Comparison of FIESTA and gadolinium-enhanced T1-weighted sequences in magnetic resonance of acoustic schwannoma

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Abstract Acoustic schwannomas (AS) are a treatable cause of sensorineural hearing loss (SNHL). Currently, the gold standard magnetic resonance (MR) examination for exclusion of acoustic schwannoma is gadolinium-enhanced T1-weighted images of the cerebropontine angles (CPA). The FIESTA (fast imaging employing steady-state acquisition) sequence is a true-FISP (free induction steady-state precession) sequence that provides high-resolution fluid-bright images of the CPAs and basal cisterns. The T1-weighted sequence adds cost and time to the examination, and possibility of contrast medium reaction exists. This study of 50 patients compared the gadolinium-enhanced T1-weighted images and FIESTA images. The hypothesis was that the FIESTA sequence could replace the gadolinium-enhanced T1-weighted images for the diagnosis of AS. The results showed that in 98% of cases, this was possible. The conclusion was that when the FIESTA sequence does not demonstrate AS, this sequence may be employed in isolation. However, gadolinium-enhanced images should be employed when pathology is seen and to follow-up post-surgical patients.

Keywords: Acoustic schwannoma, FIESTA, gadolinium, true-FISP.

Introduction

Acoustic schwannomas (AS) are small, benign tumours of the Schwann cells that support the vestibulocochlear nerve. Because these tumours may grow and have mass effect on the cerebellum, early diagnosis is vital, even though the treatment may consist of serial magnetic resonance (MR) to monitor the tumour. For many years, the gold standard imaging technique for the exclusion of AS has been gadolinium-enhanced T1-weighted images of the cerebropontine angles (CPA). Recent technological improvements in gradient design and power have resulted in true-FISP sequences that provide excellent anatomical detail in thin sections with high signal to noise. The purpose of this study is to determine whether the General Electric® true-FISP sequence, FIESTA, could replace the contrast-enhanced T1-weighted sequence to diagnose or exclude the presence of AS. This study includes a discussion on the anatomy of the VIII nerve and the pathophysiology of AS. There is a description of both the FIESTA and T1-weighted sequence and of the magnetic resonance contrast agent gadolinium. The methodology of the study is described, the results given and discussed. The final section is the conclusion from the study.

Anatomy

To fully understand the pathophysiology and imaging characteristics of acoustic schwannoma, a detailed grasp of the anatomy of the inner ear and the vestibulocochlear nerve is required.

The inner ear may also be known as the labyrinth, and consists of two parts: the bony labyrinth and the membranous labyrinth, which is found within the bony labyrinth. The space between the bony and membranous labyrinth is filled with a fluid called perilymph, and within the membranous labyrinth, space is filled by fluid called endolymph. These fluids transmit vibrations between structures of the inner ear.

The bony labyrinth may be divided into three parts, the cochlear, the vestibule, and the semicircular canals, and may be known as the otic capsule.¹ The cochlear is a snail-shell shaped structure, with two and a half coils within the temporal bone. There are three tubes within the coils of the cochlear: the scala vestibuli, the scala tympani, and the cochlear duct. The upper chamber, the scala vestibuli, begins at the oval window and is continuous with the vestibule. The lower chamber (the scala tympani) terminates at the round window. Between these two chambers lies the cochlear duct, or scala media. The scala tympani and scala vestibuli contain perilymph, and the cochlear duct endolymph. It is this fluid that allows MR imaging of the structures of the inner ear.¹

The roof of the cochlear duct is called the vestibular membrane and the floor is the basilar membrane. The cochlear duct also contains the organ of Corti, which contains sound receptors that convert mechanical vibrations into electrical impulses, which in turn are transmitted by the cochlear nerve to the brain. This means that the organ of Corti is the functional organ of hearing, and may be known as the acoustic sensory apparatus.¹ The organ of Corti consists of epithelial tissue that contains hair cells, and it is movement of these microvilli caused by pressure waves transmitted by the perilymph that is registered by the brain. Sounds of different frequencies are registered by displacement of the microvilli and the basilar membrane. The cochlear nerve originates in fibres in the hair cells of the organ of Corti.² The organ of Corti is not visualised by medical imaging.¹

The vestibule is the central portion of the bony labyrinth, and connects to the middle ear via the oval and round windows. The membranous labyrinth within the vestibule consists of two saclike structures, the utricle and the saccule. These structures contain receptors that are sensitive to gravity and linear movements and form part of the organs of balance.³

The semicircular canals are three structures positioned at 90° to each other within the temporal bone and are named by location: superior, lateral, and posterior.² These canals contain semicircular ducts that terminate with an ampulla in the utricle. The ampullae of the semicircular canals contain receptors that are sensitive to rotational movement, and to acceleration and deceleration. An elevated area of the ampulla called the crista ampullaris contains these hair cells. In the vestibule, these receptors are located in hair cells found in the macula of the utricle and saccule.

Equilibrium and balance are the other important function of the inner ear, although this role is shared by visual input from the eyes, the proprioceptors of the joints, and tactile receptors in the skin. As stated previously, the semicircular canals provide information on angular accelerating and decelerating motion, such as spinning and tumbling. Also, the utricle and the saccule in the vestibule possess receptors sensitive to linear acceleration and deceleration, and are sensitive to gravity. In the vestibule, impulses from the hair cells in the utricle and the superior and lateral semicircular canals travel to the superior vestibular ganglion. Impulses from the saccule and the posterior semicircular canal pass to the inferior vestibular ganglion (also known as Scarpa's ganglion).² These nerve fibres form the superior and inferior vestibular nerves.

