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High-resolution computed tomography in evaluation of cochlear patency in implant candidates: a comparison with surgical findings

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Abstract

High-resolution computed tomography (HRCT) is important in the evaluation of cochlear implant candidates. This study examines the accuracy of radiological assessment of cochlear patency in relation to findings at the time of surgery. Older and newer HRCT methods and attending and senior radiologist interpretations are compared in a large series of cochlear implant patients.

Subjects were 50 adults (22 to 74 years) and 31 children (2.4 to 11.7 years) who received either a 3M/House or a Nucleus 22-channel cochlear implant. Attending radiologist reports were obtained by chart review and the scans were re-reviewed for this study by a senior radiologist. Accuracy in detecting cochlear ossification ranged from 86.4 per cent for attending radiologists, with all HRCT scans, to 94.7 per cent for the senior radiologist with newer HRCT scans. False positives were rare, but false negatives did occur. Overall, best results were obtained with newer HRCT scans and a senior radiologist.

Knowledge of the presence and extent of cochlear ossification is important to the implant surgeon and for patient counselling. Technical guidelines and a check list for interpretation of results are presented.

Key words: Cochlear implant; Tomography, X-ray computed; Ossification, heterotopic; Cochlea

Introduction

Good pre-operative radiology of the temporal bone is important in the evaluation of candidates for cochlear implantation. Radiological findings can influence a decision regarding candidacy, play a role in the choice of ear to be operated, and provide information that can assist the surgeon in preparing for surgery.

Contraindications to cochlear implantation determined by radiological assessment include cochlear aplasia (total absence of the cochlea) (Jackler *et al.*, 1987a) and a very narrow internal auditory canal (Shelton *et al.*, 1989). Other cochlear malformations are not a contraindication (Jackler *et al.*, 1987b); nor is presence of ossification and/or fibrosis in the cochlea (Eisenberg *et al.*, 1984; Fayad *et al.*, 1990; Green *et al.*, 1991). However, it is important for the surgeon to be aware of any anatomical abnormalities of the temporal bone that might make placement of the device more difficult or adversely influence device efficacy.

Congenital malformations of the osseous labyrinth are readily diagnosed with current computed tomography methods. However, cochlear ossification and fibrosis can vary in degree and extent, and may be more difficult to identify by radiological assessment. A radiological classification scheme concerning cochlear ossification has been developed by Dreisbach and Balkany (1988).

The accuracy of high-resolution computed tomography (HRCT) in defining cochlear patency has been variable, ranging from 54 to 92 per cent (Jackler *et al.*, 1987c; Balkany *et al.*, 1988; Laszig *et al.*, 1988; Wiet *et al.*, 1990). Differences may be related to technology and methods, experience of the radiologist in temporal bone interpretation, or other factors.

This study examines accuracy of radiological assessment of cochlear patency in relation to findings at the time of surgery. We compare older with newer HRCT methods and attending radiologist with senior radiologist interpretations in a large series of cochlear implant patients that includes both adults and children.

Materials and methods

Subjects

All patients undergoing cochlear implantation at the House Ear Clinic between January, 1984 and September, 1991 for whom pre-operative HRCT scans were available are included in this study. There were 81 patients who met

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these criteria, including 50 adults (>18 years) and 31 children (<12 years).

Adults included 27 males and 23 females, ranging in age from 22 to 74 years, with a mean age of 47.6 years. Eleven of the adults received the 3M/House single-channel cochlear implant, while 39 received the Nucleus 22-channel device. The right ear was implanted in 32 (64 per cent) adults and the left in 18 (36 per cent).

Children included 22 males and 9 females, ranging in age from 2.4 to 11.7 years, with a mean age of 5.4 years. Twelve of the children received the 3M/House implant and 19 were implanted with the Nucleus 22-channel cochlear implant. The right ear was implanted in 13 (41.9 per cent) children, the left in 18 (58.1 per cent).

The causes of deafness are presented in Table I. Twenty (64.5 per cent) of the children had been deafened by meningitis while the other 11 (35.5 per cent) were congenitally deaf – two of them have Waardenberg's syndrome and one Goldenhar' syndrome. In the group of children deafened by meningitis, 16 (80 per cent) were males and four (20 per cent) females. A difference in incidence between the sexes is expected from the reported prevalence rates of hearing loss from meningitis in the United States (Wolff and Brown, 1987). In the adult group, the most frequent causes of deafness were progressive unknown in 11 patients (22 per cent) and meningitis in 10 patients (20 per cent).

Procedures

Radiological technique

Different scanners were in use over the time period during which this series of cases was evaluated. Twenty-four earlier HRCT scans were performed using a GE 8800 scanner (General Electric; Milwaukee, WI) in 1.5 mm contiguous axial sections parallel to the infraorbital-meatal line with a bone review program. Other technical parameters for the GE 8800 scanner included head circle, 120 KVP, 480 MAS, 9 s scan time, and target 3.0 X. Since 1988, 57 HRCT scans were performed on a GE 9800 scanner (General Electric; Milwaukee, WI) in 1.5 mm sections every 1 mm oriented at + 30° to the infraorbital-meatal line with an edge enhancement algorithm to maximize the osseous details. The milliamperage (mA) varied in the scans performed with the GE 9800 from 100 mA in children/120 mA in adults in 23 patients to 140 mA in children/170 mA in adults in the remaining 34 patients. Other technical parameters on the GE 9800 included 140 KVP, 2 s scan time and 9.6 cm display field of view. A window width of 4000 HU and a level from 500 HU to 900 HU was chosen. No coronal sections were obtained.

