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Imaging of Head and Neck Cancer With CT, MRI, and US

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Imaging of head and neck (HN) cancer is a challenge for many radiologists and largely due to the challenging anatomy in a small volume of the body. Additionally, multiple pathologies and the absence of an agreed-upon standard imaging protocol for staging and surveillance add complexity in choosing the most appropriate imaging study. Computed tomography (CT) is often the first-line imaging tool used as it is readily available, relatively cheaper than magnetic resonance (MR) and is rapidly acquired. In comparison, MR is hampered not just by its greater expense and time involved with an imaging study, but the optimization of MR techniques is difficult in this complex part of the body. Over the last decade, additional advanced techniques have been developed for both CT and MR such as dual-energy CT, and perfusion imaging with CT or MR, which may aid in making a more accurate diagnosis and predication of tumor behavior. Ultrasound (US) plays an important role in HN imaging, particularly in the pediatric age group for new neck masses, and in adult patients with known or suspected thyroid pathology. US is also useful for the evaluation of other superficial masses in the neck and for guiding fine needle aspiration. This article will focus on each imaging modality, reviewing the benefits and drawbacks of CT, MR, and US as well as additional or advanced techniques within each. It will highlight disease processes where a specific modality is strongly favored as the most appropriate imaging study, and specific HN tumor behaviors that require dedicated imaging protocols or techniques. This review will also discuss the entity of carcinoma of unknown primary, which is often imaged with PET/CT, but for which specific guidelines were introduced in the 8th edition of the American Joint Committee of Cancer/Union for International Cancer Control Staging Manuals.
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Introduction

Head and neck (HN) cancer comprises a diverse group of primary malignant processes with mucosal, cutaneous, glandular, bone, soft tissue, and lymphoid tumor types that are treated with varying combinations of surgery, radiation, and chemotherapy. The majority of HN cancers are squamous cell carcinomas (HNSCC) arising from the mucosal surfaces of the pharynx and oral cavity. While HNSCC comprises over 90% HN malignancies, it accounts for only around 3% of malignancies in the United States, with an annual incidence of 53,000.[1] Skin cancers, parotid, sinonasal, and thyroid tumors are the most frequent other HN malignancies in adults.[2] This diverse range of HN cancer pathology is coupled with intricate HN anatomy, which on imaging is made more complex after surgical resection and reconstruction, and with the effects of radiation. These factors make the task challenging for the radiologist when reporting scans at tumor presentation, when staging tumors, and when conducting post-treatment surveillance.[3]

There are regional and institutional preferences for the imaging modality used at different stages of tumor management which are driven by cost and the availability of some modalities, particularly magnetic resonance (MR) imaging and positron emission tomography-computed tomography (PET/CT). As a general rule, computed tomography (CT) is the first-line modality in adults for a new neck mass given its ability to assess all tissues in the neck rapidly, its widespread availability, and its relatively cheaper cost as compared to MR. Ultrasound (US) is a first-line tool for the evaluation of

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suspected thyroid disease and is a common first-line tool for pediatric neck masses since it does not require the child to be motionless and avoids ionizing radiation. US has other uses in adult patients for cancer imaging and in particular for more focused evaluation of a potential nodal metastasis, and for imaging-guided fine needle aspirations (FNA). However, it does not allow evaluation of deep neck tissues, intraorbital, intraoral, or spinal detail, or detailed whole neck evaluation. Both CT and MR offer assessment of those structures, with MR having superior evaluation of intracranial and intraspinal pathology, and better ability to characterize tissues and tumor margins due to its superior contrast resolution.

The American Joint Committee on Cancer and the National Comprehensive Cancer Network (NCCN) provide frameworks for selecting imaging modalities for staging and the NCCN also for surveillance, although there is no radiologist member of the NCCN HN committee.[4,5] A more recently developed and trialed radiologist-developed post-treatment surveillance evaluation system known as the Neck Imaging and Reporting Data System has been proposed.[6,7] This system better standardizes a clear decision-making process for post-treatment scan evaluation, regardless of the cross-sectional modality, and it also allows documentation and analysis of the accuracy of image interpretation. Originally developed to incorporate CT and PET/CT of HNSCC, this system has now been extended to MR evaluation and for other HN tumors also.[8]

This review will discuss the role of CT, MR, and US in the diagnosis, staging, and post-treatment surveillance of HN cancer, highlighting specific tumor features and behaviors which are best evaluated by specific modalities. We will separately focus on tumor features which are important for staging, surgical decision-making and/or radiation planning such as perineural tumor spread (PNTS), bone cortex and bone marrow invasion, and cartilage invasion. We will also review the recommendations for imaging evaluation of carcinomas of unknown primary origin (CUP).

Computed Tomography

For adult patients, CT is typically the first-line imaging tool for known or suspected HN cancer. A new neck mass in an adult should be considered malignant until proven otherwise; CT allows localization of the mass, tissue characterization, and evaluation for other masses including adenopathy or a primary site. The images are relatively rapidly acquired with a multidetector CT scan requiring approximately 8 seconds of imaging time, which allows the patent to remain relatively still. For optimal neck evaluation, the patient should be quietly breathing and not swallowing or holding their breath, both of which severely limit evaluation of the larynx and pharynx.

