high and intermediate signal intensities is characteristically shown. Nodal necrosis can be either hyperintense (indicating cystic necrosis) or hypointense (indicating keratinization). Macroscopic extra nodal tumor spread can be indicated on MRI when the affected node exhibits an irregularly enhanced rim or infiltration of the adjacent fat planes.[10] On T1-weighted images, lymph nodes and tonsils have low intensity and intermediate-high signal intensity on T2-weighted images with fat suppression. MRI with diffusion-weighted imaging is a non-invasive technique that measures the motion of water in the extracellular spaces and aids in the differentiation between benign and malignant nodes [Figure 1].[11]

TMJ

TMJ imaging is challenging as the mandibular condyle is relatively small and located close to radiologically dense and complex anatomic structures. MRI produces cross-sectional multiplanar images without using ionizing radiation. It documents both soft and osseous tissue abnormalities of the joint and its surrounding structures. MRI is helpful to indicate the neoplastic, arthritic, and traumatic pathology around TMJ. Rapid scan MRI methods provide a good method for the functional imaging of the TMJ.[12] In MR of TMJ, the position of the articular disk is of utmost importance. The disk is made of fibrocartilage, has a low signal, in contrast to the adjacent synovium of the superior and inferior joint spaces, which has intermediate intensity.[3] The T1-weighted images best demonstrate osseous and disk tissues[4] and provides superior contrast and the better anatomical details.[3] The T2-weighted images may show a relationship between joint pain and joint effusion.[7]

TMJ MRI examination consists of both open and closed mouth views in the oblique sagittal plane, with the sections oriented perpendicular to the long axis of the condyle. Images may also be obtained in the coronal plane which makes easier identification of the lateral or medial disk displacement. The sagittal images are used to evaluate disk position with respect to the head of the condyle.[7]

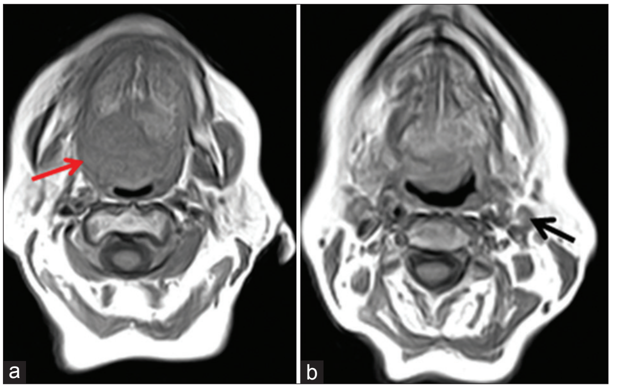

Figure 1: Axial T1 W magnetic resonance image of the neck in a known case of carcinoma base of tongue is showing hypointense mass in the base of the tongue (red arrow) and bilateral cervical lymphadenopathy (black arrow)

Volume imaging uses bilateral symmetrical surface coils. The entire volume of TMJ's are excited by the RF pulse with each image, but data are only collected from a narrow slice (3 mm) determined by an added phase gradient. The two common options for data acquisition are the two-dimensional or three-dimensional Fourier transform techniques (2-discrete Fourier transform [2-DFT] and 3-DFT). The main advantage of the 3-DFT technique is that it allows sections to be made as thin as 1.25 mm, compared to 2-3 mm with the 2-DFT technique[3] On MRI, disk is considered in position, when the posterior band is superior to the condyle (12 'O' clock position) in closed mouth position. In open mouth views, the disk is between the condyle and the articular eminence (normal or reducing) or remains the anterior to the condyle (non-reducing). Bone marrow abnormalities may also be detected by MRI. Abnormal signals on T2-weighted image from the condyle marrow indicate edema; a reduced signal indicates marrow sclerosis or fibrosis. A combination of marrow edema and sclerosis can be seen in osteoradionecrosis. Joint inflammation shows low signal because of hemorrhagic by-products, on T1- and T2-weighted MRI. In internal derangement, the T1 images show a hypodense biconcave disk between the condyle and eminence. Effusion, bone marrow edema, and soft tissue pathology are well visualized with T2 imaging.[7]