Neural pathways

Within the internal auditory canal, the crista falciformis divides the fundus of the canal into superior and inferior compartments, with a further division of the superior compartment into anterior and posterior compartments. The structure dividing the superior compartment is referred to as Bill's bar, and separates the superior vestibular nerve and the facial nerve. Bill's bar is not seen radiographically.² The superior vestibular nerve traverses the internal auditory canal (IAC) in the postero-superior compartment, while the inferior vestibular nerve travels along the postero-inferior compartment. The singular nerve, which innervates the posterior semi-circular canal, traverses separately from the inferior vestibular nerve within the postero-inferior compartment. This nerve enters the IAC through its own orifice, the foramen singulare.² The cochlear nerve courses through the IAC in the antero-inferior compartment, while the facial nerve traverses antero-superior compartment.2

The superior and inferior vestibular nerves join at a point immediately medial to the falciform crest. At approximately halfway along the IAC, at the crista falciformis, the vestibular and cochlear nerves join and are fused as they reach the medial IAC (the porus acousticus). Two separate nerves, the vestibulocochlear (VIII) and the facial (VII), enter the brainstem at the CPA. The vestibulocochlear nerve enters the CPA medially to the root of the inferior cerebellar peduncle. Nerve fibres extend to the medullopontine junction, and the fibres from the cochlear nerve bifurcate and terminate in the dorsal and ventral cochlear nuclei. The dorsal nuclei process high frequency sounds, while the ventral nuclei process low frequencies. Neurons then course from here to the contralateral side of the brain and form the trapezoid body. Neurons then ascend in the lateral lemniscus to the inferior colliculus in the midbrain. Some neurons cross back to the original side at this point, but most ascend to the medial geniculate body and enter the thalamus and sublenticular internal capsule. These axons then terminate in the transverse temporal gyri of Heschl, located in the superior temporal gyrus where the primary auditory cortex is located.1,2

Fibres from the vestibular branch of the vestibulocochlear nerve follow a different pathway. After reaching the pons, the fibres divide and terminate in four vestibular nuclei found medial to the restiform body. The four nuclei (inferior or spinal, superior, medial and lateral) form the vestibular nuclear complex, also known as the flocculonodular lobe of the cerebellum.²

The vestibular nuclear complex is linked to the cerebellum and cranial nerves III (oculomotor), IV (trochlear) and VI (abducens). There are also connections to motor nerves controlling movement of the head, neck and body. Thus the vestibular pathway links sensations of equilibrium and balance with motor nerves that allow the eyes and the body to react and adjust to these sensations.²

Vascular supply

Arterial supply of the vestibulo-cochlear nerve is via a branch of the anterior inferior cerebellar artery (AICA). This branch of the AICA, the labyrinthine (or internal auditory) artery, supplies the vestibulocochlear nerve from the CPA to the IAC. A normal variant finds the labyrinthine artery originating directly from the basilar artery. In 15–20% of people the AICA will loop into the porus acousticus. The labyrinthine artery enters the canal where it is found medial and ventral to the nerves. It divides into the vestibular and cochlear arteries and these lay intimate with the corresponding nerves.² Venous drainage of the cochlear is via anterior and posterior spiral veins. These veins join with the vestibulocochlear vein, which becomes the vein of the cochlear aqueduct, which drains into the inferior petrosal sinus. The semicircular canals veins join with the vein of the vestibular aqueduct, which drains into the lateral venous sinus.²

Neural structure

The vestibulocochlear nerve is classified as part of the peripheral nervous system (PNS). The neuroglial cell of the PNS is the Schwann cell. The Schwann cell performs the same function in the PNS that oligodendrocytes carry out in the central nervous system (CNS): they form myelin sheaths around the axon of the nerve. Successive layers of the Schwann cell membrane wrap around the axons of myelinated PNS cells, forming the myelin sheath, or neurolemma. Each Schwann cell covers approximately 1 mm of an axon, with gaps between successive Schwann cells called nodes of Ranvier.³

The vestibulocochlear nerve is myelinated by Schwann cells to a point medial to the porus acousticus, where it becomes sheathed by oligodendroglia.⁴ This area is called the Obersteiner-Redlich zone.²

Pathology

Acoustic schwannoma

The term acoustic schwannoma (AS) describes tumours of the Schwann cells that form the neurolemma of the vestibulocochlear nerve. These tumours may also be known as acoustic or vestibular neuromas, neurinomas, or neurilemmomas.⁵ Following is a discussion of the signs and symptoms of AS and the pathology and management of AS.

Auditory dysfunction

Hearing loss may be either conductive or sensorineural. Conductive hearing losses relate to disorders of the outer or middle ear, and are not of relevance to this paper. Sensorineural hearing loss (SHNL) relates to disorders of the inner ear, the cochlear, the VIII nerve, or the brain. Unilateral SNHL is one of the first and most common symptoms of acoustic schwannoma. Kentala and Pyykko report that 93% of patients with AS present with hearing loss.⁶ Tinnitus was the next most common symptom (83%), and vertigo is also common (43%).

Hearing loss is usually gradual or insidious, however in up to 26% of cases SNHL may be sudden.⁷ Sudden SNHL has been described as an otological emergency.⁸ Causes of sudden SNHL include infection (bacterial and viral), inflammation, tumour (including acoustic schwannoma, metastases and meningioma), vascular disruption (e.g. AICA thrombus or embolus, or post radiation), trauma, toxin induced, and idiopathic. Hypothesised causes of idiopathic sudden SNHL include viral infection, intracochlear membrane rupture, and immune-mediated inner ear disease.⁸

Resolution of the hearing loss does not absolve the clinician from investigating the underlying cause of the SNHL. Nageris and Popovtzer found that 16% of patients diagnosed with AS recovered hearing within one month of diagnosis, leading them to conclude that investigation is essential.⁹ They found the reason for hearing restoration to be unclear.

