

Carotid Artery Invasion by Head and Neck Masses: Prediction with MR Imaging¹

PURPOSE: To determine the value of magnetic resonance (MR) imaging in predicting resectability of head and neck neoplasms around the carotid arteries.

MATERIALS AND METHODS:

Forty-nine patients (28 male patients and 21 female patients aged 17–79 years; mean, 57.3 years) with head and neck masses and clinical evidence of carotid wall invasion underwent MR imaging. T1-weighted, T2-weighted, and gadolinium-enhanced T1-weighted images were analyzed to determine circumferential involvement of 53 arteries by tumor.

RESULTS: More than 270° of circumferential involvement was considered suggestive of unresectability of the malignant neoplasm; 270° or less was considered lack of invasion. The sensitivity of MR imaging for determination of unresectable disease was 100% (12 of 12 cases), specificity was 88% (36 of 41), and accuracy was 91% (48 of 53). Accuracy was 100% for squamous cell carcinoma ($n = 29$).

CONCLUSION: Tumor that encompasses more than 270° of the carotid artery probably cannot be removed from the artery. Tumor that involves 270° or less of the artery can be removed.

Index terms: Carotid arteries, MR, 90.12941 • Carotid arteries, surgery, 90.459 • Head and neck neoplasms, 20.37, 90.8334

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THE criteria for unresectability of head and neck neoplasms have undergone revision in recent years because of the advent of more effective microneurovascular surgical procedures and more innovative use of musculocutaneous flaps. Nonetheless, encasement of the internal carotid artery by a primary neoplasm of the head and neck or by adjacent lymph nodes remains not only a poor prognostic indicator but also a potential contraindication to surgical resection. Carotid artery involvement with tumor appears to be particularly common in patients with recurrent cancer. Reoperation in these patients, particularly if there has been previous radiation therapy, is difficult. If additional irradiation is not an option, surgery is usually the only alternative for cure.

In patients in whom tumor is adjacent to the carotid artery, the preoperative examination to determine if the carotid artery has to be resected is crucial. The patients often undergo noninvasive examination with computed tomography (CT) or magnetic resonance (MR) imaging before surgery. When clinical or imaging assessment suggests that the carotid artery is encased with tumor, temporary balloon occlusion of the affected vessel may be performed before the operation. Monitoring for neurologic deficits is performed during carotid artery occlusion.

In this study, we sought to assess the value of MR imaging in the prediction of carotid artery invasion by neoplasms of the head and neck. Our standard of reference was the surgical assessment of whether the vessel had to be sacrificed for macroscopic tumor-free margins or was the pathologic evaluation of the resected arteries. For surgeons, a favorable result is one in which no macroscopic evidence of tumor remains on the blood vessel at the time of resection. Although it is possible that microscopic

disease remains, these implants are unusual and may be dealt with at the time of postoperative radiation therapy.

MATERIALS AND METHODS

Between January 1991 and October 1994, 49 patients who subsequently underwent surgery on the affected side were identified by the head and neck cancer service as possibly having common carotid or internal carotid artery invasion by masses. The 49 patients consisted of 28 male patients and 21 female patients with a mean age of 57.3 years (range, 17–79 years; standard deviation, 13.2 years). For the most part, the clinical impression was based on tumor fixation to the internal or common carotid artery at the time of palpation or on proximity in the cavernous sinus.

Each of the patients underwent MR imaging as part of a prospective study to evaluate the potential of MR imaging in the prediction of carotid artery invasion. Two criteria were used to predict carotid artery invasion with the MR images: tumor involvement of the carotid artery around more than 270° of its circumference or intraluminal tumor identified at MR imaging. If tumor encompassed 180°–270° of the carotid artery circumference, invasion was stated to be possible. If the tumor encompassed less than 180° of the carotid artery circumference, no carotid artery invasion was predicted.

A total of 53 carotid arteries were evaluated. Four patients had bilateral masses fixed to the carotid arteries (two patients with squamous cell carcinoma, one patient with a chordoma, and one patient with a sinonasal adenocarcinoma). Forty-five patients had unilateral masses. The most common histologic findings were squamous cell carcinomas (29 arteries), chordomas (five arteries), meningiomas (four arteries), and adenocarcinomas (four arteries) (Table 1). The mass adjacent to the vessel arose from a lymph node in 26 arteries and from the primary tumor in 27 arteries. The site of origin of the tumors was varied (Table 2). The most common locations were the bones and meninges (12 arteries), the larynx (nine arteries), the oral cavity (seven arteries), and the oropharynx (seven arteries).