MRI images in various disk positions

Disk displacement

When the disk is chronically anteriorly positioned, the posterior attachment is pulled between the articulating surfaces of the condyle and temporal bone, and owing to resulting fibrosis, its tissue signal may become lower and approximate that of the posterior band. MRI is helpful to identify the position of the thin intermediate part of the disk to determine if it is anteriorly displaced from its normal position between the articulating surfaces of the condyle and articular eminence. Anteromedial displacement is indicated in sagittal image slices, when the disk is in a normal position in the medial images of the joint but anteriorly positioned in the lateral images of the same joint. Medial or lateral displacement is indicated on coronal MRI, when the body of the disk is positioned at the medial or lateral aspect of the condyle, respectively. Posterior disk displacement is rare.[4]

Disk reduction and non-reduction

The disk reduction can be diagnosed on MRI if the disk is anteriorly displaced in closed mouth views but is in a normal position in open mouth views. If the disk remains anteriorly displaced on opening, it is diagnosed as non-reducing. It appears bent or deformed as the condyle pushes forward against it. Fibrotic changes of the posterior attachment of a displaced disk may alter its tissue signal to approximate the signal of the disk and make identification of the disk itself difficult or impossible.[4]

Deformities and perforation

MRI can indicate an alteration in the normal biconcave outline of the disk, which may vary from enlargement of the posterior band to a bilinear or biconvex disk outline. Disk deformities may be accompanied by changes in its signal intensity, including an increase in signal.

Changes in the condyle and temporal component of the joint consistent with the degenerative joint disease often accompany cases with long-standing displaced disks. Perforations most commonly occur in the retrodiscal tissue, just behind the posterior band of the disk. Loss of the joint space, resulting in bone-to-bone contact between the osseous components is suggestive of perforation of the disk or its attachment.[4]

Fibrous adhesions and effusion

MRI studies show tissue with low signal intensity can detect adhesions which can be seen when there is no movement of the disk relative to the articular eminence in mandibular open position in MRI. It can detect joint effusion, which appears as an area of high signal intensity in the joint spaces on T2-weighted images. Avascular necrosis is seen if there is low signal intensity in the bone marrow of the condyle.[4]

Scar tissue

Seen with areas of low signal intensity is extended into the joint space irregularly. The use of gadolinium as an MRI contrast agent permit early detection of the inflammatory changes in joints with rheumatoid arthritis.[13] MRI with a contrast agent is used in juvenile idiopathic arthritis because it can demonstrate early synovial inflammation.[13]

Paranasal sinuses

MRI is one of the advanced imaging modalities which provides superior visualization of the soft tissues, i.e., extension, development, or infiltration of neoplasms into the sinuses or surrounding soft tissues, or the differentiation of fluid secretions from soft tissue masses within the sinuses.[4] MRI of the paranasal sinuses must include high-resolution (3 mm) T1-weighted and T2-weighted images. Images are picked up in both the axial and coronal planes. In addition, gadolinium chelate contrast agents are used to evaluate enhancement on MRI. Inflamed and non-inflamed normal tissue can be well-distinguished on MRI when compared with CT since inflamed mucosa is associated with increased submucosal edema and increased surface secretions, both of which are water. The long relaxation time of water can be well appreciated as "dark" on T1-weighted images, and conversely as "bright" on T2-weighted images. This helps in distinguishing the smooth and uniform normal sinonasal mucosa from the polypoid, thick, inflamed mucosa.[14]

Sinusitis

It is well-documented in MRI, when it is complicated by a more serious problem, such as tumors, venous sinus thrombosis, and intracranial extension of the infection. MRI is excellent for differentiating tumor occluding a sinus cavity. Mucus retention is smooth, dome-shaped structures frequently seen along the inferior aspect of the maxillary sinus and appears dark on T1-weighted images and bright on T2 weighted images. On T1-weighted images, tumors have low signal intensity and low to intermediate on T2-weighted images. It is because of this that T2-weighted images are the best to differentiate inflamed mucosa from an adjacent tumor. Initial infiltration of bone may be difficult to identify on MRI unfortunately in areas where the bone is thin. Tumor infiltration can be well appreciated in thicker bones with the adequate medullary cavity. MRI is excellent for revealing the extent of soft tissue penetration into adjacent structures and in differentiating mucous accumulation from the soft tissue mass of the neoplasm.[3]

Fungal disease of the paranasal sinuses (FDPNS)