The pathophysiology of hearing loss caused by AS is unknown. Mahmud *et al.* hypothesise that the tumour causes degeneration of the acoustic nerve, and that the tumour induces degeneration of the organs of hearing including the hair cells through deposition of proteinaceous material.¹⁰ Sudden SNHL may occur as a result of tumour compression of the labyrinth artery causing spasm or occlusion.^{7, 11} Prasher *et al.* hypothesised that possible mechanisms for hearing loss included chronic partial obstruction of blood supply to the cochlear by the tumour, alterations in the perilymph or endolymph, and hair cell degeneration secondary to neuronal loss in the eighth nerve.¹²

Unexplained SNHL must therefore be investigated, and auditory brainstem response (ABR) testing and magnetic resonance imaging (MRI) are the two tests used to examine patients.¹³ Auditory brainstem response, however, is progressively less sensitive as tumour size decreases, with Schmidt *et al.* finding that only 7% of patients with an AS smaller than 1 cm detected by abnormal ABR.¹³ Cueva stated that if use of MR imaging is conditional on abnormal ABR testing in patients with unexplained SNHL, 29 lesions per 1000 will be missed or diagnosis delayed.¹⁴ He argued that MRI should become the screening method of choice for all patients with unexplained SNHL. As ABR is insensitive to small AS, and Schmidt *et al.* state that negative ABR should not be used as a criterion to not perform MRI.¹³

Tinnitus

Tinnitus has been described as the sensation of sound where sound is not present in the environment.¹⁵ The perception may be of roaring noise, high pitched ringing, or a buzzing noise. The sensation may also be pulsatile, with the pulsations synchronised with the heartbeat, where the clinician should be alerted to the possibility of aneurysm, glomus tumour or stenotic vascular lesions. The pathophysiology of tinnitus is unknown.¹⁵

Vestibular dysfunction

Vestibular dysfunction relates to disorders of the vestibular system, and the most common symptom of vestibular dysfunction that occurs with AS is vertigo.

Vertigo may be physiological or pathological. Pathological vertigo is of greater concern when AS is suspected, and results from a lesion of the vestibular system, the visual system or the somatosensory system. With respect to the vestibular system, the most common cause is labyrinthine dysfunction, and AS may be a cause of this dysfunction.¹⁶

Caloric tests (in which bithermal fluids are introduced into the ear to induce nystagmus) investigate the integrity of the oculovestibular reflex, which is mediated by the superior vestibular nerve.¹⁷ Abnormal caloric tests may be a result of an AS of this nerve, however, caloric tests may be normal if the AS is associated with the inferior branch of the vestibular nerve.¹⁸ Caloric asymmetry increases with increased tumour size.⁶

Acoustic schwannoma

Overwhelmingly, the most common tumour of the CPA is the AS.¹⁹ These lesions account for about 80% to 90% of tumours found in the CPA.^{1,20} Tos *et al.* cite an incidence of approximately 13 cases per million inhabitants per year in a comprehensive Danish study.²¹ A retrospective study of 46,414 MRI head scans to determine the prevalence of unknown AS found an incidence of 0.02%.²²

The cause of the tumour has been linked to an aberration of chromosome $22.^{23}$ There are reported cases of radiation induced AS in the literature, with Salvati *et al.* describing five cases with a latency of 20 years.²⁴

The vestibular nerve (90%) is more commonly involved than the cochlear nerve (10%), and Stone *et al.* state that the inferior segment was more commonly involved than the superior vestibular nerve.^{1,2} A study by Komatsuzaki and Tsunoda of 271 surgical cases found 85% of the AS arose from the inferior branch, 9% from the superior branch, and in 5% of cases they were unable to determine whether the origin was from the superior or inferior branch.²⁵ They found two tumours arising from the facial nerve, and none from the cochlear nerve. The preponderance of the vestibular nerve to be involved would seem to infer that the term acoustic schwannoma is a misnomer, however, overwhelmingly symptoms are auditory in nature rather than vestibular.⁵

Histologically, AS appear as differentiated neoplastic Schwann cells.²⁶ These tumours may contain both Antoni type A cells and Antoni type B cells in different ratios. Tumours consisting of predominately Antoni type A tissue usually appear smaller and homogenous on MR. Tumours with a predominance of Antoni type B cells appear cystic and larger.²⁷ The WHO (World Health Organization) classifies AS as a grade 1 lesion.²⁶

Most AS are intracanalicular, located near the porus acousticus, with extension to the fundus of the IAC. The most common site is at the junction of the Schwann cells with oligodendrocytes, the Obersteiner-Redlich zone.² The tumour is usually focal and lobulated.¹⁹ Most AS are hypovascular, however, some AS may be highly vascular. This type of tumour must be identified, as surgical intervention may present serious complications.²⁸

Acoustic schwannoma contained purely to the labyrinth are rare, with Neff citing 447 cases in the literature.²⁹ Schwannomas found in this location may arise from either the vestibular or cochlear nerves.

Acoustic schwannoma may extend from the fundus of the IAC into the inner ear structures. These tumours will appear as a dumbbell shape, with one component in the IAC fundus and another in the membranous labyrinth or cochlear or the geniculate ganglion of the facial nerve. An isthmus of tumour connects the two components. Extension into the geniculate ganglion is indicative of a facial nerve schwannoma, while a bulbous component into the labyrinth or cochlear indicates a vestibular schwannoma. Clinical treatment and prognosis for each condition is different. Therefore, these lesions are important to identify and differentiate from purely intracanalicular schwannomas.¹⁹

Serial studies show that these lesions may be slow or non-

growing tumours.³⁰ There is no predominance of side of location (left or right) of AS.³¹ Most AS are unilateral and where bilateral or multiple schwannomas are seen, neurofibromatosis type 2 (NF2) should be suspected.²⁶ NF2 should also be suspected when children and young adults present.^{2,32} Massinger *et al.*, in reporting of case of AS in a 12-year-old girl who presented with unilateral hearing loss, state that only 20 cases of AS in juveniles have been reported in the literature.³³