¹ From the Departments of Radiology (D.M.Y., H.H., R.W.H., H.M.S.), Otorhinolaryngology-Head and Neck Surgery (D.M.Y., G.S.W., R.E.H., A.N.G., D.C.B.), Pathology (K.T.M.), and Neurosurgery (M.J.K.), Hospital of the University of Pennsylvania, 3400 Spruce St, Philadelphia, PA 19104. Received November 2, 1994; revision requested December 27; revision received January 23, 1995; accepted January 30. Address reprint requests to D.M.Y.

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The same 1.5-T imaging unit was used for all examinations (Signa; GE Medical Systems, Milwaukee, Wis). The standard clinical MR imaging protocol included sagittal images obtained with T1-weighted sequences (400–600/11–17 [repetition time msec/echo time msec]) and axial images obtained with T1-weighted sequences (500–700/11–20) with 5-mm contiguous sections and a 256 × 192 matrix in which two signals were acquired. A fast spin-echo T2-weighted sequence (3,000–5,000/80–108) with fat suppression was used with 5-mm contiguous sections, two signals acquired, and a 256 × 192 matrix. Gadolinium-enhanced fat-suppressed images were obtained with a protocol similar to that for the T1-weighted axial images obtained before administration of contrast material. The contrast agent was administered at a concentration of 0.1 mmol/kg, and imaging was performed immediately after injection of the agent. A volume neck coil (Medical Advances, Milwaukee, Wis) or a quadrature head coil (GE Medical Systems) was used depending on the site of origin of the tumor.

Before surgery, an experienced head and neck radiologist (D.M.Y.) used the two criteria defined herein and performed a prospective evaluation of the images. Sagittal and axial images in every patient were evaluated to determine the extent of tumor apposition to the carotid artery. Coronal images also were provided for 26 patients. All images obtained with all sequences and in all planes were analyzed. The T1-weighted images were used primarily when a discrepancy was noticed between T1-weighted, T2-weighted, and gadolinium-enhanced T1-weighted images. The T1-weighted images best demonstrated the fatty (high signal intensity) interface, when present, between tumor (intermediate signal intensity) and vessel (low signal intensity).

Obliteration of the interface (fatty, muscular, or otherwise) between the artery and tumor defined the degree of circumferential involvement. A protractor was used on axial T1-weighted images to assess the degree of circumferential involvement of the artery by the neoplasm (Fig 1). This analysis was performed in concert by two radiologists (D.M.Y., H.H.) who provided a consensus determination of values. The presence or absence of intraluminal tumor was recorded.

The surgeon's assessment of whether there was tumor invading the carotid artery was used as the standard of reference. A curative peel meant that no carotid artery invasion was present. A palliative peel meant that tumor had to be left behind because of extension into the wall of the carotid vessel or that a pathologic specimen showed carotid arterial wall invasion through the adventitia. Often the surgeons obtained biopsy specimens of the adventitia of the carotid artery to assess resection margins. Easy surgical separation of tumor from the carotid artery and normal pathologic specimens from biopsies of tissue adjacent to the carotid arteries confirmed the absence of neoplas-

tic vascular invasion. The carotid artery was included in eight surgical specimens, and pathologic assessment of the vessel wall was performed on these specimens. Five of these arteries had confirmed carotid artery invasion, and three did not.

Twenty-one of the 49 patients underwent temporary carotid artery balloon occlusion to determine whether carotid artery resection was feasible if it was found to be necessary during the operation. The diagnostic carotid arteriograms were examined in a retrospective review to assess angiographic accuracy in predicting carotid invasion. Carotid arteries were judged to be normal, displaced, or narrowed and irregular.

RESULTS

Of the 53 carotid arteries in 49 patients with clinical evidence of neoplastic invasion, 22 had a tumor less than 180° around the carotid artery. None of these had carotid artery invasion at surgery. Seventeen arteries had more than 270° of tumor encasement. Twelve of these arteries had invasion, which led to either carotid artery resection ($n = 5$) or leaving macroscopic disease on the artery ($n = 7$). Of the 12 arteries that demonstrated carotid artery invasion at surgery, 10 showed complete encasement (360°) and two had 300° of involvement (Fig 2). Fourteen arteries had tumor 180°–270° around the artery, and none of these had invasion (Fig 3).

