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Magnetic resonance imaging in the investigation of sensorineural hearing loss: is contrast enhancement still necessary?

D. J. Annesley-Williams, F.R.C.R., R. D. Laitt, M.R.C.P., F.R.C.R., J. P. R. Jenkins, M.R.C.P., F.R.C.R., R. T. Ramsden, F.R.C.S.*, J. E. Gillespie, F.R.C.R.

Abstract

High resolution T2-weighted magnetic resonance (MR) imaging has been proposed as a rapid, inexpensive means of investigating patients with sensorineural deafness, particularly to exclude vestibular schwannomas. Whether the accepted 'gold standard' of contrast-enhanced T1-weighted images can be omitted, however, remains controversial. Over a 22-month period the use of axial turbo-spin echo T2-weighted images (T2W) were prospectively compared with contrast-enhanced T1-weighted spin echo scans in the evaluation of 513 patients presenting with audiovestibular symptoms. A 2-D T2W turbo spin echo (TSE) sequence with 3 mm slices was used in 340 patients while a 3-D sequence with overlapping 1 mm slices was used in 173 patients. The T2-weighted image findings were documented and subsequently compared with contrast-enhanced images. With the 2-D sequence 24 patients (25 lesions) had internal auditory meatus (IAM)/cerebello-pontine angle (CPA) masses identified by contrast-enhanced T1-weighted images, all of which were seen on the T2-weighted TSE sequence; there was one false positive 'mass' on the T2-weighted scans and one false negative case of IAM dural enhancement on T1-weighted imaging; six were considered normal initially on the T2-weighted images although three were subtly abnormal in retrospect. With the 3-D sequence three acoustic neuromas were all identified correctly with no false positive and only one false negative result (labyrinthitis). The 2-D and 3-D images were judged technically inadequate for clinical assessment in 15 and nine per cent respectively. We conclude that mass lesions of the IAM/CPA can be reliably identified on T2W TSE imaging but labyrinthine lesions may be missed without contrast enhancement. This is of particular importance in planning the management of neurofibromatosis type 2. Non-neoplastic disorders of the inner ear are also likely to be missed.

Key words: Hearing Loss, Sensorineural; Magnetic Resonance Imaging

Introduction

Exclusion of vestibular schwannoma or other lesions causing unilateral audiovestibular symptoms has become an increasingly common request to diagnostic imaging departments. Contrast-enhanced T1-weighted imaging is recognized as the 'gold standard' for detecting pathology of the IAM and labyrinth.[1] More recently, high resolution T2-weighted fast (or turbo) spin-echo and gradient echo sequences have become available with initial studies reporting a high degree of accuracy in the detection of vestibular schwannomas.[2–5] Given their potential for increasing patient throughout and reducing contrast medium costs, these new T2-weighted techniques have been proposed as a cost effective 'screening' method for patients with symptoms suggesting they may harbour a vestibular schwannoma. Concerns have been expressed, however, regarding the sensitivity of T2-weighted scanning in the identification of small lesions (4 mm or less) within the internal auditory meatus,[6] raising doubts about the exclusion of contrast-enhanced T1-weighted imaging from 'screening' protocols routinely.

In 1996 the installation in our department of a new 1.5 T magnetic resonance imaging (MRI) unit provided us with our first opportunity to implement a T2W TSE sequence for this purpose. Given the uncertainty surrounding the precise role of the new imaging sequence a prospective study was undertaken to compare the use of T2W TSE imaging with post-contrast T1W spin-echo imaging in the diagnosis of cerebello-pontine angle or labyrinthine pathology.

Materials and methods

This prospective study was undertaken between October 1996 and August 1998. MR imaging was

From the Departments of Neuroradiology, and Otolaryngology, Head and Neck Surgery*, Manchester Royal Infirmary, Manchester, UK.
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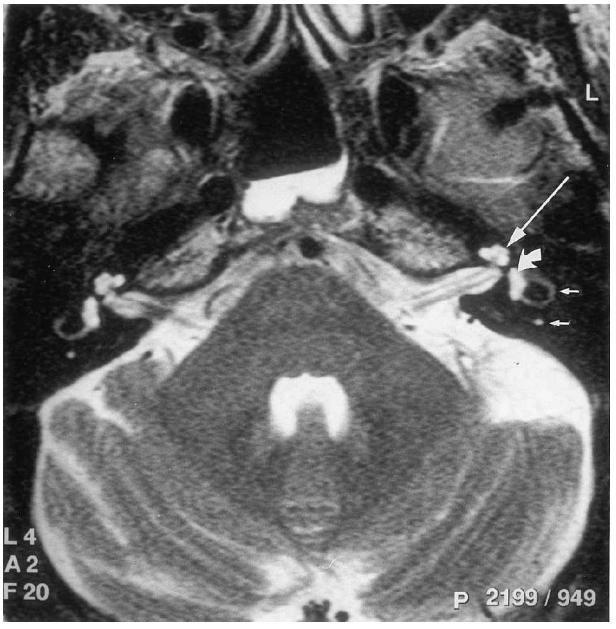