Small AS (between 3 and 15 mm) tend to be ovoid and conform to the IAC, where larger (1.5-3 cm) AS tend to form an 'ice-cream cone' configuration, with the canalicular portion forming the cone, and extension of the tumour into the CPA forming the ice-cream.^{2, 26}

Cystic formation within the AS is usually secondary to coalescence.² Charabi *et al.* cite a growth rate 10 times faster for cystic tumours compared to non-cystic lesions.³⁴

Malignant acoustic schwannomas are extremely rare and include epithelioid malignant schwannoma, malignant peripheral nerve sheath tumours (MPNST) and melanotic schwannomas.³⁵ Tan and Lam state that only four cases of VIII nerve epithelioid schwannoma have been reported.³⁶

As an AS grows, the tumour can cause mass effect on the pons, trigeminal or the facial nerves producing signs and symptoms consistent with compression.⁵ These include trigeminal neuropathy, headaches, hydrocephalus, other cranial neuropathies and death.² Acoustic schwannoma may increase in size during pregnancy and these patients must be monitored.²

Other benign tumours of the CPA include facial nerve schwannoma, choroid plexus papilloma and meningioma. Malignant tumours include metastases, glioma and ependy-moma.²⁶ Intracanalicular meningiomas are rare, with a study by *Asaoka et al.* reporting 17 cases in the literature. All of these tumours may mimic AS on MRI.²⁰

Management of acoustic schwannoma

Management of patients with AS appears somewhat controversial. Options include:

- Conservative management with serial MRI to assess tumour growth;
- 2) Surgical intervention; and
- 3) Gamma knife surgery.

Up to 70% of AS show no signs of growth, and interval MRI may be appropriate to ensure that the lesion remains stable.³⁷ Some patients report a decreased life quality post surgery and radiologic surveillance of the AS would appear appropriate for a population.³⁷ Complications (other than VII and VIII nerve dysfunction) of surgical intervention are rare if the operation is conducted at specialised clinics.³⁸ These complications include CSF leak, VI nerve dysfunction, subdural haematoma, CPA haematoma and cerebral oedema.³⁸

Gamma knife or radiosurgery may result in better outcomes with regard to hearing preservation if the tumour is less than 3 cm in size.³⁹ Gamma knife surgery is also associated with some risks, with Shin *et al.* reporting a case of malignant transformation of an AS six years post radiosurgery.⁴⁰ More common is adherence of the nerves, which may result in sacrifice of the VII nerve if surgery is subsequently required.²

Image contrast

The greatest asset that MRI has is exquisite tissue contrast, especially when compared to other imaging modalities. The intent of this study was to compare two methods of generating image contrast to diagnose acoustic schwannoma: post-contrast enhanced T1 weighted images, and the FIESTA sequence.

Post-contrast T1-weighted sequence

The T1-weighted sequence is a classical spin-echo pulse sequence. The MR pulse sequence is a chain of events that consist of radio frequency pulses in conjunction with magnetic gradient activation. This results in a signal from the anatomy that is detected by a receive coil, which is converted into an image via Fourier transformation. The amount of signal detected is dependant on a number of tissue characteristics, the most important being the T1 recovery, the T2 relaxation and the proton or spin density of the tissue.

By manipulating the pulse sequence, the resultant image can be weighted toward one of these characteristics. By selecting a T1-weighted sequence, tissues with a short T1 will appear bright, and tissues with long T1 values will appear hypo-intense.

Contrast agents

Magnetic resonance-specific contrast agents were introduced to the medical community in 1988, after patents were filed in 1981.⁴¹ The value of these contrast agents is that they effect change of the T1 or T2 values of the tissues that the agent targets, in effect, to manipulate image contrast. To increase the conspicuity of AS, T1 shortening contrast agents are administered. For this study, 5 mL of a gadolinium chelate (Magnevist[®]) was administered to each patient.

Gadolinium is a paramagnetic contrast agent, and thus develops a magnetic moment when placed in a magnetic field (Bo). When the gadolinium chelate is placed in the presence of tumbling water molecules, for example in tumours such as AS, fluctuations in the local magnetic field are created. The T1 value of the water is thus reduced, and therefore appears brighter on the image.

Adverse effects

Adverse effects (AE) from gadolinium agents have been reported in clinical trials as 19.8%, although most were of a nonserious, transient nature, and included headache, nausea, injection site reaction, and taste alterations. Serious reactions were reported at 0.2%. Follow-up studies after release of the drug found AE of 0.03%, with serious AE of $0.005\%^{42}$. A 10-year study by De Ridder *et al.* of 30,000 injections of either gadoterate meglumine or gadopentetate meglumine found three cases of moderate or severe reaction.⁴³

Serious AE have been reported in the literature. These include an incidence of laryngospasm in an eight-year-old child after injection of gadopentetate dimeglumine, an anaphylactoid reaction to gadoteridol, and an incidence of anaphylactoid shock following administration of gadoterate meglumine.^{44, 45,46}

Niendorf and Esser report that after administration of 45 million doses of Magnevist[®], the most common reported AEs were subjective symptoms (11.61 per 100,000), cardiovascular reactions, vomiting, and urticaria (all between 4 and 5 per 100,000).⁴¹ Oedema of the larynx and anaphylactoid shock was reported at less than 0.5 cases per 100,000. Death was reported as possibly drug related in 0.04 cases per 100,000.