The use of intravenous (IV) iodinated contrast provides additional important information to any neck scan. Since normal and pathologic tissues enhance to different degrees, iodinated contrast allows differentiation between the 2 and further characterizes some lesions which are known to be hyper-enhancing or cystic masses which have only peripheral enhancement. IV contrast also improves the sensitivity of detection of lymph nodes which will be more readily differentiated from intensely enhancing arterial and venous structures, and increases sensitivity of characterizing nodes as malignant with heterogeneous enhancement and/or have areas of frank necrosis. To maximize the enhancement of mucosal lesions and to demonstrate normal venous filling, the CT scan is best performed at least 90 seconds after rapid IV administration. When viewing a contrast enhanced CT on a picture archiving and communication system (PACS), narrowing the imaging window width will maximize the difference in density between muscular structures and subtly enhancing tumors.[9] This technique will allow increased conspicuity for subtle small tumors and also detection of retropharyngeal nodes, which often appear of similar density to adjacent prevertebral muscle. In order to best view osseous structures, such as the mandible, maxilla, skull base, and spine, a separate re-processing of the acquired CT data with a high-frequency algorithm is performed. These images are best viewed on much wider "bone windows" and are particularly important for tumors around the skull base such as sinonasal tumors and oral cavity tumors which may erode or invade the maxilla and/or mandible. The acquisition of thin axial CT slices improves spatial resolution and also allows reformatting into coronal and sagittal planes in order to best localize a mass in all directions.

Contrast administration is not possible for patients with advanced renal disease since it is nephrotoxic, and contrast cannot be administered without steroid premedication for patients with known iodine allergies. When a thyroid malignancy is suspected, iodinated contrast may be omitted since it may delay I-131 therapy, or US and MR can be used as alternative imaging modalities in order localize and completely evaluate for disease extent. The routine absence of iodinated IV contrast and multiplanar reformats for some PET/CT studies significantly hampers complete evaluation of masses and accurate presurgical planning.

Additional CT Techniques

One of the chief frustrations of CT and MR imaging in the neck is obscuration of soft tissues and bone due to artifacts from metal hardware. All removable metallic prostheses, including hearing aids, dentures and piercings, should be removed prior to any cross-sectional neck or head imaging. Unfortunately, implanted dental hardware and dental fillings will always result in some image loss around the oral cavity. For many years with CT scanning, a second set of images were obtained with a different gantry tilt around dental hardware. Additionally, thinner slices of a multidetector computed tomography (MDCT) can significantly reduce metal streak artifact and should be routinely employed. There are additional postprocessing techniques with CT such as iterative metal artifact reduction technique over conventional filtered back-projection,[10] or the use of a dual-energy CT scanner to further maximize evaluation of all of the oral cavity tissues.[11,12]

Additional patient techniques can also be employed to more clearly evaluate opposed mucosal surfaces, such as the buccal mucosa and the hypopharynx and larynx. The buccal mucosa is the lining of the cheeks and is continuous with the gingival mucosa overlying the alveolar portion of the maxilla and mandible. By asking the patient to puff their cheeks with air for the duration of a neck CT, these mucosal surfaces will be separated. This "puffed cheek technique" allows more clear separation of mucosal surfaces and delineation of the oral cavity tumor contours.[13] A similar "phonation technique" can be used for the larynx and hypopharynx where the patient is instructed to say "eeeeeeeee" for the short duration of a neck CT scan. This technique separates the opposed mucosal surfaces of the pyriform sinuses and separates the false and true vocal cords to allow evaluation of the laryngeal ventricles.[14]

MR Imaging

Relative to CT, MR is a more time-consuming process, with a typical contrast-enhanced MR study requiring around 45 minutes of magnet time. The relatively long scan time compared with CT plus the additional expense of MR means that it is not the usual first-line imaging examination; however, MR offers some advantages over CT. Furthermore, in many instances, a tumor that was initially imaged with CT will require further evaluation with MR. When MR scans are protocoled to answer directed questions, such as the entire mucosal extent, intracranial invasion, orbital extension, marrow infiltration, or perineural tumor spread, highly detailed and sensitive imaging studies can be obtained that may have great significance for surgical and radiation planning.

MR offers better contrast resolution than CT. That is, 2 different adjacent tissues are better able to be distinguished from each other by their MR characteristics such that the margins of an infiltrating mass are better delineated from surrounding normal tissue by MR than CT (Fig. 1). Additionally, tumors may be better able to be differentiated from each other by specific image qualities. For example, chondroid neoplasms, such as chondrosarcomas and chordomas, will both enhance; but on T2-weighted images, they will display markedly increased signal intensity as a characteristic finding. These features allow their differentiation from other skull base neoplasms such as invasive nasopharyngeal carcinoma, lymphoma, and metastases. The improved contrast resolution also allows for more sensitive evaluation of perineural tumor spread (Fig. 2), intracranial extension, vascular invasion, and bone marrow involvement. MR is more sensitive to contrast enhancement than CT so that tumors appearing subtly enhancing on CT will be comparatively more so on MR.

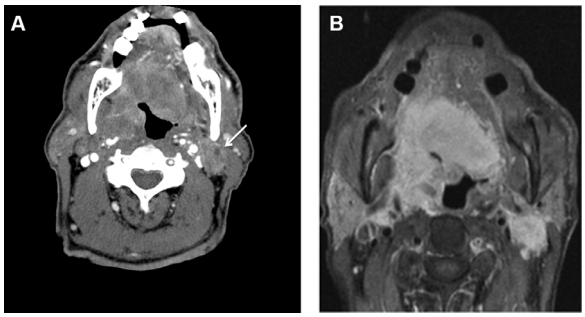

Figure 1 A 74-year-old male smoker with throat pain presented to ENT clinic and found to have a large oropharyngeal mass. Biopsy revealed squamous cell carcinoma. Axial CECT (A) shows a large mass in the oral tongue and tongue base with extension into the right glossotonsillar sulcus and palatine tonsil. There is also a heterogeneously enhancing left level IIA lymph node (arrow in A). These findings are better demarcated on postcontrast FS MR (B), which has better contrast resolution with clearer tumor margins.