Acute invasive fungal sinusitis: Complications such as vascular occlusions with infarcts and cerebritis, leptomeningeal involvement, intracranial granulomas (characteristically hypointense on T1- and T2-weighted images), and pseudoaneurysms are better depicted on MRI.[15]

Chronic invasive FDPNS

The chronic invasive form is a slowly progressive fungal infection. MRI shows decreased signal intensity on T1-weighted images and strikingly decreased signal intensity on T2-weighted images [Figure 2].[15]

Allergic FDPNS

On MRI, very low T2 signal intensity is seen due to high protein and low water-free content of the allergic mucin. Although, T1 intensity is variable and low signal intensity can also be observed, high signal intensity or mixed low, intermediate, and high signal intensity is frequently observed in allergic fungal sinusitis.[15]

Fungus ball

The bony margins of the involved sinus are usually intact. MRI shows intermediate T1 and markedly hypointense T2 signal.[15]

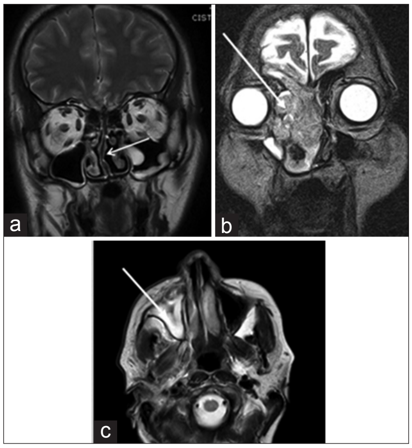

Figure 2: (a) Coronal T2-weighted image of the face is showing the rightward nasal septal deviation and bilateral maxillary sinusitis, (b) T2-weighted coronal image is showing a soft tissue mass in the right ethmoid sinus and the nasal cavity - Carcinoma ethmoid sinus, (c) T2-weighted sagittal section is showing hyperintense signals in the right maxillary sinus – Mucormycosis

Salivary gland MRI imaging

MRI is a good diagnostic modality to distinguish an inflammatory from a neoplastic disease, to identify a diffuse or a focal suppurative process and to localize sialoliths and demonstrate ductal morphology. MRI can be a substitute to conventional sialography for ductal pathosis and is generally the imaging method of choice in assessing parenchymal masses or cystic lesions because of accurate picturization of swellings of salivary glands and its extension into surrounding structures particularly in examining the submandibular glands. Intravenous contrast agent use is helpful in differentiating cystic and solid masses and in assessing the perineural spread of malignant tumors. With MR sialography, a natural contrast medium that can reveal ductal morphology accurately can be used for localization of sialoliths. T1-weighted and T2-weighted non-contrast sequences are obtained, followed by post contrast, fat-suppressed T1-weighted images.[4,16]

Indications for MRI of salivary gland can be summarized as follows:

Major glands

1. Parotid gland-masses confined to the deep lobe
2. Tumors with involvement of both the deep and superficial lobes of the parotid gland (dumbbell tumors)
3. Parotid or submandibular gland tumors with evidence of neural involvement or malignancy with extension into the underlying bone
4. Congenital diseases of parotid gland
5. Frequently diseased glands.[4,16]

Minor glands

1. Extension into the nasal cavity or maxillary sinus in case of palatal tumors
2. Any tumor with clinically ill-defined margins.[4,16]

Signal intensity of various glands

Parotid gland: T1 sequences show a high signal intensity and a low signal intensity are seen on T2 sequences with fat suppression. The parotid ducts will have high signal intensity on T2 sequences with fat suppression and low signal intensity on T1 sequences.

Submandibular gland: T1 sequences show intermediate signal intensity and T2 sequences with fat suppression show low signal intensity. The ducts have high signal intensity on T2 sequences with fat suppression and low intensity on T1 sequences.