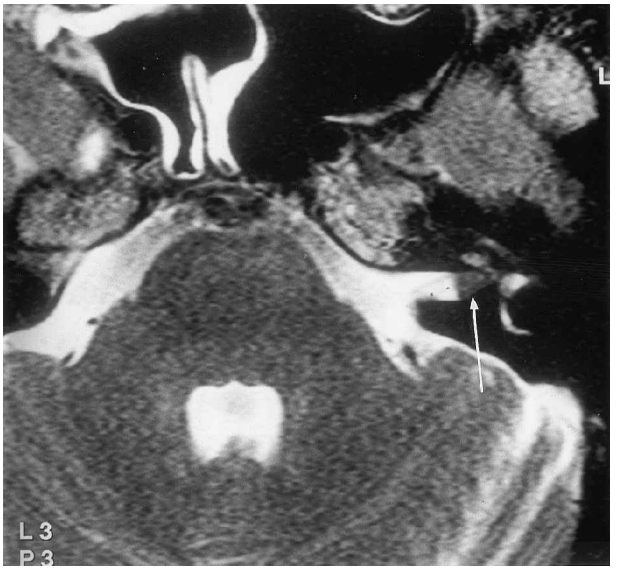
FIG. 1

Normal anatomy. T2W TSE 3 mm slice at the level of the IAM/CPA showing portions of the VIIth and VIIIth cranial nerves coursing from the lateral end of the meatus to the brainstem. Note the bright labyrinthine fluid signal within the cochlea (long arrow), the vestibule (curved arrow), and the lateral and posterior semicircular canals (small arrows).

performed in 513 patients, ranging in age from 15 to 98 years (median = 55 years) and with an almost equal sex incidence. All patients were referred for imaging in order to exclude a vestibular schwannoma or other lesion resulting in symptoms such as hearing loss, tinnitus, dizziness or vertigo.

MRI was performed with a 1.5 T superconducting magnet system (Philips Gyroscan ACS-NT). The study was divided into two parts. In part 1, 340 patients underwent 3 mm interleaved T2W-TSE axial scans (TR/TE 2733/120 msec, four acquisitions, 512/512 matrix, scan time three minutes 42 seconds) and 3 mm T1-weighted (T1W) spin echo images through the IAMs (TR/TE 448/20 msecs, two acquisitions, 256/256 matrix, scan time two minutes 32 seconds) after intravenous injection of 10 mls of a gadolinium-based contrast agent. All patients had axial 5 mm thick, 2.5 mm gap T2-weighted gradient spin-echo (GRASE) images through the whole brain performed to exclude intrinsic brain disease.

The findings were documented on a proforma at the same time as the examination was being reported by one of three consultant radiologists experienced in brain and skull base MRI (JEG, RDL, JPRJ). For the purposes of the study only abnormalities of the labyrinth, IAM and the cerebello-pontine angle (CPA) cistern were recorded on the proforma; pathology in other locations was included in the final examination report but did not form part of this study. Only the T2W TSE images were initially viewed by the reporting radiologist and the proforma questions answered (without recourse to the post-contrast images). The radiologist then documented whether he would have proceeded to post-contrast



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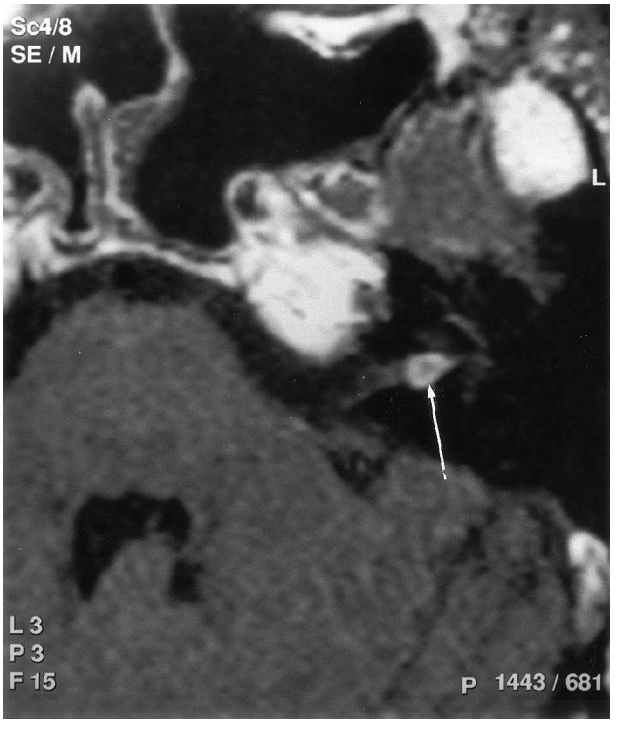

(b)

FIG. 2

Acoustic neuroma. Axial 3 mm T2W TSE image (a) demonstrating a well defined filling defect within the lateral portion of the left IAM (arrow) which enhances strongly on the post-contrast T1W SE image (b).