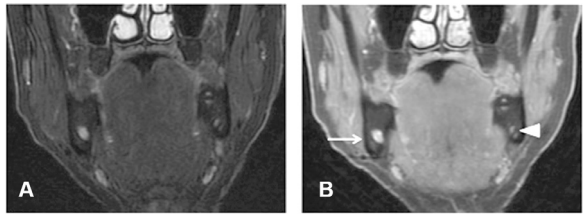

Figure 2 A 56-year-old female presenting with chin and jaw numbness. The patient had previously undergone treatment for melanoma of the lower lip. Coronal MR T2 FS (A) and T1 postcontrast FS (B) show enlarged, hyperintense right inferior alveolar nerve with marked enhancement (arrow in B) compared to the contralateral side (arrowhead in B).

While there are several patient and safety concerns with MR imaging that require careful discussion with each patient beforehand, the greatest problem with MR imaging is suboptimal protocoling and imaging techniques. Not infrequently, patients experience claustrophobia in the magnet or are unable to tolerate the time involved with lying still in the magnet. Each patient must also be evaluated prior to entering the MR suite to verify that any patient hardware such as pacemakers or implants are MR compatible. Hardware that is MR safe can still result in some heating due to the radio frequency deposition with MR imaging; therefore, patients must be advised of this problem and be able to communicate with technologists during the scan to report any concerns. Any implanted metallic hardware will also result in susceptibility artifacts where there is complete loss of signal around a prosthesis. This same artifact can also be seen where there are air-bone interfaces, such as around the skull base. Such susceptibility artifacts are exaggerated with the higher field strength magnets (3T as compared to 1.5T), and are more markedly evident when using fat-saturation MR sequences. While a 3T magnet provides overall better signal with reduced noisiness in the image (known as signal-to-noise ratio) and allows thinner slice acquisition, these susceptibility artifacts are particularly problematic in the HN where fat saturation sequences are usually required. For this reason, 1.5T magnets with careful choice of imaging sequence parameters can produce excellent quality directed HN scans. The ideal protocols maintain a relatively small field of view of 18 cm in the axial and coronal planes tailored to the primary site of disease, with 3-4 mm thick slices. Precontrast T1-weighted sequences should be performed without fat saturation for

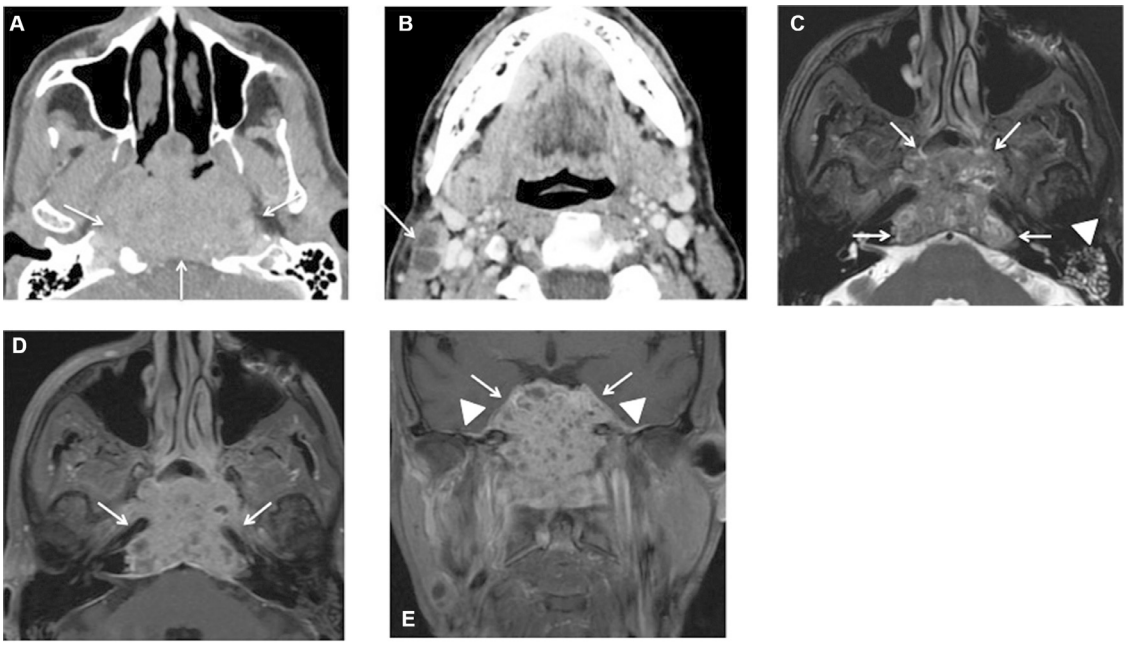

Figure 3 A 64-year-old male with nasopharyngeal carcinoma. Axial CECT through the nasopharynx (A) demonstrates a relatively homogeneous, infiltrative soft tissue mass (arrows in A) infiltrating the nasopharynx, invading the clivus and petrous apices, the posterior nasal cavity, and the clivus. The mass also partially encases the internal carotid arteries. An axial CT image through the suprahyoid neck reveals a necrotic right level 2a lymph node metastasis (arrow in B). Given its higher contrast resolution, MR imaging of the same patient was performed; axial T2 FS (C), T1 postcontrast FS (D), and coronal T1 postcontrast FS (E) images are shown. The infiltrative nasopharyngeal mass is depicted as a heterogeneous, predominantly T2-hypointense with avid, heterogeneous enhancement. There is encasement of the petrous segments of both internal carotid arteries (arrows in D), invasion of both cavernous sinuses (arrows in E), and dural invasion (arrowheads in E). Note the left mastoid effusion (arrowhead in C); hearing loss related to this finding is often a presenting symptom in patients with nasopharyngeal carcinoma. The findings are consistent with T4 N1 disease per AJCC 8th Edition head and neck cancer staging guidelines