Sublingual gland: T1 sequences show an intermediate signal intensity, whereas a high signal intensity is seen on T2 sequences with fat suppression.[8]

Neoplastic lesions

Parotid gland diseases are well recognized on T1 sequences because of the hyperintense (fatty) background of the gland. The excellent assessment of the margins of the tumor, deep extent, and pattern of infiltration can be assessed with the T1-weighted image. The coupled sequence, with fat-saturated, contrast material shows enhanced T1-weighted imaging and is used primarily to assess perineural and bony invasion, or involvement of meninges, which is the best means for "mapping" the tumor. The sequence may be obscured if there is the presence of focal mass that may be superimposed due to diffuse inflammatory process. The bone marrow and cortex of the mandible, maxilla, and skull base will be hypointense on fat-saturated images. The bone invasion must be suspected when a hyperintense tissue is seen extending into the hypointense background. T1-weighted images will show deep infiltration into the parapharyngeal space, muscles, and bone, which strongly suggest malignancy or less frequently, rupture of the capsule of a pleomorphic adenoma. The benign and malignant masses may exhibit considerable overlap, with regard to geographic properties such as margins, shapes, and borders, MR imaging is a good predictor of a benign or malignant tumor on T2-weighted images. T2 sequences show a very high signal intensity in the cases of benign tumors. Cysts may also be hyperintense on T2-weighted images, and, depending on the presence of hemorrhage, infection, or hyperproteinaceous fluid, the T1-weighted image may show intermediate (solid-appearing) intensity [Figure 3].[17]

Obstructive or inflammatory lesions

Usually fast T2-weighted MRI is used with thin sections, for evaluation of ductal architecture of the salivary glands and to identify stones. The effect the sialolith on the ductal system can be visualized through T2-weighted MRI but tiny calculi can be overlooked because of the signal void [Figure 3].[17]

MR sialography replaces conventional sialography in the identification of ductal obstruction. MRI in inflammatory conditions of the parotid and submandibular glands may be helpful for evaluating the extent of the lesion in the coronal plane. MRI is currently the best imaging modalities to demonstrate a glandular abscess because of the fatty attenuation and intensity.[17]

Systemic disorders of the major salivary glands

In Sjogren's disease, MRI has been particularly helpful with identifying dominant masses within glands.[18]

Sialosis - are usually rarely imaged but shows enlarged parotid glands of increased attenuation and slightly increased T2 intensity.[18]

Cranial base

MRI aids in the accurate localization of the intracranial lesion and establishes its relationship with surrounding vital structures. MRI has an edge over CT scan because of tissue characterization, the ability to depict intracranial extent, demonstrate calcifications, and to assess neural, vascular, and bony involvement. Benign and malignant tumors are better differentiated from diffusion weighted images.[3,4,18]

On T2 sequences, benign tumors show a high intensity and malignant tumors show an intermediate signal intensity. MRI accurately differentiates meningocele from encephalocele by determining the contents and intracranial relationships.[3,18]

Skull base inflammation

MR can detect marrow invasion, intracranial extension, and differentiate fungal from other infections. Fungal infection is accurately diagnosed by definite shortening on T2 sequences. In pyogenic infections, MRI can be used to identify mucosal thickening and fluid levels within the sinus.[4,18]

Tumors involving the skull base

Skull base tumors like Schwannoma and others, as well as fibro-osseous lesions like fibrous dysplasia, can be accurately localized and defined on MRI through their characteristic features [Figure 4].[3,4,18]

Soft tissue masses

MRI owing to its high soft tissue resolution is the ideal imaging technique for soft tissue masses and has an edge over CT and other imaging techniques. A combination of lobulations, septations, and central low signal intensity dots are the specific for hemangiomas.[19]

MRI is also the best-suited modality to diagnose lipomas and also evaluate for atypical features characteristic of liposarcomas. Intramuscular lipomas present as high signal intensity lesions on T1- and T2-weighted images with saturates on fat-saturated sequences with minimal or no enhancement [Figure 5].[20]

A summary of appearances of various tissues in T_1 and T_2 weighted images is listed in Tables 1 and 2.

Conclusion

This review adds to the current evidence of literature on MRI imaging in the head and neck region. MRI, with its ability to

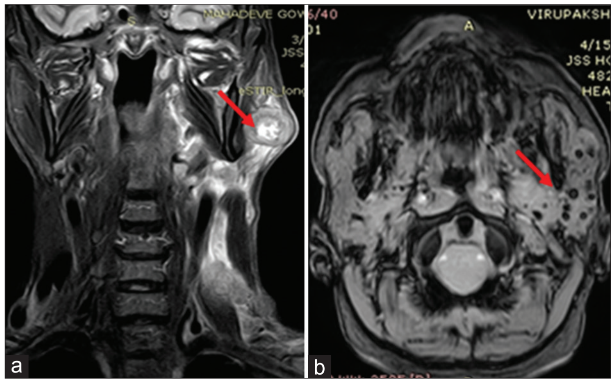

Figure 3: (a) Coronal short-tau inversion recovery image is showing an irregular necrotic mass (arrow) in the left parotid gland - Carcinoma parotid, (b) axial gradient-recalled echo image of the neck showing multiple hypointense calculi in the left parotid gland - Sialolithiasis