TABLE I

CAUSES OF DEAFNESS IN STUDY SUBJECTS

	Children	Adults
Meningitis		
Unknown	10 (32.3%)	9 (18%)
Diplococcus pneumoniae	4 (12.9%)	1 (2%)
Haemophilus influenzae	6 (19.4%)	
Congenital		
Unknown	7 (22.6%)	4 (8%)
Syndrome	3 (9.7%)	
Viral	1 (3.2%)	
Progressive unknown		11 (22%)
Sudden unknown		3 (6%)
Otosclerosis		3 (6%)
Ototoxic drugs (gentamicin; silver nitrate)		2 (4%)
Other*		17 (34%)

*Includes patients in which a different cause was responsible for deafness in each of the two ears and other causes that were responsible for only a single patient (vascular; progressive hereditary; bilateral glomus tumour; autoimmune disease; skull trauma; Acoustic trauma, tympanogenic labyrinthitis, Ménière's disease, etc).

Data collection

The inner ear appearance was classified as normal or according to the Jackler, Luxford and House classification (Jackler *et al.*, 1987a) if malformations were present. When cochlear ossification was identified on the scan, it was classified as: Partial scala tympani (ST); Full ST; Full ST + scala vestibuli (SV); or Total. The extent of ossification was measured in millimeters (mm) from the most lateral aspect of the round window niche to the most medial aspect of the bone obstruction in a line traced along the basal turn of the cochlea.

Surgical findings were classified as: Patent ST; Partial ossification; Complete ossification; or Soft tissue. In addition, the number of millimeters drilled and the number of electrodes inserted was noted.

The radiological data were recorded as found in the reports of the attending radiologist. The scans were then re-reviewed by the senior radiologist (W.W.M.L.), blinded to the history and to the surgical results, using the classification proposed by Dreisbach and Balkany (1988) which uses four categories: C0 = normal cochlea (Figure 1); C1 = indistinctness of the endosteum of the basal turn (Figure 2); C2 = definite narrowing of the basal turn (Figure 3); and C3 = bony obliteration of at least a portion of the basal turn or the middle turn or the entire cochlea (Figure 4).

Results

Radiological findings

Data were obtained from the radiological reports by chart review regarding the general appearance of the mastoid, middle ear, and inner ear, and the degree of ossification of the cochlea. Mastoid pneumatization was extensive in 62 cases (76.5 per cent), partial in 13, and sclerotic in one. Previous mastoid surgery had been performed in five cases. The middle ear was normal in 77 cases; previous middle ear surgery had been performed in three cases; and in one case a malformation of the ossicular chain was present. Two patients had an enlarged vestibular aqueduct; one patient had a dysplasia of the lateral semicircular canal; and one patient had cochlear otosclerosis. The most serious deformities were a severe incomplete partition in one case and a common cavity in another. Otherwise, excepting labyrinthine ossification, the inner ear was normal in 75 patients (92.6 per cent).

The HRCT report of the attending radiologist was negative for cochlear ossification in 59 patients (72.8 per cent). In 20 patients (24.7 per cent), partial ossification of the scala tympani (ST) was reported. One case had full ossification of the basal turn, and one total cochlear ossification was present. In cases where partial ossification was pres-