identification of the fat planes and delineation of normal anatomy. T2-weighted sequences should be acquired with fat suppression to increase the conspicuity of pathologic processes which often have increased T2 signal. The use of fat suppression on postcontrast T1-weighted sequence also maximizes the conspicuity of enhancement, since enhancing tissues may otherwise be the same signal intensity as surrounding fat. This technique is particularly important in the detection of perineural spread and for skull base involvement. Fat suppression for postcontrast T1 and T2 sequences also increases the conspicuity of nodal necrosis and extranodal extension of tumor, increasing the confidence of the radiologist in detecting metastatic nodal disease.

Nasopharyngeal carcinoma and other tumors around the skull base are best evaluated by MR since MR offers improved evaluation of the skull base for early marrow invasion, for intracranial extension, and perineural involvement (Fig. 3). Similarly, MR is better than CT for evaluating the intracranial and intraorbital extent of sinonasal tumors and also allows differentiation between obstructive sinus debris vs solid enhancing tumor in the paranasal sinuses. In practice, since most tumors presenting as a neck mass are often initially evaluated with CT, many patients will undergo both CT and MR imaging. The superior ability of CT to detect cortical bone erosion and the ability of MR to best determine bone marrow invasion mean that the 2 modalities are complementary particularly for skull base tumors and both are usually obtained.

As MR has better soft tissue contrast than CT, it can be useful for mapping the extent of deep soft tissue invasion prior to radiation and for the detection of small tumors in the tonsils. Thus, MR is often used in our practice for determining the primary site for p16+ nodal SCC which are favored to be in the oropharynx, whereas PET/CT may be used as a first-line imaging tool in other places. Many HN oncologic practices choose to use CT for most of their HNSCC imaging due to the greater MR cost and potential prolonged wait time for appointments. In our practice, MR is typically used on all oropharyngeal SCC prior to definitive chemoradiation to best delineate the intensity-modulated radiation therapy plan. Therefore, follow-up imaging is also performed with MR in order to maintain consistency of imaging which is believed to enable easier detection of subtle treatment failure by comparing like imaging studies.

Advanced MR Techniques

Since its introduction to MR, the diffusion-weighted imaging (DWI) sequence has become an essential tool for brain

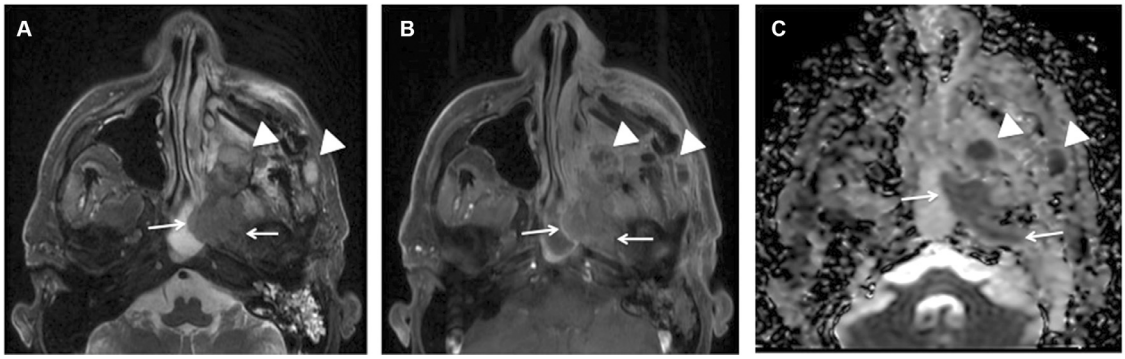

Figure 4 A 63-year-old male with a history of a left hard palate (oral cavity) squamous cell carcinoma who subsequently underwent partial maxillectomy and reconstruction without chemoradiation 1 year prior. He underwent imaging after developing facial pain which showed recurrent disease, which was then resected and irradiated. Axial T2 FS (A), axial T1 postcontrast FS (B), and axial ADC map (C) performed after resection and irradiation revealed extensive multifocal recurrent tumor in the deep aspect of the treatment bed (arrows in A-C) as well as multifocal rim enhancing fluid collections with more reduced diffusion consistent with abscesses (arrowheads in A-C). As in brain imaging, abscesses in the face and neck will usually also manifest as rim-enhancing fluid collections with markedly reduced diffusion. Squamous cell carcinomas will typically be hypointense on T2-weighted images, whereas abscesses usually are hyperintense on T2, as denoted in this case.

imaging since it allows the detection of acute infarcts and differentiates abscesses from cystic brain masses. DWI is routinely used in *every* brain MR protocol. The use of DWI in the HN has become more common over the last decade since it has been shown to be useful for the detection of abscesses but also the detection of high grade and very cellular tumors (Fig. 4). DWI can also be helpful in the HN for differentiating a malignant from benign lesion during initial staging and for assessing residual or recurrent disease vs granulation tissue on post-treatment examinations. However, it is only an additive sequence to any MRI protocol with overlapping appearances of benign and malignant disease on DWI.

DWI works by exploiting the Brownian (random) motion of water molecules. The reduced ability of water molecules to move due to specific disease processes is quantitatively displayed as an apparent diffusion coefficient (ADC) map. Higher ADC values (high signal ADC map) correspond to a greater magnitude of water motion whereas lower ADC values (low signal ADC map) correspond to a relative reduction of motion, which is most often seen in high-grade tumors but also in abscesses and in brain infarcts. Those tissues with high signal on DWI and low signal on an ADC map are said to have reduced diffusivity or to be "reduced" or "restricted" on DWI.