All five false-positive assessments of the arteries showed complete encasement (360°) of the internal carotid artery (Fig 4). Of these five arteries, three were involved with chordomas; four masses involved the petrous or cavernous segment of the carotid artery. One adenocarcinoma of the paranasal sinus and one meningioma of the sphenoid wing showed false-positive findings of invasion on MR images. No patients had evidence of intraluminal tumor (second criterion mentioned earlier).

Circumferential involvement of 270° or less of the wall meant no invasion, and more than 270° meant wall invasion. With use of this rule, the sensitivity of MR imaging was 100% (12 of 12), and the specificity was 88% (36 of 41). The accuracy was 90% (48 of 53). Negative predictive value was 100% (36 of 36), but positive predictive value was only 70% (12 of 17).

When the data were separated according to histologic characteristics with the 270° criterion, we found that MR imaging was 100% accurate for evaluation of the 29 squamous cell

Table 1
Histologic Characteristics of Tumors around Carotid Arteries

Histologic Type of Tumor	No. of Arteries
Squamous cell carcinoma	29*
Chordoma	5†
Adenocarcinoma	4†
Meningioma	4
Paraganglioma	2
Papillary carcinoma (thyroid)	2
Acinic cell carcinoma	1
Basal cell carcinoma	1
Cholesterol granuloma	1
Chondroblastoma	1
Chondrosarcoma	1
Mucoepidermoid carcinoma	1
Undifferentiated carcinoma	1

* Two patients had bilateral involvement of the carotid arteries (counted twice for a total of 53 arteries).

† One patient had bilateral involvement of the carotid arteries (counted twice for a total of 53 arteries).

Table 2
Primary Sites of Origin of Tumors around Carotid Arteries

Primary Site	No. of Arteries
Bone and meninges	12*
Larynx	9†
Oral cavity	7
Oropharynx	7
Parotid gland	3
Hypopharynx	3
Paranasal sinuses	3*
Thyroid gland	2
Carotid body	2
Ear	1
Esophagus	1
Nasopharynx	1
Skin	1
Unknown	1

* One patient had bilateral involvement of the carotid arteries (counted twice for a total of 53 arteries).

† Two patients had bilateral involvement of the carotid arteries (counted twice for a total of 53 arteries).

carcinomas (seven with invasion and 22 without). Two of five chordomas were correctly predicted; three false-positive findings occurred for chordomas that affected the cavernous and petrous portions of the internal carotid arteries. Three of four adenocarcinomas and meningiomas were correctly predicted. All other histologic types (Table 1) were correctly evaluated. The accuracy when a node abutted the carotid artery ($n = 26$) was 96% as opposed to an accuracy of 85% when the primary tumor involved the artery ($n = 27$). These results probably reflect the preponderance of squamous cell carcinoma in