Overall, gadolinium chelates are thought to be very safe, but clearly the MR department need to be aware of the possibility of a moderate or severe AE.⁴⁷

The value of contrast agents is that tissue contrast is increased. T1 weighted scans of acoustic schwannomas are iso-intense with surrounding structures. Introduction of gadolinium contrast results in the AS becoming hyper-intense on T1-weighted images. Comparison of FIESTA and Gadolinium-enhanced T1 weighted sequences in magnetic resonance of acoustic schwannoma

FIESTA

Fast imaging employing steady state acquisition (FIESTA) is the General Electric Company acronym for a sequence that employs gradients to induce a constant or steady amount of transverse magnetisation. FIESTA is a true-FISP (Fast Imaging with Steady-state Precession) sequence.

Historically, steady-state free precession imaging was not clinically feasible due to the slow switching rates of the gradients, low rise times, and small slew rates. Indeed, Zur *et al.* stated in 1987 that pulse sequences where the TR was equal to or less than the T2 of the sample seemed technically impossible.⁴⁸ However, by the late 1990s, advances in gradient and power amplifier design had allowed true-FISP imaging to be revisited.⁴⁹

This sequence uses very short TRs and TEs, and produces images with high signal to noise ratios (SNR). Balanced gradients refocus transverse magnetisation at the completion of each TR cycle. The short TRs used in FIESTA imaging are essential to maintaining this spin coherence. The sequence is very sensitive to field inhomogeneities, and requires shimming to reduce inhomogeneity to less than 1 ppm.⁵⁰

The TR of this sequence is much smaller than the T2 of the tissue under investigation.⁵¹ Image contrast in FIESTA is due to the differences in the ratio of T2/T1 in the tissue. As short TRs and TEs are employed, tissues with long TR values will have increased signal.⁵² It is the fact that image contrast is a function of the ratio of T2 to T1 values of the tissue, together with high SNR values that make true-FISP imaging unique.⁵³ The signal intensity is a function of the proton density, the T2 and the T1 of the tissue, the flip angle, and the TR of the sequence, with the maximum intensity established when the TR is approximately 5 x T1/TR.⁵⁴

In order to maintain high SNR, high image contrast, and decrease the scan time, the TR and the TE must be kept as low as possible. Again, this requires high-powered gradient performance. As with other MR pulse sequences, increasing the matrix, or decreasing the slice thickness or field of view results in increasing resolution, at the cost of deceased SNR.

The FIESTA sequence may be thought of as a fluid-bright sequence. These sequences are those in which fluids exhibit hyper-intensity compared to surrounding tissues. When studying the CPA and basal cisterns, CSF is uniformly hyper-intense in these sequences.

Problems for FIESTA

Acoustic noise

One of the products of the MR process is high levels of acoustic noise. Acoustic noise is a result of the alternating energising of the magnetic gradients in the presence of a strong magnetic field. As the coils are energised, they vibrate against their mountings, and noise is produced. The effects of this noise include annoyance, difficulties in radiographer/patient communication, increased anxiety, and temporary or permanent hearing loss.55 The loudness of the noise increases with decreases in slice thickness, field of view (FOV), repetition time (TR), echo time (TE), and echo spacing.55 Clearly, as a FIESTA sequence to study the inner ear requires small FOV, small slice thickness, and because the FIESTA sequence requires small TRs and TEs, acoustic noise will be greater than for a spin echo or gradient echo sequence. Use of hearing protection when performing FIESTA sequences is mandatory. All patients in this study were made to insert Laser Lite® multi-color (sic) foam ear pads, manufactured by Howard Leight Hearing Protection. When used in accordance

with the manufacturer's directions, the manufacturer claims that these plugs reduce noise levels by 32 dB.

Peripheral nerve stimulation

The Signa LX Release 9.1 New Features Learning and Reference Guide (2002) states that peripheral nerve stimulation (PNS) may be a problem when the FIESTA sequence is employed.⁵¹ Peripheral nerve stimulation is a condition that presents when electrical currents are induced in the human body by magnetic field gradients rapidly changing with time (dB/dt). This stimulation is an application of Faraday's Law, which states that when a conductor (in this case a peripheral nerve) is placed in a changing magnetic field, an electrical current will be induced. The major concern of producing a current in the body is changed neuro-muscular function. This may be graded, with the least severe response being a pins and needles sensation. Higher levels of slew rate may produce pain in the individual. Very high levels of dB/dt have the potential to produce cardiac stimulation, with the possibility of ventricular fibrillation.⁵⁶

The 3D FIESTA *Pulse Sequences Learning and Reference Guide* advises caution, and advises that verbal and visual contact be maintained with the patient at all times.⁵⁷ Prior to examination, the patient must be warned that there is a possibility of tingling or twitching sensations and that, while these are not harmful, they should be avoided. Peripheral nerve stimulation may be reduced or eliminated by breaking closed loops caused by crossed arms or legs. Therefore, it is crucial the radiographer instruct the patient not to cross their arms or legs. The patient experiencing PNS sensations should use the emergency button to alert the radiographer. The radiographer must then abort the sequence, and use a non-FIESTA sequence to complete the examination.

Materials and methods

Ethics approval for this study was obtained from the University of Queensland and written permission to use the data was also obtained from the medical imaging company.

Data from 50 patients that presented to the MRI Department of Queensland Diagnostic Imaging's Brisbane Private Hospital branch were retrospectively reviewed. These patients presented consecutively between 12th October 2004 and 19th January 2005. The criterion for inclusion was that the patient presented with a referral from an ear, nose and throat (ENT) specialist, requesting MRI examination of the cerebro-pontine angles. Basis for the referral (as notated on the referral) is given below.