In general, ADC values lower than 1.0×10^{-3} mm^2/s (1.5T magnet) and 1.3×10^{-3} mm^2/s (3T magnet) favor malignancy.[15,16] Highly cellular tumors, such as lymphoma, tend to have a lower ADC value (more reduced) than squamous cell carcinoma with the ADC value of less than 0.7×10^{-3} mm^2/s.[15] These are generally good guidelines to use, but care must be taken when measuring such values and particularly with small structures since the DWI sequence suffers from poor spatial resolution.

On a 1.5T magnet, an ADC value cutoff of 0.9×10^{-3} mm^2/s has been suggested to distinguish malignant from benign lymph nodes.[17] As lymph node involvement is a known adverse prognostic factor for HN squamous cell carcinoma,[18] there was much hope that DWI would dramatically increase the accuracy of MRI for detection of small nodal metastases as an additional feature beyond the morphologic characteristics that are evaluated with MR/CT (size, shape, extracapsular spread, and necrosis). Unfortunately, the problem with relatively poor spatial resolution and the significant overlap in ADC values between normal and abnormal nodes make this sequence a less reliable than initially hoped.

Elsewhere in the HN, DWI has been studied to try to better differentiate tumors. In the parotid gland, high-grade tumors tend to have low ADC values (Fig. 5); however, there is an overlap of ADC values for benign and malignant salivary gland neoplasms, especially Warthin tumors. In the post-treatment setting, ADC values less than 1×10^{-3} mm^2/s are suggestive of recurrent malignancy rather than granulation tissue.[19] Often in the post-treatment setting, an indeterminate soft-tissue mass but with low ADC values might lead the neuroradiologist to favor recurrence and recommend additional evaluation such as with PET/CT imaging for further evaluation prior to biopsy. Thus in clinical practice, DWI is often used as an additional problem-solving tool to favor a benign or malignant diagnosis.

Perfusion-weighted imaging (PWI) is the qualitative and/or quantitative determination of delivery of blood to tissue. Blood volume (BV) and blood flow (BF) are related through the equation BV = BF x MTT where MTT is the mean transit time, or the time taken for blood to flow through a tissue. PWI can be performed by contrast administration with 2 different sequences: dynamic contrast enhanced or dynamic susceptibility contrast imaging. Dynamic contrast enhanced exploits T1 shortening effect of the contrast agent, which is the relative enhancement of tissues with contrast, whereas dynamic susceptibility contrast relies on susceptibility of the contrast agent, which is the immediate drop in signal from in-flowing high concentration contrast material. Alternatively, PWI can be performed without contrast administration

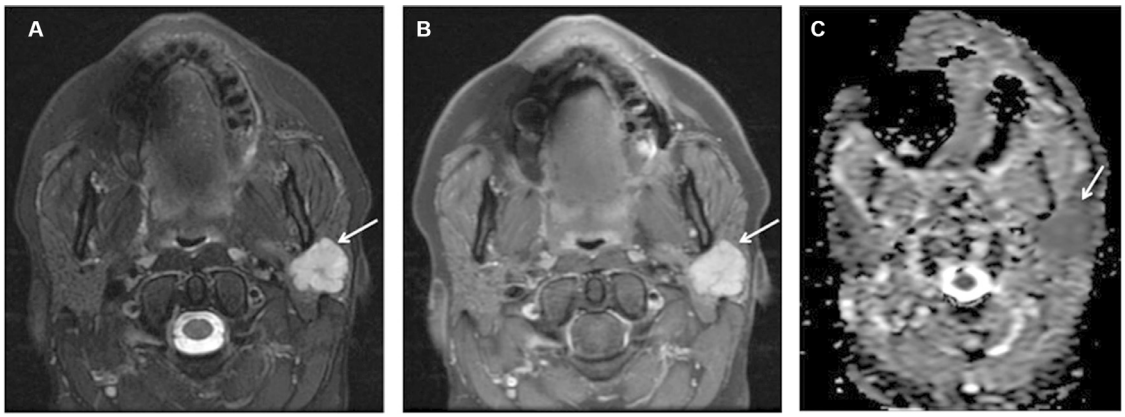

Figure 5 A 40-year-old female with an enlarging left periauricular mass. Axial T2 FS (arrow in A) and T1 postcontrast FS (arrow in B) images reveal a well circumscribed, T2 hyperintense left intraparotid mass with lobulated margins and avid, homogeneous enhancement. While the T2 signal intensity and enhancement characteristics are typical of benign mixed tumor (pleomorphic adenoma), the presence of reduced diffusion on the ADC map (arrow in C) is unusual. Fine needle aspiration of this mass revealed low-grade parotid carcinoma.

through arterial spin labeling where arterial blood is "magnetically labeled" through a specific sequence, and its flow into nonlabeled tissues is traced. Malignant tumors tend to have relatively increased blood supply through neo-angiogenesis, and poorly differentiated cancers tend to have abnormal vessels leading to insufficient oxygen delivery and tissue hypoxia. Therefore, malignancies tend to have higher BV and BF but lower MTT than normal tissue. Tissue hypoxia has been found to be a poor prognostic factor in HNSCC.[20,21] Tissue perfusion (blood flow and volume) may be increased in nonmalignant tumors of the HN including juvenile nasopharyngeal angiofibroma and paragangliomas, which are benign but highly vascular neoplasms which often receive embolization prior to resection. PWI can be extremely helpful in the patient with treated hypervascular tumors for demonstrating subtle tumor recurrences as areas of relatively increased flow to differentiate from granulation or scar tissue.