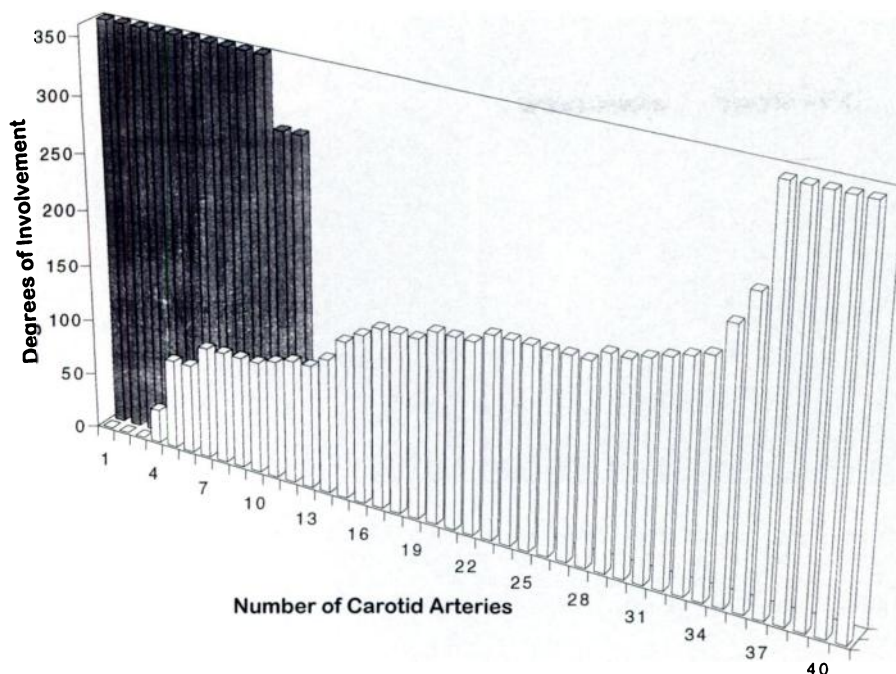


Figure 1. Graph shows the degree of involvement of the carotid artery by the neoplasm. Gray bars = invasion, white bars = noninvasion.

the former group and chordomas and meningiomas in the latter.

An unpaired Student *t* test with one tail was used to determine whether the values for the degree of carotid artery encasement in patients with carotid artery involvement were statistically different from those in patients without carotid artery involvement. The two sets were different with a *P* value of $< .0001$. A χ^2 test from the 2×2 contingency table of the MR imaging and surgical data (one degree of freedom) showed a statistical significance of $< .001$, verifying the reliability of MR imaging for prediction of invasion.

Four of the 21 patients who underwent balloon occlusion arteriography had carotid arterial wall invasion recorded at surgery. Two of these four arteries had luminal irregularity or narrowing that suggested invasion, and the other two were judged to be normal in appearance. Of the 17 carotid arteries that were not invaded, 13 had a normal arteriographic appearance, three were displaced, and one was narrowed and irregular. The sensitivity of arteriography was 50% (two of four arteries), and the specificity was 76% (13 of 17 arteries).

Among the patients who underwent complete resection of the carotid artery, which included five abnormal and three normal arteries, MR imaging allowed the correct prediction of the presence or absence of carotid artery invasion in all eight. In

only one of these patients was the cavernous carotid artery affected.

DISCUSSION

Only 5%–20% of patients who undergo radical neck dissection for squamous cell carcinoma have carotid artery invasion (1,2). The prognosis for these patients is dismal. Brennan and Jafek (3) recently described a series of seven patients who underwent carotid artery resection for malignant infiltration; none of the patients survived 1 year. Other reports cite 1-year survival rates of 0%–44% with high local and distant recurrence rates (1–4). The survival data are obfuscated by the fact that 38%–63% of patients who undergo carotid artery resection for presumed neoplastic infiltration do not show involvement at pathologic examination (4–6). Our rate of 62% (five of eight) falls at the upper end of this range. Clearly, carotid artery invasion is difficult to assess, even at operation.

When the carotid artery is ligated or resected, perioperative morbidity includes stroke (13%–38% of patients), carotid artery rupture, abscess formation, and fistulas (1,3–5). Preoperative or postoperative carotid artery rupture may be associated with previous irradiation. Radiation therapy also may lead to premature atherosclerosis (7), adventitial fibrosis, or wall necrosis soon after treatment or later (5). Because the prognosis and

perioperative morbidity are poor, some surgeons recommend preserving the artery at all cost to allow the best quality of life for the patient in the months remaining.

In a series of 28 patients with tumor invading the carotid artery described by Kennedy et al (1), distant metastases was the cause of death in 68% ($n = 19$). Local recurrence was the only cause of death in 18%. Kennedy et al asked whether these 18% would benefit from more aggressive surgery. They found no difference in the prevalence of local recurrence between patients with carotid artery invasion who underwent curative peel, palliative peel, and carotid artery resection. The 5-year survival rate in that series was 7%.

Surgeons differ in their approach. Some recommend curative peels of tumor from the carotid artery. Some recommend palliative peels (a nononcologic debulking from the carotid artery). Some recommend carotid artery resection without graft revascularization, and some recommend resection with bypass grafting (1–4). External-beam radiation therapy usually follows surgery, although some authors advocate intraoperative irradiation (15–20 Gy) or interstitial irradiation or both (4,8). The important issue addressed in our study was not how to operate in patients with carotid artery invasion. It was predicting which tumors have or have not invaded the artery.

Investigators in previous studies have used ultrasound (US) and CT to predict vascular encasement by tumor. The criteria used for the determination of carotid artery invasion on US scans have remained constant throughout evaluation of that modality. The loss of the echogenic (hyper-echoic) border to the vascular wall and the presence of intraluminal tumor are the sine qua non for US (9–11). Wall abnormalities must be documented in two planes (9,10). When these two simple criteria are used, the sensitivity of US has been reported to range from 92% to 100%. However, the false-positive rate has been reported to be 27%–56% (9,10,12). Specificities are 75%–80%.