T1W imaging if they were not already part of the routine study and indicated why (for example, uncertainty regarding normality or characterization of a definite abnormality). Subsequently, the post-contrast images were viewed and the findings documented again. A definitive report was then issued on the basis of all the imaging information available. Any uncertainty regarding the presence or absence of a lesion on the TSE T2W sequence was considered an indication for contrast as it was felt only a definitive result would be considered accep-

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table in routine clinical circumstances. A negative result required identification of normal looking nerves within the IAM and CPA cistern, absence of a filling defect, and normal signal from all parts of the labyrinth (Figure 1). A positive result was recorded when the normal high CSF signal was replaced by a well-defined filling defect (Figure 2).

In Part 2 of the study, which involved 173 patients the methodology was identical to part 1 except that the T2W sequence was altered to a 3-D TSE sequence (TR/TE 3000/120, 512/236 matrix, one acquisition, scan time eight minutes) with overlapping 1 mm slices reconstructed every 0.5 mm. Contrast-enhanced T1W images were obtained as in part 1 of the study. The change to the 3-D TSE sequence was prompted by an interim analysis of the proforma data already collected.

Double reading of the scans was not performed as this was not our routine clinical practice.

Results

Part 1: 2-D T2W TSE vs contrast-enhanced T1W SE in 340 patients

a) *IAM and cerebello-pontine angle lesions.* Twenty-five mass lesions in 24 patients (seven per cent) were identified on the post-contrast T1W SE images (one patient had bilateral CPA tumours). Twenty patients had masses identified as vestibular schwannomas (Figure 2); three patients had lesions eccentrically positioned in relation to the IAM and were considered meningiomas (Figure 3). The patient with bilateral tumours was found to have multiple-enhancing lesions throughout the brain consistent with a diagnosis of metastatic disease; the CPA lesions were very evident on the 2-D TSE T2W images but would have been difficult to categorize as dural metastases without recourse to the post-contrast and GRASE sequences. Vestibular schwannoma size was measured as the longest diameter inside the IAM for intracanalicular tumours and within the cerebello-pontine angle for CPA and IAM/CPA lesions. Tumour size varied from 5×4 mm to 22×18 mm.

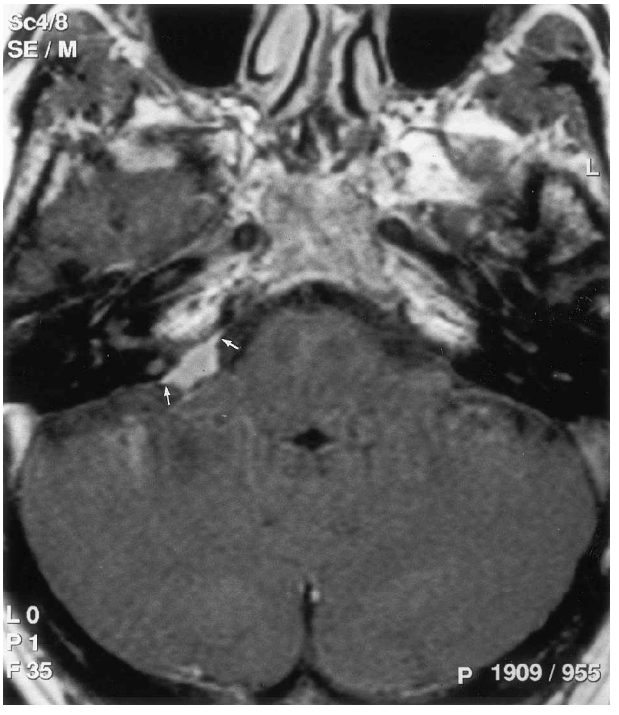

FIG. 3

Contrast-enhanced axial 3 mm T1W SE image showing a right sided meningioma within the CPA overlying the IAM. The T2W TSE image had demonstrated the presence of the mass but the dural origin of the lesion with the characteristic dural 'tail' (arrows) was only clearly evident on the contrast-enhanced images.

One patient demonstrated dural enhancement within the IAMs of unknown origin but was undetected on T2W scans.