Table 1 Total nun	nber of referral	s for each	clinical	indication
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Clinical Indication	Number of Referrals		
Sensorineural hearing loss	17		
Sudden sensorineural hearing loss	1		
Exclude acoustic schwannoma	14		
Follow-up or monitor CPA tumour	6		
Vertigo or dizziness	8		
Tinnitus	3		
Ear pain	1		
Total	50		

Total number of referrals for each clinical indication

All patients that presented to the MR Department were screened for exclusion due to incompatibility for MR examination. Absolute contraindications include patients with pacemakers, neural stimulators, and aneurysm clips. Once the patient had



Figure 1 FIESTA image from Patient 1.

been cleared for examination, they were scanned on a 1.5 Tesla General Electric Echo-Speed with Version 9 software platform. This scanner has gradient amplitude of 33 mT/m, and a slew rate of 120 mT/m/s.

The departmental protocol of sequences performed on these patients is:

- 1) 3-plane Localiser;
- 2) Axial FLAIR Whole head;
- 3) Axial Diffusion-weighted images (DWI) Whole head;
- 4) 3D FIESTA Axial across the CPA;
- 5) Axial T1-weighted sequence across the CPA; and
- 6) Axial T1-weighted sequence post intra-venous Gadolinium.

The purpose of the 3-plane localiser is to permit prescription of the imaging sequences, and is a fast gradient recalled echo (GRE) sequence. The purpose of the FLAIR (Fluid Attenuated Inversion Recovery) and DWI is to exclude causes of SNHL other than AS, such as demyelination or stroke. These sequences also allow for examination of the central vestibulocochlear pathways. The precontrast T1-weighted scans are performed to provide a baseline for the following post-contrast sequences. If an area of CPA demonstrates high signal intensity on the post-contrast images and is iso-intense compared with grey matter on the pre-contrast scans, a diagnosis of AS can be made confidently.26 The pre-contrast T1weighted sequence also removes the possibility of the presence of fat being misdiagnosed as enhancing tumour. The FIESTA sequence demonstrates the CSF and the peri- and endolymph as high signal intensity. The vestibulocochlear nerve bundles will appear as hypo-intense structures. Acoustic schwannoma appear as filling defects in the high signal CSF of the CPA.

The parameters for the FIESTA sequence were:

- 1) TR 6.3 msec;
- 2) TE: 2.5 msec;
- 3) Flip Angle: 45;
- 4) Frequency: 288 steps;
- 5) Phase: 224 steps;
- 6) Slice thickness: 1.2 mm;
- 7) Overlap: 0.6 mm;
- 8) Bandwidth: 41.67 KHz;
- 9) Field of View: 18 cm;
- 10) Number of Excitations (NEX): 6;
- 11) Frequency Direction: Anterior-Posterior; and
- 12) Scan Time: 3 min 29 seconds.

The parameters for the T1-weighted contrast-enhanced sequence were:

1) TR 450 msec;



Figure 2 Axial T1-weighted post-contrast image from Patient 1.

- 2) TE 9 msec;
- 3) Frequency: 288 steps;
- 4) Phase: 224 steps;
- 5) Slice Thickness: 3 mm;
- 6) Spacing: 0.2 mm;
- Bandwidth: 10.42 KHz;
 Field of View: 18 cm;
- S) Field of Vie
- 9) NEX: 2;
- 10) Frequency Direction: Anterior-Posterior; and
- 11) Scan Time: 3 min 20 seconds.

Each patient was administered 5 mL of Magnevist® intravenously. From each patient, the FIESTA sequence and the post-contrast T1-weighted sequence were transferred to a GE workstation. The

cases were de-identified and reviewed by a neuro-radiologist.

For each case, by way of a pro forma, the neuro-radiologist was asked the following questions:

- 1) Are the FIESTA and the T1 weighted post-contrast images of diagnostic quality?;
- 2) Do the FIESTA images demonstrate the absence or presence of acoustic schwannoma?;
- 3) Do the T1 weighted post-contrast images demonstrate the absence or presence of acoustic schwannoma?;
- 4) Have the T1 weighted post-contrast images added information that is not demonstrated by the FIESTA images?;
- 5) Have the FIESTA images added information not seen in the T1 weighted post-contrast images?; and
- 6) Could this examination have been satisfactorily performed with the FIESTA images and not the T1 weighted post-contrast images?

The results of the pro forma were collated.

Results

There was a 50 from 50 (100%) Yes answer to Question 1 - Are the FIESTA and the T1 weighted post-contrast images of diagnostic quality?

There was a 50 from 50 (100%) Yes response to Question 2 - Do the FIESTA images demonstrate the absence or presence of acoustic schwannoma?

There was a 50 from 50 (100%) Yes answer to Question 3 - Do the T1 weighted post-contrast images demonstrate the absence or presence of acoustic schwannoma?

There was a three from 50 (6%) Yes answer to Question 4 – Have the T1 weighted post-contrast images added information that is not demonstrated by the FIESTA images?

There was a 50 from 50 (100%) Yes response to Question 5

Comparison of FIESTA and Gadolinium-enhanced T1 weighted sequences in magnetic resonance of acoustic schwannoma



Figure 3 Axial T1-weighted post-contrast image from Patient 41.



Figure 5 T1-weighted post gadolinium from Patient 4.

– Have the FIESTA images added information not seen in the T1 weighted post-contrast images?

There was a 49 from 50 (98%) Yes response to Question 6 – Could this examination have been satisfactorily performed with the FIESTA images and not the T1 weighted post-contrast images?

Discussion

Question 1

Question 1 was designed to elucidate whether the image quality of both sequences was clinically useful. If the image quality was degraded in any way (for example, by patient movement, or presence of ferro-magnetic bodies), the case would have been deleted from the study.