Gritzman et al (11) showed that when malignant lymphadenopathy is in contact with a 4-cm or greater length of carotid artery, the wall is invaded in 80% of cases. They found that when tumor is present around 150° or more of the circumference of the vessel at US, the wall is invaded in 79% of cases (11).

Pitfalls of sonographic evaluation

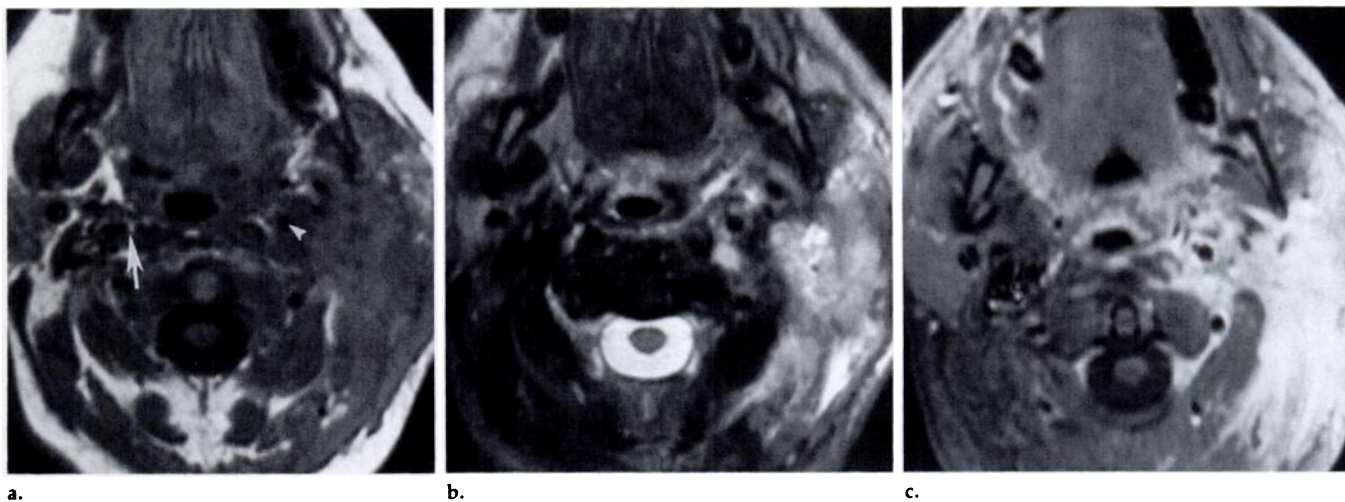


Figure 2. Carotid invasion by squamous cell carcinoma nodal mass. (a) T1-weighted MR image (600/11) shows circumferential (360°) involvement of the internal carotid artery (arrowhead) by a metastatic nodal mass. Note fat (arrow) apposed to a normal right carotid artery in contrast to the findings on the left. (b) T2-weighted fast spin-echo fat-suppressed MR image (4,000/80) shows less disease than does a. (c) Gadolinium-enhanced fat-suppressed MR image (600/11) shows more remarkable enhancement than a or b. Carotid adventitial invasion was found at resection.

arise from problems with tangential imaging with the transducer; calcified, atherosclerotic, or fibrotic walls of vessels before or after irradiation; very large masses that prevent sufficient penetration; postoperative status of the neck; and invasion of vessels at the skull base (above the mandible) or thorax (below the clavicles), where US cannot scan (9–12).

The ability of CT to depict carotid artery invasion is not well gauged. The efficacy of CT differs according to the criteria used by various authors for suggesting carotid artery invasion. If one uses the criterion of loss of fat planes between the mass and carotid artery, the false-positive rate is 92%–94%, but the sensitivity is 100% (13–15). If one uses tumor in contact with one-half the circumference of the artery and loss of tissue planes, sensitivity is still high, and the false-positive rate decreases to 13% (14,16). These wide swings in accuracy cause confusion with regard to the role of CT in the evaluation of vessels for tumor invasion.