Twenty-six CPA/IAM lesions in 25 patients were 'identified' on analysis of the 2D TSE T2-weighted images. As the T1W enhanced image were considered the 'gold-standard' for the study there were 24 definite true-positive patient scans on T2W imaging. The one potential false-positive outcome was in a patient demonstrating a 6×4 mm filling defect within the IAM on T2W imaging. The post-contrast T1W images did not show an obvious area of enhancement but the reporting radiologist considered there might be a small area of non- or poorly enhancing soft tissue and reported the scan as suspicious based largely on the T2W images. Follow-up T2W scans one year later demonstrated the same appearance and a further interval scan showed the soft tissue on post-contrast T1WI to be slightly larger. No definite diagnosis has been made but the case is probably best categorized as a true positive on T2W imaging.

b) *Intralabyrinthine lesions.* Contrast-enhanced T1W imaging revealed seven patients (two per cent) with enhancing lesions within the labyrinth. Five of these had nodular or linear areas of enhancement within the vestibule (three cases), basal turn of the cochlea (one case), or the vestibule and posterior semicircular canal (one case) (Figure 4) with no abnormality initially appreciated on the 2-D TSE T2W images. In retrospect subtle filling defects were visible in corresponding locations in two of these cases. The nodular areas of enhancement were in the 2–4 mm diameter range while the longest linear enhancing lesion was 5 mm.

Unconfirmed diagnoses of intralabyrinthine schwannomas were made in all five patients with abnormalities still visible on subsequent follow-up MRI at least one year later (except for one patient who died from an unrelated cause before follow-up). In another patient diffuse but patchy enhancement of the normally non-enhancing fluid filled spaces of the labyrinth on T1W imaging indicated the possibility of labyrinthitis. The 2-D TSE T2W examination was reported as normal although in retrospect a subtle area of signal loss was seen in the second cochlear turn. A computed tomography (CT) scan was performed that showed evidence of labyrinthitis obliterans, the enhancement presumed to be within areas of fibrous replacement not yet

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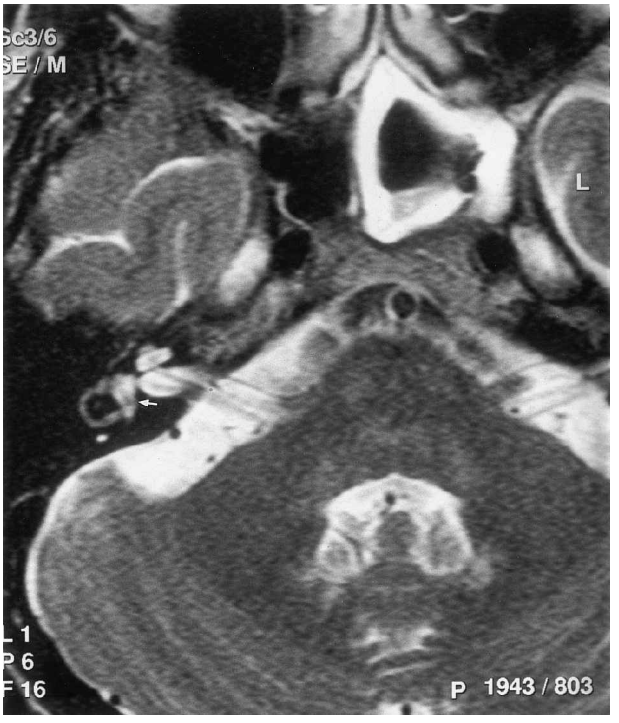

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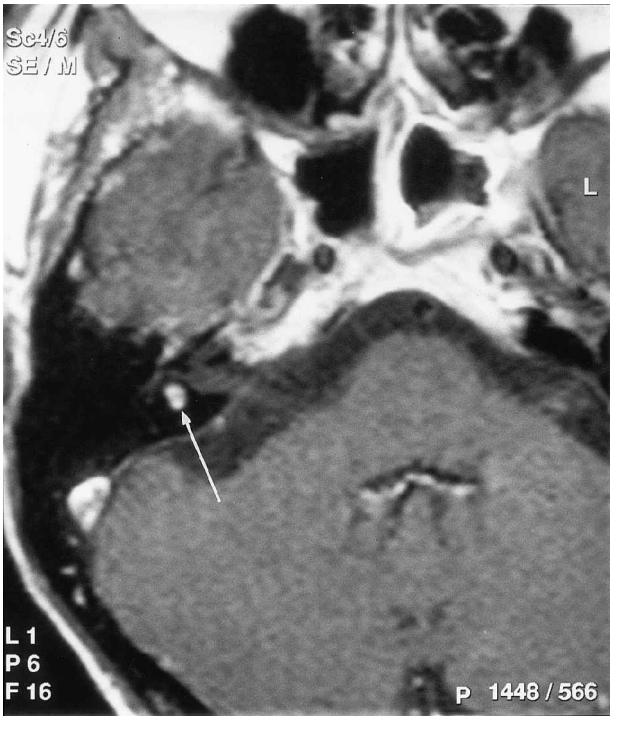