Ultrasound

US provides real-time, noninvasive assessment of a mass with higher spatial resolution than either CT or MR without ionizing radiation. For HN imaging with US, high-frequency linear array transducers are used with the bandwidth centered at 10 MHz. US allows excellent assessment of relatively superficial soft tissue structures such as the parotid and thyroid glands and the lymph nodes in the submandibular region and along the jugular chains. Grayscale images allow for the assessment of the echotexture and morphology of normal tissues and masses. Cystic masses tend to have few internal echoes but will show increased bright signal at their posterior margin. Aggressive masses are more likely to have irregular margins and heterogeneous echotexture with reduced acoustic transmission. Malignant nodes usually lose the fatty appearance of the nodal hilus and become overall more echoic in texture. Power or color Doppler images can add information regarding the vascularity of a neck mass with solid masses showing internal signal and hypervascularity, which are seen in some aggressive lesions. US is favored in children for initial imaging evaluation of a neck mass since it does not require sedation to perform and results in no ionizing radiation to the child. In adults, it is utilized predominantly for most thyroid masses and may be used for the initial evaluation of salivary gland tumors (Fig. 6). US is usually the first tool for the investigation of incidental thyroid nodules found on cross-sectional imaging scans, or for a palpable thyroid mass. Microcalcifications, which are highly specific for malignancy, can be detected by US with accuracy and positive predictive values of 76% and 78%,

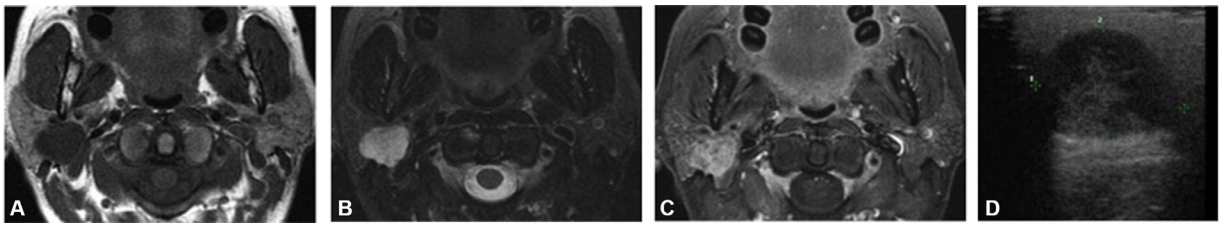

Figure 6 A 59-year-old female presenting with right parotid fullness. Axial T1 (A) shows a well-circumscribed, T1 hypointense mass in the right parotid gland. It has lobulated margins, T2 hyperintensity (B) with postcontrast enhancement (C). US image of a right parotid mass performed in preparation for US-guided biopsy shows heterogeneous internal architecture and posterior acoustic enhancement.

respectively.[22] US-guided FNA is then often performed for suspicious thyroid nodules.

In oncologic practice, US is also favored for the detailed evaluation of an equivocal lymph node when it may alter tumor management, and most often for imaging-guided FNA of nodes or relatively superficial masses.[23] US is less useful for evaluation of deeper anatomic structures such as the deep lobe of the parotid and retropharyngeal nodes, due to limited beam penetration into tissues. It is also inadequate for the full mapping of many HN tumors such as for invasion into bones, trachea, and esophagus. Given the complexity of neck anatomy and the limited field of view during any US exam, adequate US neck evaluation requires an experienced user.

Special HN Tumor Imaging Considerations

There are specific features of HN cancer behavior that portend a poorer prognosis including perineural tumor spread, bone marrow invasion, and cartilage invasion. These features may upstage the primary tumor and are also important for surgical and/or radiation planning. Additionally, detection of not just lymph node metastasis, but in many HN tumors, extranodal extension of tumor is important for staging and treatment planning. Even with the advancements in CT and MR imaging techniques we have described, it is important for radiologists to remember that CT, MR, and US are often complimentary problem solving tools.

Perineural Tumor Spread

The tendency for some tumors to spread along nerves is known as its neurotropism. There are several tumors in the HN which are well known for this behavior, such as adenoid cystic carcinoma, SCC, and melanoma, particularly of the desmoplastic subtype. It is critical to record this finding for surgical planning and/or for radiation planning, and for some malignancies will upstage the tumor. While US has not been shown to reliably demonstrate this phenomenon, both CT and MR can depict PNTS along large nerves. MR, with its higher contrast resolution and greater sensitivity to contrast enhancement has been shown to be more sensitive for PNTS depiction, but it should be sought on both cross-sectional modalities (Fig. 7).

On CT scans, the PNTS can result in widening of the bony neural foramina at the skull base or at the mandibular or mental foramina of the mandible. There may also be loss of normal fat padding around the nerve at the skull base. On MR, noncontrast T1 sequence allows demonstration of loss of hyperintense fat around the nerve. T2 and contrast-enhanced fat-sat T1 are important MR sequences also for seeing the abnormal nerve. Muscle denervation subsequent to perineural tumor spread (eg, with cranial nerves V3, VII, X, XI, XII) may also be evident and is much easier to detect on MR than CT, due to early T2 hyperintensity and contrast enhancement of denervated muscles.

High-resolution imaging of the nerves ("MR neurography") has been proposed for perineural tumor spread, and it has been said to have 95% sensitivity in the HN.[24] This is a time-intensive MR study to perform and should probably only be used when there is indecision by prior imaging, and/or there is a critical decision point for treatment with otherwise unexplained symptoms.