Arteriography is less helpful than CT and US because of false-negative rates as high as 86% (13). The sensitivity of arteriography in our study was 50%, but only four arteries that were invaded were evaluated. The main value of arteriography is the ability to perform temporary balloon occlusion to predict neurologic complications and resectability of the vessel.

To our knowledge, only one study has investigated the use of MR imaging for evaluation of neoplastic invasion; that study compared MR imag-

ing with US (12). At examinations of 18 patients, the authors used a primary criterion of tumor effacing any part of the carotid arterial wall. They reported a sensitivity of 100% and a specificity of 87% (12). Only three of the patients actually had carotid artery invasion, making sensitivity assessment somewhat misleading. The false-positive rate was 40% (two of five cases). The false-positive studies occurred in the setting of previous irradiation and previous surgical intervention in the area in question. In four of five cases in which the MR and US findings were discordant, MR imaging enabled the correct assessment of the carotid artery.

Our study demonstrated that MR imaging is useful for highly accurate prediction of the lack of carotid artery invasion when the criterion used is tumor involvement around 270° or less of the wall of the carotid artery, obliterating adjacent fat. Focal obliteration of fat around 270° or less of an artery on MR images did not correlate with vascular invasion at surgery. Encasement of the arterial wall with obliteration of intervening planes in more than 270° of the circumference of the artery was a good predictor of carotid artery invasion.

There may be a bias in our study in that patients who showed more than 270° involvement around the carotid artery who were not good candidates for surgery did not undergo surgical therapy and therefore were not included in our evaluation. This factor is difficult to address while maintaining an ethically appropriate study. Nonetheless, we had five false-posi-

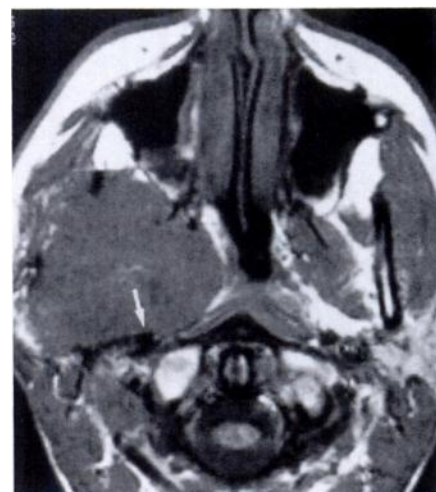


Figure 3. Chondrosarcoma in a 17-year-old boy. T1-weighted image (600/17) shows the internal carotid artery (arrow) plastered against the lateral mass of the C-1 vertebral body, obliterating anterior fat planes near the chondrosarcoma. The posterior wall of the artery is not surrounded, and the degree of encasement is 205° (on the basis of all of the relevant images). The artery was removed in the surgical specimen because the patient passed a balloon occlusion test, primary radiation therapy and chemotherapy had failed, and surgery was the final option. No infiltration of adventitia, media, or intima was noted at pathologic examination.

tive examinations among 17 MR images that showed more than 270° wall involvement. Three of the five tumors were chordomas, and four affected the petrous or cavernous carotid arteries.

According to the surgeons (R.E.H., D.C.B., M.J.K.) at our institution who specialize in operations on the base of the skull, chordomas are often gelati-

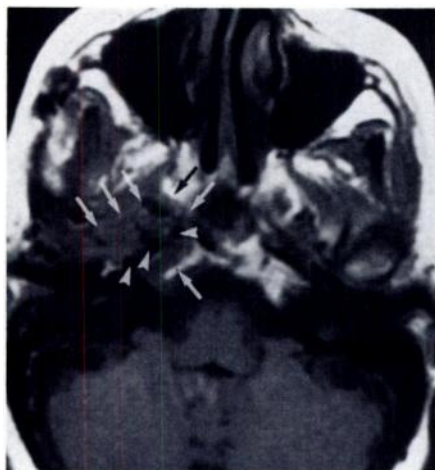


Figure 4. False-positive T1-weighted MR image (600/11) in a patient with a chordoma. The horizontal portion of the internal carotid artery (arrowheads) goes in and out of the plane, but there appears to be tumor medial, lateral, and anterior to it (arrows). The image was interpreted as showing 360° of involvement, but at operation, the surgeons believed they were able to remove all macroscopic disease from the vessel without sacrificing it.

nous in texture and can be aspirated completely from vessels (essentially a curative peel) much more readily than tumors such as squamous cell carcinomas and meningiomas, which are more adherent. The surgeons were not surprised at the results with regard to the failure of our criteria applied to chordomas. Elimination of the chordomas from the analysis yielded an accuracy of 96%. MR imaging enabled an accurate prediction in all 29 squamous cell carcinomas.