(b)

FIG. 4

Labyrinthine mass. a) 3 mm T2W TSE and, b) contrast-enhanced T1W SE images. The obvious enhancing nodule (arrow) within the vestibule on (b) was not identified initially on the T2W scan. Even in retrospect the subtle filling defect (small arrow) in (a) is barely perceptible. A presumptive diagnosis of labyrinthine schwannoma was made.

ossified. A history of previous middle-ear infection was subsequently elicited. The final patient in this group had enhancement within the cochlea and vestibule that was correctly identified as abnormal on the T2W images. A meningioma was noted over the parietal convexity on the whole brain T2W GRASE sequence suggesting a possible diagnosis of NF2 (Figure 5).

A summary of the true/false positive/negative results of part 1 of the study is given in Table I divided into tumours of the IAM/CPA, and the overall results for all pathology.

Overall, reviewers indicated contrast would have been required in 52 of the 340 patients (15 per cent) because of diagnostic uncertainty on the 2-D TSE T2W examination.

Part 2: 3-D T2W TSE vs contrast-enhanced T1W SE in 173 patients. Three vestibular schwannomas were shown within the IAM/CPA on the contrast-enhanced images and all were correctly identified on the 3-D T2W images. Tumour size was 12–15 mm. No intralabyrinthine pathology was seen on any sequence. One small non-enhancing (presumed arachnoid) cyst was seen on both sequences in the CPA of the symptomatic side. In one patient there was diffuse labyrinthine enhancement demonstrated on the contrast-enhanced T1W images but the T2W images were normal; a diagnosis of viral labyrinthitis was made. No false-positive findings on the 3-D T2W TSE occurred but in 16 cases (9.25 per cent) the reviewers felt contrast would have been required to diagnose or exclude pathology with complete confidence.

The true/false positive/negative findings of part 2 of the study are summarized in Table II.

Discussion

Vestibular schwannoma is an uncommon condition with an annual incidence of 12.7 cases per million-population,[7] occurring predominantly in middle-aged and older patients with an equal sex ratio. In our study, vestibular schwannomas were identified in 24 out of 513 patients (4.7 per cent); the described incidence in the literature ranges from 4.26 per cent[8] to 15 per cent.[9] The relative infrequency of vestibular schwannoma combined with the gradual onset of symptoms often leads to a delay in diagnosis.[10,11] However, it is highly desirable to detect a vestibular schwannoma as early as possible as surgical complications such as facial nerve palsy and brain stem damage are closely related to tumour size. The correct treatment for the majority of intracanalicular vestibular neuromas is prompt removal by an experienced neuro-otologist. Both the peri-operative mortality and the likelihood of neurological sequelae at this stage are very low. A policy of wait and re-scan is acceptable in old or infirm patients with small tumours and a long clinical history. In a younger patient such a policy will lead to high imaging costs as well as uncertainty for the patient.[12]

The approach to imaging a patient with suspected vestibular schwannoma has progressed dramatically within the last few years. T1-weighted examinations following the administration of a gadolinium-based contrast agent is the generally accepted gold standard for detecting these tumours.[13] False negatives are to our knowledge unknown,[10,14] but false

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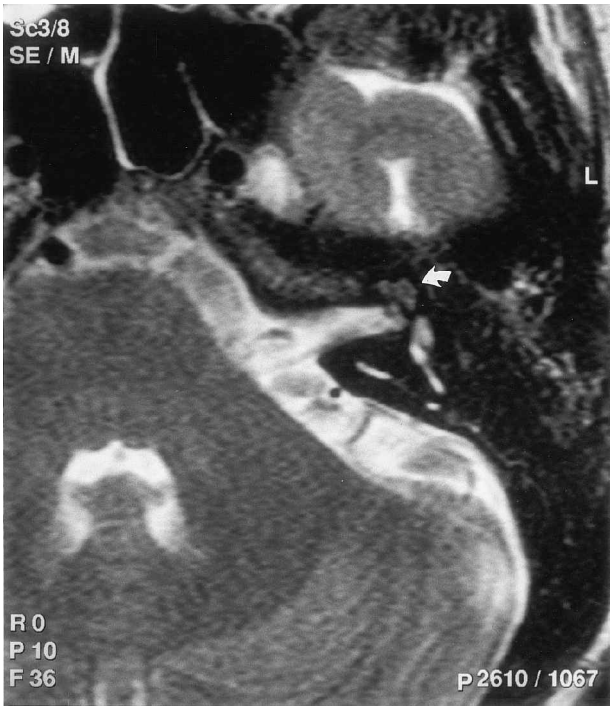