Bone Invasion

CT is more sensitive for demonstration of cortical erosion whereas MR is better for early marrow invasion (Fig. 8). It is this marrow invasion, which is evident in up to 56% of oral cavity cancers, which will result in upstaging oral cavity tumors to T4 disease.[25] CT and MR are often used as complimentary tools for preoperative planning. Frequently, marrow invasion will be evident on CT with aggressive tumors involving both sides of the mandible and extensive mandibular lytic destruction. It is only when there is subtle irregularity of the mandible and a critical surgical decision must be made, as to whether there is marrow invasion, that MR may be necessary. Marrow invasion of the mandible with oral cavity tumors will require surgical resection with a segmental mandibulectomy, rather than a marginal mandibulectomy for cortical erosion.

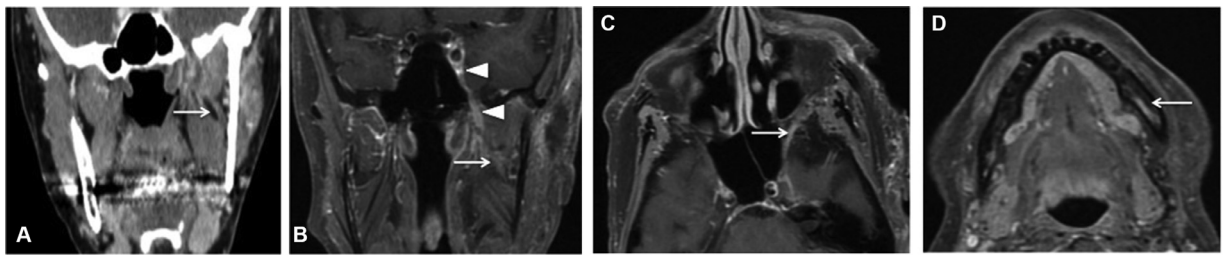

Figure 7 A 71-year-old female who was previously treated for melanoma of the left temporal scalp presented with new-onset trismus and left jaw pain. Initial CT shows (A) an enlarged structure traversing through the left masticator space (arrow in A), which corresponds to enlarged inferior alveolar nerve on the coronal T1 postcontrast FS MR (B) which has more proximal nerve involvement extending to the foramen ovale (arrowhead in B) and asymmetrical enlargement of the left cavernous sinus (arrowhead in B). Axial T1 postcontrast FS MR(C,D) shows asymmetrical left V2 enlargement (arrow in C) and intramandibular course of the left inferior alveolar nerve (arrow in D).

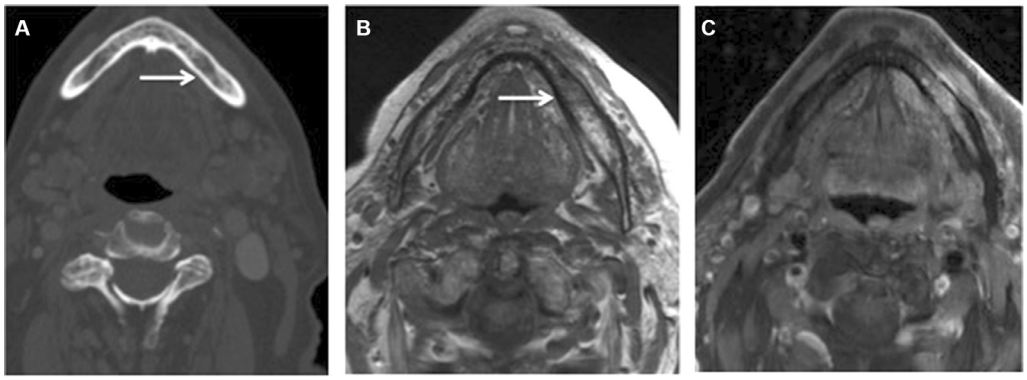

Figure 8 An 87-year-old male presenting with left mandibular gingival squamous cell carcinoma. Axial CT (A) of the mandible with questionable subtle lucency within the diploic space of the left mandibule (arrow in A). Pre (A) and postcontrast FS (B) axial T1 MR images shows marrow invasion of the left mandible (arrows in B and C).

Cartilage Invasion

Thyroid and cricoid cartilage invasion are important features in the evaluation of laryngeal and hypopharyngeal tumors as they can upstage tumors to critical points where decision-making for offered treatment is between chemoradiation and total laryngectomy. The first-line imaging for these tumor types is usually CT, which affords excellent evaluation of these areas without swallowing artifact in most cases. Tumor extending beyond the external margin of the cartilage ("extralaryngeal") is the most reliable feature of cartilage invasion. This finding can be difficult to define on CT; additionally, variable degree of cartilage ossification makes it more challenging when looking for erosion, lysis, or transmural extension (Fig. 9). In these situations of equivocal cartilage involvement on CT, MR with dedicated 3D fast spin echo T2 and T1 postcontrast FS sequences through the cartilage can be useful. The T2 cartilage signal and enhancement patterns are compared to the signal intensity of the tumor.[26] The radiologist should be mindful of false-positive cartilage invasion secondary to inflammation. Recently, dual-energy CT has shown promise for cartilage evaluation with sensitivity and specificity of 86% and 96%, respectively.[27] When the virtual noncontrast (weighted average) and iodine overlay images both show corresponding tumor involvement, it is interpreted as positive cartilage invasion.