The factors that account for false-negative and false-positive imaging examinations can be divided into MR imaging factors, patient factors, and surgical factors. MR images may be degraded by patient or vascular-flow motion artifact, which may distort the boundaries between tumor and artery. Contrast material-enhanced images may exaggerate the extent of tumor around the carotid artery for the following reasons. The adventitia may show normal enhancement; this enhancement is exaggerated after radiation therapy or surgery. Without fat suppression, enhanced tumor and fat may be isointense. The vasa vasorum becomes enhanced. Slow flow in the periphery of a vessel may cause the area to become enhanced, resembling perivascular tumor.

On T2-weighted MR images, tumor may be isointense with suppressed fat around the carotid arterial sheath, making differentiation difficult. Non-homogeneous fat suppression, a frequent finding on MR images of the

neck, often leads to ambiguities in image interpretation on enhanced and fast spin-echo T2-weighted images. For these reasons, we found the non-fat-suppressed unenhanced T1-weighted images most reliable and easiest to interpret.

Patient factors may decrease the accuracy of MR imaging. Previous surgery or radiation therapy distorts planes around the carotid artery, particularly if the carotid arterial sheath has been opened during a neck dissection. Atherosclerotic changes in the artery can sometimes simulate neoplasm when tumor is adjacent. Because many patients with head and neck cancer smoke cigarettes, which predisposes them to atherosclerosis, this factor is a common one.

Surgical factors are errors the surgeon might make in assessment of the artery before or during operation. Fixation of a mass to the carotid artery by palpation need not imply invasion, but this was our most important preoperative clinical inclusion criterion for patients with neck disease. This factor accounts for our high rate of negative examinations. Previous reports have shown a high rate of lack of invasion in carotid arteries resected because of tumors (4–6). In the case of cavernous sinus meningiomas, at least one group of authors reported a carotid arterial wall invasion rate of only 42% of encased cavernous carotid arteries that were resected (6).

The extracavernous and cavernous intracranial portions of the carotid artery are difficult to assess because the carotid artery is not invested in arachnoid in that location. Complete resections of masses that affect these portions of the artery are uncommon (17,18). We questioned whether the preponderance of false-positive examinations of the cavernous carotid artery in our series was the result of the surgeons' inability to assess whether macroscopic disease was left behind in this shielded location. Surgeons also may not see carotid artery invasion when the operative view is obscured by indistinct fascial planes as a result of radiation therapy or previous surgery.

We defined as our standard of reference the surgeon's operative assessment of the vessel combined with the pathologic features of resected specimens. The reliability and accuracy of the former compared with the latter may vary. However, because resecting uninvolved carotid arteries is not acceptable, we believe the data reflect a reasonable attempt to determine the value of MR imaging in prediction of

carotid arterial wall invasion. Our surgical colleagues readily admit that the clinical ability to assess for residual disease at operation is far superior in the neck than at the skull base. Our results show that MR imaging allows greater accuracy in the assessment of arteries in the neck than elsewhere. This finding suggests that the standard of reference (surgical assessment) is not reliable in the petrous and cavernous carotid arterial regions.

We believe that when T1-weighted MR imaging demonstrates neoplasia around more than 270° of the carotid artery, a temporary balloon occlusion test should be performed if the patient is otherwise a good candidate for surgical treatment. Because of the 29% false-positive rate, particularly in patients with chordomas and cavernous carotid artery encasement, we recommend temporary rather than permanent balloon occlusion. Temporary occlusion allows the surgeon to assess the integrity of the vascular wall at the time of operation. The patient population with head and neck cancer is one in which smoking and other vascular risk factors may coexist, which makes reliance on a single carotid artery for anterior circulation risky. Nonetheless, the temporary balloon occlusion test may give a surgeon a sense of reassurance if he or she must sacrifice the carotid artery for definitive surgical ablation of head and neck cancer.

If the carotid artery has tumor wrapped 270° or less around it, the surgeon should expect to perform the resection without having to sacrifice the carotid artery. Temporary balloon occlusion, except in selected patients who have already undergone surgical or radiation therapy, is probably not warranted in this patient group. ■

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