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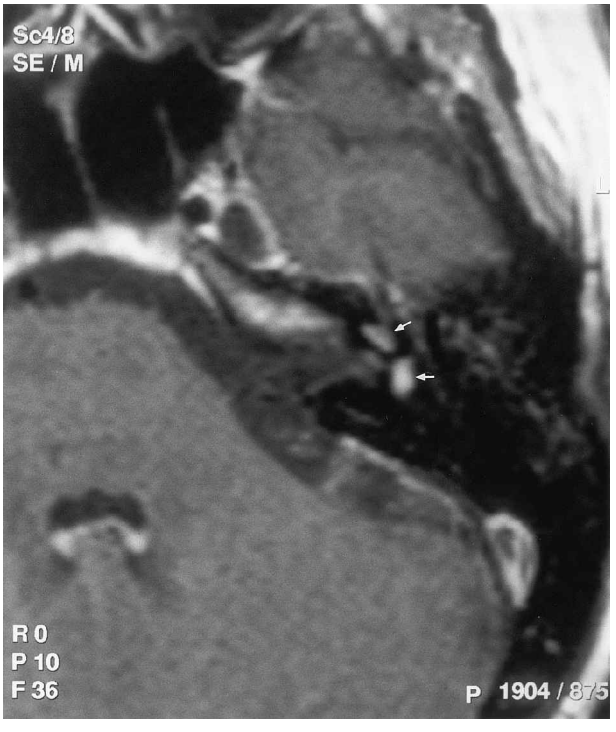

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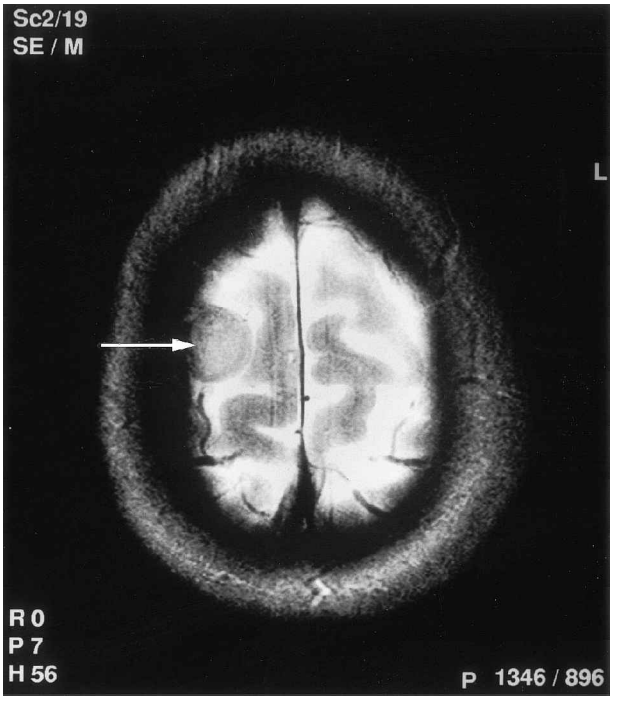

(c)

FIG. 5

Labyrinthine masses. Loss of the normal high signal from the cochlea (arrow) on the T2W TSE image (a) was identified confidently although the vestibular signal pattern was less obviously abnormal (compare with Figure 1).

On the post-contrast image (b) the enhancing (presumed) cochlear and vestibular schwannomas are equally evident (arrows). A meningioma (arrow) was identified at the vertex of the right cerebral hemisphere on the GRASE images (c).

positive findings are described. Inflammatory lesions or vascular structures, for example a small AVM, can closely mimic acoustic tumours. This limitation has much less serious consequences than missing a tumour and can be addressed by means of a follow-up scan after a reasonable interval to assess progression.[14]

MRI is being used increasingly as a screening test for most, if not all, patients with unilateral sensorineural hearing loss, placing even greater pressure upon what are often overstretched MRI services in the UK. The attraction of having a reliable T2-weighted screening sequence is obvious.[3,5,15] Gadolinium-based contrast agents are relatively expensive and require either a radiologist to administer or at least be available in the immediate vicinity if technical staff are performing the injections. If contrast was not required routinely for all patients then more cases per session could be scheduled and late evening or weekend sessions utilized for this clinical indication. Discarding the routine use of contrast-enhanced imaging, however, requires the availability of a T2W sequence that is proven to be both accurate and reliable.