The question also queried the integrity of both sequences: were the sequences of a standard required by a clinical neuro-radiologist to confidently make a diagnosis. The 100% Yes response would indicate that all the images in this study were of a high standard, and that the neuro-radiologist was able to interrogate the images for the purposes of this study. Figure 1 demonstrates the exquisite detail of the VII and VIII nerves on the FIESTA sequence, where they appear as linear hypo-intense structures from the apparatus of the inner ear, traversing the IAC surrounded by hyper-intense CSF, and joining the CPA. The hyper-intense perilymph and endolymph is seen within the cochlear and semicircular canals.

Figure 2 is an image taken from the T1-weighted post-contrast sequence of the same patient as Figure 1. Again, the image is of



Figure 4 FIESTA image from Patient 41.



Figure 6 FIESTA Sequence from Patient 4.

diagnostic quality and no evidence of AS is seen.

Figure 3 demonstrates the high sensitivity that the T1-weighted post-contrast sequence has when an AS is present. The AS is seen as a hyper-intensity within the confines of the left Internal Auditory Canal (IAC).

By contrast Figure 4 demonstrates the FIESTA image of the same patient as in Figure 3 as a signal void in the same position.

Question 2

This question asked the neuro-radiologist if he could make a diagnosis of AS or exclude AS with the FIESTA images alone. The response was 100% that the FIESTA images could achieve this goal. That is, if the question being asked of the neuro-radiologist is 'Does the patient have an AS or not?' then in every case the FIESTA images were sufficient.

Question 3

Similarly to Question 2, this question asks the neuro-radiologist to ascertain whether the post-contrast sequence is able to confirm or exclude AS. Again, a 100% 'Yes' response indicates that this sequence can be employed to provide an answer to the referring specialist. This was not surprising, given that for many years this sequence has been regarded as the gold standard for imaging diagnosis of AS.⁵⁸

Question 4

This question was designed to assess whether the T1-weighted post gadolinium scans provided information not demonstrated by the FIESTA. If this was so, then the hypothesis, that this sequence was not required, could be proved null. In three cases (6%), the response was a Yes, that the post-contrast T1-weighted sequence



Figure 7 FIESTA sequences for Patient 27.



Figure 9 FIESTA sequence for Patient 46.

did provide further information. The three cases were checked against the specialist referral, and with the report of their case.

Patient 4: This patient was referred to follow-up of a right sided AS. As seen in Figure 5, the post-contrast T1-weighted sequence demonstrates an area of low signal within the tumour, suggestive of an area of necrosing tissue or cystic changes. The FIESTA image, Figure 6, demonstrates merely a signal void, and does not further characterise the lesion.

Patient 27: This patient was referred to assess AS post-surgery. The contrast-enhanced T1-weighted scans better demonstrated post-surgery fat packing than the FIESTA scans. Comparative images from this patient's scans are shown in Figures 7 and 8.

Patient 46: This patient was referred to monitor the progress of a large lobulated mass in the CPA. The T1-weighted post-contrast better demonstrated post-surgical appearances than the FIESTA sequence. Images from this patient's scans are shown in Figures 9 and 10.

Significant from this question was that the T1-weighted postcontrast sequences added additional information on only one follow-up and two post-surgical patients. This would suggest that while the hypothesis of the study did not hold true for this class of patient, it may still be true for patients presenting for diagnosis or exclusion of AS.

Question 5

This question was answered with a 100% 'Yes' response: in every case, the FIESTA sequence added information not seen by the T1-weighted scans. The question was designed to determine whether the FIESTA sequence provided a benefit additional to a T1-weighted post-contrast sequence. If it was found that the FIESTA did not add information demonstrated by the T1weighted contrast-enhanced images, then the FIESTA sequence



Figure 8 T1-weighted post gadolinium for Patient 27.



Figure 10 T1-weighted post gadolinium for Patient 46.

could be deleted from the protocol. It appears that in every case, the FIESTA added to the diagnostic yield of the examination. This would appear to support study by Schmalbrock *et al.* (1999), which found that high-resolution T2-weighted images of the IAC demonstrate more detail of the VII and VIII nerves, and more accurate tumour volume measurements.⁵⁹

Question 6

This was a critical question to this study. If it were found in all cases that the FIESTA sequence was all that were required, then the hypothesis could be unequivocally proved correct. Even though in 6% of cases the T1-weighted post-contrast scans demonstrated information not seen in the FIESTA sequence (Question 4), this information may not be of relevance to the clinical question being asked i.e. does this patient have an AS? However, there was one case where the neuro-radiologist found that the examination could not be performed by producing the FIESTA sequence without the addition of post-contrast T1-weighted images.

The patient for whom the neuro-radiologist found the FIESTA without the addition of a post-contrast T1-weighted scan insufficient was Patient 46. Clearly, the neuro-radiologist felt that the FIESTA sequence was adequate for Patients 4 and 27, but not for patient 46. This patient's images are shown in Figures 9 and 10. The radiologic report description of the lesion of patient 46 is of a large, lobulated, enhancing mass measuring 22 mm x 20 mm, with evidence of oedema in the pons due to the mass. There is also evidence of a mastoidectomy on the same side as the tumour. It would seem that this patient presents as a complex post-operative case. One could assume that the mastoidectomy is evidence of surgical intervention. It is not possible to determine without access to the patient's clinical history why this large lesion is present after surgical intervention. Several possibilities present

themselves, including that the surgery was unsuccessful, or that tumour has become malignant, or that the lesion was not an AS, but some other CPA tumour such as a meningioma or metastasis. The conclusion that may be drawn from the images of patient 46 and the 'No' response to Question 6 is that post surgical follow-up MR requires inclusion of the post-contrast T1-weighted sequence.