Carcinoma of Unknown Primary

The presentation of a nodal mass, which is determined to be SCC, but without clinical evidence of a primary tumor site is known as a CUP (Fig. 10). HPV-associated/p16+ oropharyngeal SCC now accounts for greater than 90% of CUP cases.[28] Since these arise from the palatine tonsils and base of tongue, it is essential to evaluate CT and MR scans for subtle asymmetry in the size and signal intensity to identify the primary lesion. It is critical to be aware that skin and lung cancers can both be p16+ but not related to HPV. In this situation, high-risk HPV should be performed on the nodal sample prior to assuming oropharyngeal primary origin, so that other potential primary sites are considered. This is particularly important when the palpable node is in the supraclavicular fossa or the posterior triangle of the neck, both of which are unusual sole nodal metastatic sites of oropharyngeal SCC. If the SCC nodes are negative for p16, other sites of pharyngeal mucosal origin must be considered and Epstein-Barr virus testing should also be performed, which is positive in the majority

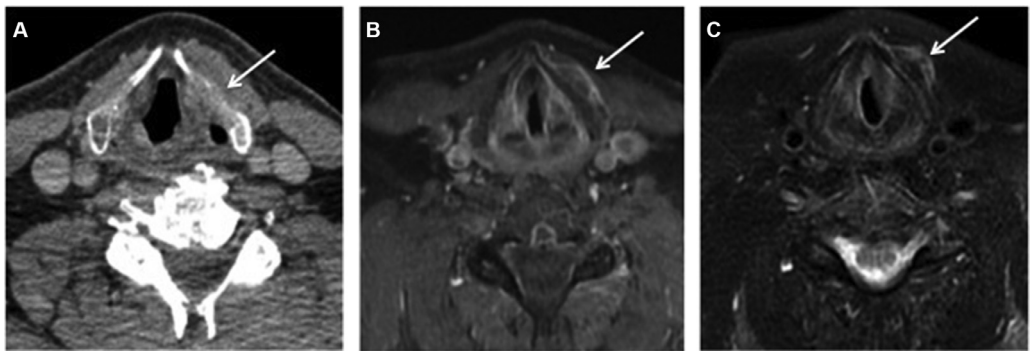

Figure 9 A 67-year-old male who previously treated for SCC of the left vocal cord. Axial CT (A) shows slight asymmetrical enlargement of the left strap muscle and aryepiglottic fold, as well as irregularity of the left thyroid cartilage (arrow in A; the CT was initially read as normal). The superior contrast resolution of T1 postcontrast FS (B) and T2 FS (C) MR better demonstrates a mass extending through the left thyroid cartilage and invading the left strap musculature (arrows in B and C).

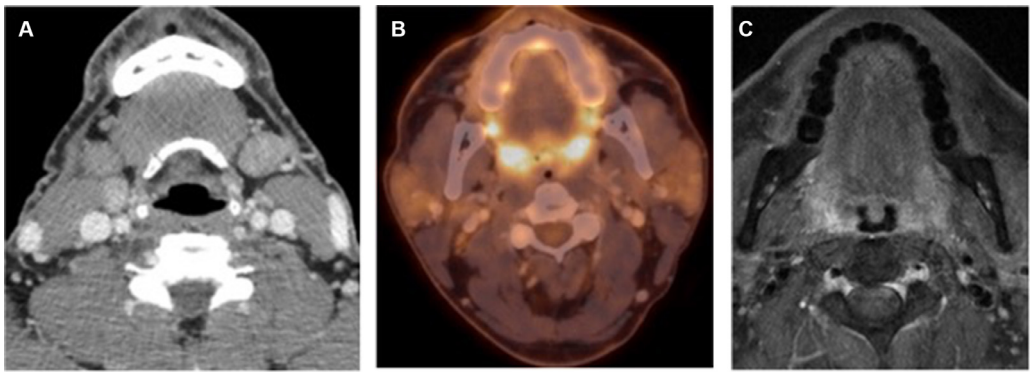

Figure 10 A 50-year-old male presented with a right upper neck mass. Physical exam and axial CECT (A) revealed enlarged right-sided level IIA lymph node (biopsy proven p16+ SCC). Endoscopy did not reveal any obvious oropharyngeal mass. Subsequent PET/CT (B) showed increased uptake in right-sided node (not included) and bilateral palatine tonsils. Patient's T1 postcontrast FS MR (C) revealed asymmetric enhancement in right palatine tonsil and the glossotonsillar sulcus. Bilateral TORS showed p16+ SCC in right tonsil only.

of nasopharyngeal carcinomas. PET/CT has been shown to be both sensitive (84%) and specific (84%) for detection of an occult primary tumor.[29] When the primary tumor is not evident on CECT or MRI, FDG-PET/CT has shown to add value in aiding biopsy and tonsillectomies.[30] Additionally, some studies have shown that up PET/CT can detect up to 30% where clinical exam, CT, or MRI were not revealing.[31,32] Furthermore, PET/CT can assess for distant metastatic disease for staging and follow-up scans.

Additional HN Cancer Imaging Points

HN cancer anatomy and pathology is complex, and reliable imaging evaluation is critical for initial staging and post-treatment surveillance. As such, multiple modalities can, and should, be used as collaborative problem-solving tools. Additionally, prior to interpreting a HN cancer study, it is critical to have clinical information available such as the tumor type, as well as the duration and types of treatment. A combination of focused imaging protocols and problem-solving tools in conjunction with clinical history is key to optimal imaging evaluation of HN cancer patients.

Take Home Message/Concluding Remarks

Diverse types of pathologies and complex anatomy of the HN pose challenges for many radiologists. Additionally, many imaging modalities at our disposal add to the complexity since it is crucial for radiologists to understand the role of each modality to obtain best diagnostic images to answer the clinical question. This review highlighted the roles and shortcomings of CT, MRI, and US, and we also discussed advanced imaging techniques available to serve as supplementary tool for accurate diagnosis. Lastly, we must keep in mind that different imaging modalities supplement each other when assessing HN tumors for answering formidable yet important prognostic questions such as perineural spread of tumor, bone invasion, or cartilage invasion.

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