Vestibular schwannomas and most other tumours stand out on contrast-enhanced T1W images as bright areas on dark background and are readily identified. T2W images are effectively cisternograms

TABLE I
2D T2W TSE VS T1W SE+C

Tumours of the IAM/CPA		All pathology	
True positive	25	True position	25
True negative	263	True negative	255
False positive	0	False positive	0
False negative	0	False negative	8
Sensitivity	100%	Sensitivity	75.7%
Specificity	100%	Specificity	100%

Total no. patients 340
Total non-diagnostic/indeterminate scans 52 (15.3%)

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TABLE II
3D T2W TSE VS T1W SE+C

Tumours of the IAM/CPA		All pathology	
True positive	4	True positive	4
True negative	153	True negative	152
False positive	0	False positive	0
False negative	0	False negative	1
Sensitivity	100%	Sensitivity	80%
Specificity	100%	Specificity	100%

Total no. patients 173
Total non-diagnostic/indeterminate scans 16 (9.25%)

with tumours recognized as filling defects within the bright CSF signal. Judging such a scan as normal requires sufficiently narrow slices to allow adequate definition of the nerves within the IAM, particularly in the region of the inferior lip of the canal where the nerves merge together and clear separation becomes more difficult.[14] Inhomogeneity of CSF signal can arise from turbulent CSF flow or pulsation of nearby arteries and even relatively minor patient movement may degrade image quality enough to impede confident diagnosis.

In our study, both the 2-D and 3-D TSE T2W imaging sequences were highly accurate in detecting or excluding the presence of a vestibular schwannoma, or other mass lesion within the IAM or CPA, provided scan quality was satisfactory (85 per cent and 91 per cent of cases for the 2-D and 3-D sequences respectively) confirmed on enhanced T1W SE imaging. No tumours confined to the IAM/CPA were missed. Although an encouraging result, our smallest vestibular schwannoma was 5 by 4 mm. Previous reports have highlighted detection problems on T2W scans for tumours under 5 mm[3,5,15,16] although overall sensitivities were as high as 98 per cent. Very small lesions remain a concern as vestibular schwannoma is an uncommon cause of hearing loss, but a potentially treatable one. A patient with a negative imaging outcome who has been reassured is likely to be lost to follow-up.[6,14]

In Renowden's study of 157 patients T2-weighted images were found to be satisfactory in 43 per cent of patients allowing a confident diagnosis in seven out of nine acoustics, without the necessity for administration of gadolinium.[2] In our series the observers felt they could make a confident decision on 85 per cent of the 2-D T2W scans, probably due to the improved spatial resolution afforded by the 512 image matrix employed. Image quality in the remaining 15 per cent suffered due to partial volume effects from the bony roof and floor of the IAM, and pulsation artefacts from the basilar artery or its branches and were thus diagnostically indeterminate. Given that the height of a normal IAM ranges between 2 and 8 mm with the majority between 5 and 7 mm, a series of contiguous 3 mm slices would be expected to produce at least one if not two slices devoid of partial volume effects from adjoining bone in most patients. Reducing slice thickness below 3 mm would be expected to decrease the partial volume problem in those with narrower canal heights, improve detection of lesions under 5 mm diameter, and further decrease the number of indeterminate examinations. Although the 3-D T2W sequence with overlapping 1 mm sections did reduce to nine per cent the number of unsatisfactory examinations the improvement was less than had been anticipated. Reasons for this are not entirely clear but it is suspected that the relatively long scan time (which more than doubled up to eight minutes), allowing more scope for patient movement was probably the major factor. A 'technical failure' (and thus a patient recall for contrast) rate of even nine per cent is, in our opinion, still too high for a high patient throughout screening sequence. Despite this, the 3-D-volume approach is felt to be the most promising and further modifications to this sequence should resolve the situation.

There was one false positive case on T2W imaging, a situation that might lead to unnecessary treatment. For this reason we recommend confirmation of all 'positive' T2W scan results by contrast-enhanced T1W imaging prior to surgery.

Lesions other than vestibular schwannoma within the IAM/cerebello-pontine angle can also lead to sensorineural hearing loss. It is in the imaging of this 'non-acoustic' group of patients that the administration of an intravenous paramagnetic contrast agent is particularly important. Lesions of the membranous labyrinth can be all too easily overlooked. In our series, seven patients had presumed space-occupying lesions within the labyrinth, six of which were overlooked initially, with only three visible even in retrospect.