It would appear that in the majority of cases, the FIESTA sequence is sufficient to diagnose or exclude AS. Question 2 'Do the FIESTA images demonstrate the absence or presence of acoustic schwannoma?' elicited a 100% yes response. Clearly the integrity of the sequence is strong, with the neuro-radiologist confident that the sequence was of diagnostic quality (Question 1). In only a small number of cases (6%) did the T1-weighted postcontrast sequence provide information not seen in the FIESTA sequence. Review of these cases showed that two patients were referred for MRI to image post-surgery changes. In view of this finding, it would appear prudent to perform gadolinium-enhanced T1-weighted images on all post-surgery patients. The third case where the neuro-radiologist found post-contrast T1-weighted images to be of benefit in excess of the FIESTA was a patient whose known AS was referred to follow-up. The post-contrast T1-weighted images of this patient demonstrate an area of hypointense signal intensity within the brightly enhanced AS. This finding is suggestive of necrosed tissue or cystic change within the AS. This is a significant finding, as cystic AS may expand at a rate of 10 times faster growth compared to non-cystic lesions.³⁴ The FIESTA sequence in this case did demonstrate the AS; however, the changes in the central part of the lesion were not seen. The conclusion that should be drawn from this is that all patients in whom the FIESTA demonstrates an AS should then proceed to gadolinium-enhanced T1-weighted images to exclude cystic changes within the lesion.

This study seems to demonstrate that the FIESTA sequence is an ideal method to interrogate the CPA to exclude AS. It would seem that the FIESTA sequence should be the first sequence employed to investigate possible AS and then pre- and postcontrast T1-weighted sequences should be performed if an AS is found on FIESTA imaging. Post-contrast imaging should be performed on patients requiring MR after surgical intervention. These cases would also benefit from FIESTA images, as in all cases it was found that this sequence added information not seen in the post-contrast T1-weighted images.

The advantages of FIESTA imaging as a stand-alone protocol for AS include:

- 1) Reduction in the time taken for the examination;
- No contrast administration required, and the possibility of AE removed;
- 3) Detailed anatomy of the inner ear; and
- 3D imaging the FIESTA images can reformatted into thinner/thicker slices, and Maximum Intensity Projections (MIP) images created.

In order to maintain a high level of signal to noise, the slice thickness of the T1-weighted sequences is limited to 1.5–3 mm, so characterisation of small lesions is not possible. The FIESTA sequence allows sub-millimetre sections, permitting better depiction of small tumours. The fluids of the inner ear (perilymph and endolymph) appear hyper-intense on the FIESTA sequence, allowing visualisation of the cochlear and semi-circular canals, which is not possible on the T1-weighted sequences in this study. Our 3D FIESTA sequence employs a slice thickness of 1.2 mm, with overlap of 0.6 mm. These fine sections allow reformatting to any slice thickness or orientation, and Maximum Intensity Projections (MIP) images.

The disadvantages of FIESTA-only protocol for the exclusion or diagnosis of AS without post-Gadolinium T1-weighted scans include:

- Further characterisation by post-contrast T1-weighted images of lesions in patients found to have AS, or returning for monitoring of known AS;
- 2) Patients with other pathologies of inner ear may be missed and;
- 3) Post-operative changes appear to be better demonstrated by post-contrast T1-weighted images.

As shown by Patient 4, cystic degeneration of the AS is possible, and may be a marker of a fast growing tumour.³⁴ The post-contrast sequence demonstrated this change, while the FIESTA sequence did not.

Other pathologies of the CPA may be better characterised by the post-gadolinium T1-weighted images than the FIESTA sequence, including epidermoid cysts, arachnoid cysts and metastasis.²⁶

Conclusion

Without Patient 46, the hypothesis that T1-weighted postgadolinium sequences were not required when FIESTA sequences are employed would have been proved within the context of the relatively small number of patients in this study. However, the findings of this study with regards to Patient 46, and to a lesser extent Patients 4 and 27, demonstrate that contrast-enhanced T1weighted scans have a major role to play in cases where a tumour is seen, or cases that require post-operative follow-up.

The findings of this study would appear to concur with studies performed previously comparing post-contrast T1-weighted images of the CPA with bright fluid sequences such as T2weighted sequences, CISS (Constructive Imaging in the Steady State) sequences and SIMCAST (Segment-Interleaved, Motion-Compensated Acquisition in STeady state) sequences.⁵⁹⁻⁶⁴ These studies suggest that contrast enhanced T1-weighted images are not required when fluid bright sequences are employed in the majority of cases. However, the FIESTA sequence may be employed to separate patients without pathology from those with CPA pathology.

This study has found that the MRI examination of patients found not to have pathology in the CPA may be considered complete after the FIESTA sequence. Those patients whose FIESTA sequence demonstrates pathology in the CPA should be further examined by post-contrast T1-weighted sequences. In addition, in cases where gadolinium may not be administered, such as pregnant patients or patients with known sensitivity to gadolinium, the FIESTA sequence may be used in isolation from contrastenhanced T1-weighted sequences to exclude AS. Although no pregnant patients were included in this study, it has been shown that AS may appear or enlarge during pregnancy.⁶⁵ In these cases, the use of the FIESTA sequence would appear to sufficient to exclude AS, without the need for gadolinium-enhanced sequences. This would agree with Stuckey et al., who found that in the absence of T1-weighted gadolinium-enhanced sequences, CISS images were sufficient to diagnose or exclude AS.64

By limiting the pre- and post-contrast T1-weighted sequences to a targeted patient population (i.e. those with pathology seen on the FIESTA sequence), there are savings to be made in terms of:

- 1) Time taken for the examination;
- 2) Cost of gadolinium contrast; and

3) Risk of adverse reaction from gadolinium injection. All may be achieved without compromise of the patient.

Marx *et al.* and Stuckey *et al.* state that a screening sequence for exclusion of AS should be sensitive, specific, inexpensive and non-invasive when compared to the use of gadolinium-enhanced T1-weighted sequence.^{64,66} By these criteria, the FIESTA sequence is an ideal tool for investigation of possible AS.

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