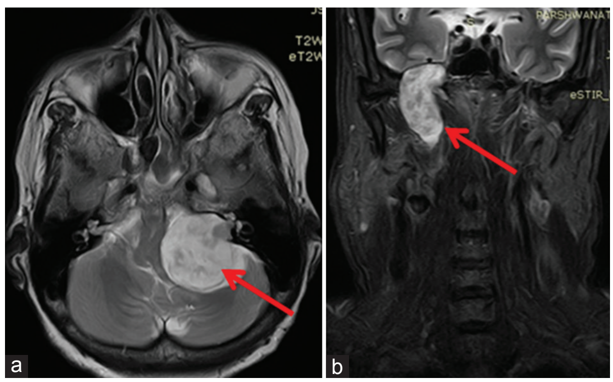

Figure 4: (a) Axial T2-weighted image of the posterior cranial fossa is showing an ice cream cone like left cerebellopontine angle mass - Schwannoma, (b) coronal short-tau inversion recovery weighted image is showing an insinuating heterogeneously hyperintense right infratemporal fossa mass - Schwannoma

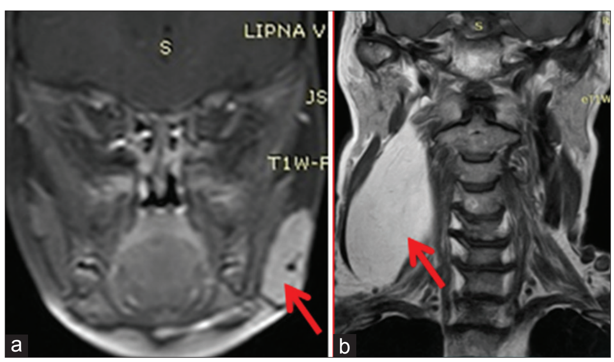

Figure 5: (a) Post contrast T1-weighted coronal image of the face is showing intensely enhancing on the left cheek mass with a hypointense flow void - Hemangioma, (b) coronal T1 weighted magnetic resonance image is showing a fusiform hyperintense intramuscular mass on the right side of the neck - Lipoma

Table 1: Appearance of various tissues in T1- and T2-weighted images

Tissue	T1 images	T2 images
Water	Dark	Very bright
Fat	Very bright	Bright
Ail-	Dark	Dark
Fibrous tissue	Dark	Dark
Organs	Intermediate	Dark
Bone	Dark	Dark
Muscle	Intermediate	Dark
Fresh blood	Dark	Dark
Disk	Dark	Dark
Old blood	Bright	Bright
Tumors	Intermediate	Bright

Table 2: Appearance of various pathologies in T1- and T2-weighted images

Pathologies	TI images	T2 images
Cysts		
Tornwaldt cyst	Bright	Dark
Thyroglossal duct cyst	Bright	Dark
Ranula	Intermediate	Bright
Parotid cyst	Intermediate	Dark
Sinus		
Mucous retention cysts	Dark	Bright
Acute fungal disease	Dark	Dark
Chronic fungal disease	Intermediate	Bright
Adenitis	Intermediate	Bright
TMJ		
Disk	Intermediate	Intermediate
Pseudo disk	Dark	Dark
Benign tumors		
Hemangioma	Grey	Bright
Lymphangioma	Grey	Bright
Neurofibroma	Gray	Gray

TMJ: Temporomandibular joint

capture the internal disease process with considerable accuracy, is gaining entry in head and neck diagnostics. Appropriate use of MRI can assist greatly in the identification and management of head and neck pathologies, further enhancing the quality of medical care to the patient.

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How to cite this article: Guledgud MV, Patil K, Shankar HP, Deshpande P, Raman R. Magnetic resonance imaging in head and neck radiodiagnosis: An overview. J Med Radiol Pathol Surg 2015;1:24-30.