Schwannomas of the labyrinth, although uncommon, are being increasingly recognized with greater use of contrast-enhanced MRI. Their identification is important as they can be indistinguishable from end-stage Ménière's disease on clinical grounds alone,[17] but the treatment of these lesions is very different. The ability to accurately diagnose intralabyrinthine schwannoma with MR can save unnecessary diagnostic tests as well as years of ineffective medical therapy. Intralabyrinthine schwannomas may occur in isolation either sporadically or not uncommonly as a feature of neurofibromatosis type 2 (NF2) (Figure 5). They may be confined to the vestibule and semicircular canal system and are thus truly 'intralabyrinthine' or may occur in the cochlea. An intralabyrinthine schwannoma may also be an extension of a schwannoma within the adjacent IAM. Accurate pre-operative imaging helps the surgeon to plan the most appropriate surgical intervention. A tumour confined to the vestibule and semicircular canal system is easily accessible through a standard translabyrinthine approach, whereas if tumours extends into the cochlea a more extensive petrosectomy with cochlear resection offers the best chance of tumour removal.[18,19] In planning the long-term auditory rehabilitation of certain NF2 patients the surgeon needs to be sure about the state of the inner ear. If the cochlea is free of tumour, a cochlear implant may be the treatment of choice assuming that a functioning cochlear nerve is present. It certainly gives a better result than an

auditory brain stem implant (ABI) in the small number of patients for whom it is suitable. If the inner ear is filled with tumour, placement of an intracochlear device is clearly not possible.

While intralabyrinthine space-occupying lesions may be detected by carefully checking for areas of signal loss on the T2W images, our experience suggests this can often be difficult. Abnormalities at this site accounted for six of the eight false negative results in the whole study, reducing the sensitivity of 100 per cent for IAM/CPA masses alone down to 76–80 per cent for all pathology. It would be expected that more of these lesions would be detectable on the thinner 3-D T2W images but as no intralabyrinthine masses were present in part 2 of the study this has not been confirmed. At the present time, therefore, it is felt for the surgical benefits outlined above that a T1W gadolinium-enhanced protocol is still essential in the evaluation of all individuals suffering from NF2.

Purely inflammatory diseases of the inner ear have no areas of T2-weighted signal loss and will only be detected if intravenous contrast is given.[20]

Similarly metabolic disorders of the otic capsule such as otosclerosis or osteogenesis imperfecta will not be detected without the use of gadolinium, although high definition CT scanning might well provide diagnostic imaging in these conditions. Omitting contrast and failing to make a positive radiological diagnosis in benign self-limiting conditions such as viral labyrinthitis is unlikely, however, to cause a significant problem in patient management. More importantly, subtle degrees of dural inflammation or thickening, as may occur in sarcoidosis, can be inconspicuous on T2W scans and the diagnosis missed without enhanced images. In addition the presence of co-existing facial nerve symptoms or signs demands a more detailed examination of the temporal bone so that lesions of the intrapetrous course of the nerve are not missed.

Pathology within the central acoustic pathway such as primary or metastatic brain tumour, stroke and multiple sclerosis may also present with sensorineural hearing loss. Although not part of this study it is strongly recommended that some form of axial T2-weighted imaging of the whole brain be included in the patient's assessment;[1] its value in categorizing posterior fossa pathology is well shown in our two patients with metastases and possible NF2 respectively.

Our study does not include an assessment of inter-observer variation and we accept this may be a source of criticism. However, as scans are not routinely double reported it is felt that the results reflect the routine clinical practice of the department.

Conclusion

Sensorineural hearing loss is challenging problem with MR imaging playing a central role in its investigation. In our study TSE T2W imaging accurately detected all tumours of the IAM/CPA and we now no longer routinely give contrast. A nine–15 per cent rate of indeterminate examinations is inadequate for a screening tool but this figure should improve with further sequence modification. Slice widths of 2 mm or less are required to obtain adequate spatial detail and we consider 3-D acquisition techniques with overlapping slices the most promising method of achieving this goal provided scan time is not excessive. Inflammatory and metabolic pathology and small space-occupying lesions of the labyrinth are likely to remain elusive if contrast enhanced T1W images are omitted. It seems clear from this study that, if the aim of MR imaging is simply to exclude a vestibular schwannoma, the use of gadolinium enhanced T1 protocols is unnecessary. If, however, the aim is to investigate fully all cases of sensorineural deafness the omission of this adjunct will leave a number of conditions undiagnosed. In formulating an imaging protocol for this group of patients individual departments will need to strike a balance between the sometimes-conflicting goals of absolute diagnostic accuracy and acceptable patient waiting times. The specific value of gadolinium-enhanced T1 images in the management of NF2 is highlighted.

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Address for correspondence:
Dr. J. E. Gillespie,
Department of Neuroradiology,
Manchester Royal Infirmary,
Oxford Road,
Manchester M13 9WL,
UK.

Fax: 0161 276-4141

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