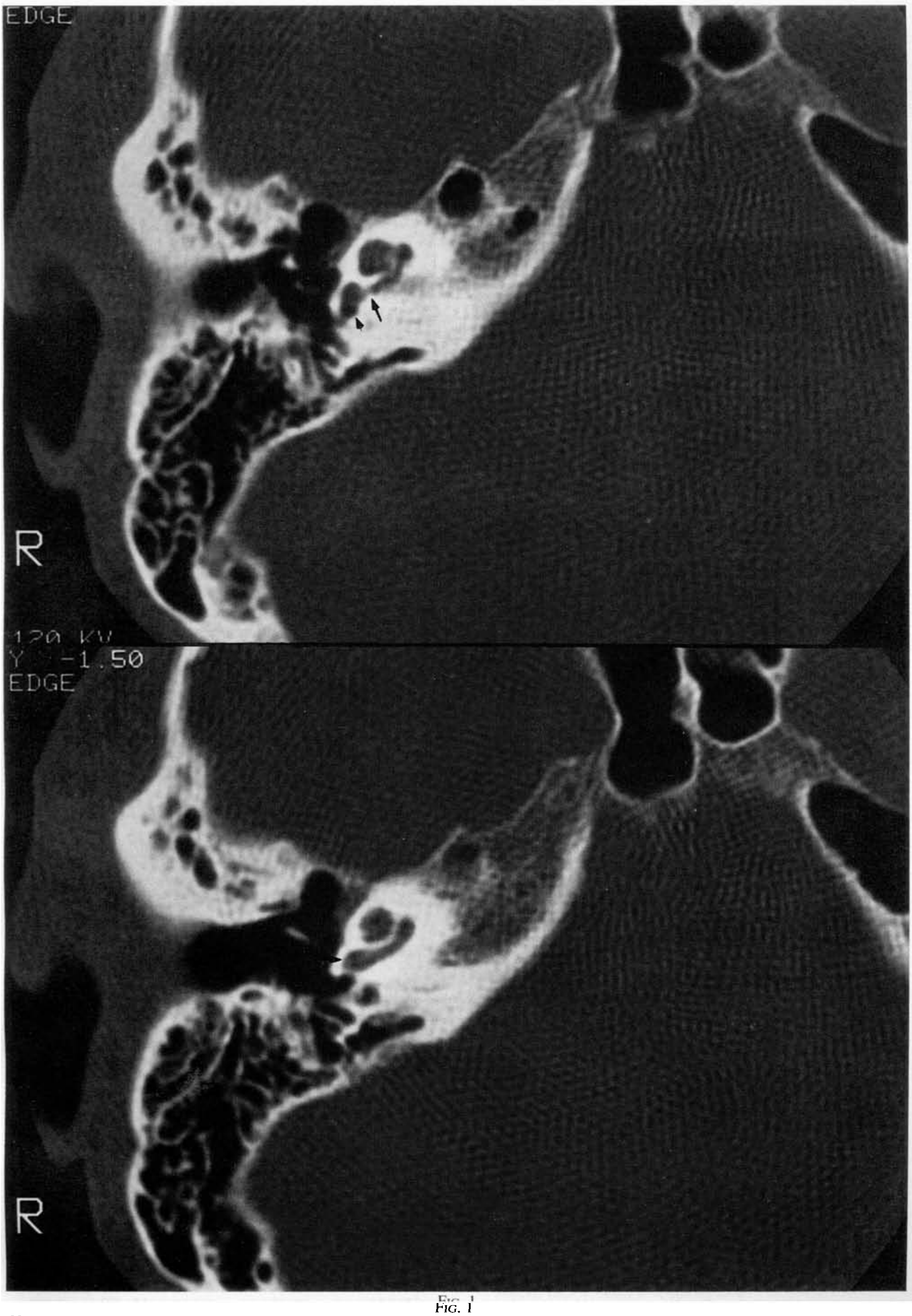

FIG. 1

Normal cochlea (C0). Top: Medial wall of the basal turn of the cochlea (arrow); air-filled round window niche (arrowhead); bone-free basal, middle and apical turns. (Reprinted with permission of the House Ear Institute). Bottom: Osseous spiral lamina (arrow) with the smooth walls of the scale tympani posteriorly and of the scala vestibuli anteriorly. (Reprinted with permission of the House Ear Institute).

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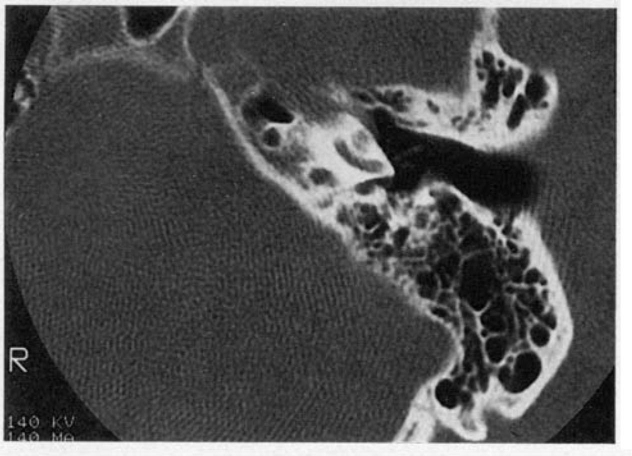

Fig. 2.
Indistinctness of the endosteum (C1). Questionnable ossification behind the round window membrane for indistinctness of the endosteum. (Reprinted with permission of the House Ear Institute).

ent, it began near the round window, extending along the scala tympani for a variable distance.

Surgical findings

At surgery, the scala tympani was found to be patent in 48 (59.3 per cent) patients. Partial ossification was present in 29 (35.8 per cent) cases, complete ossification in two (2.5 per cent), and soft tissue in two (2.5 per cent). The distance drilled at surgery, in millimeters (mm), is reported in Table II. Where 1 mm of drilling is reported, only the round window membrane was found to be ossified.

The number of electrodes inserted in the cochlea is reported in Table III. The single electrode was successfully inserted in all 23 3M/House cases. In 49 of the 58 (84.5 per cent) Nucleus 22-channel cases, 22 electrodes plus a number of stiffening rings ranging from 1 to 10 were inserted. In the other nine (15.5 per cent) cases, less than the full complement of 22 electrodes were inserted.

Comparison of radiological with surgical findings

Table IV presents the surgical findings as a function of the radiological findings as determined from the attending

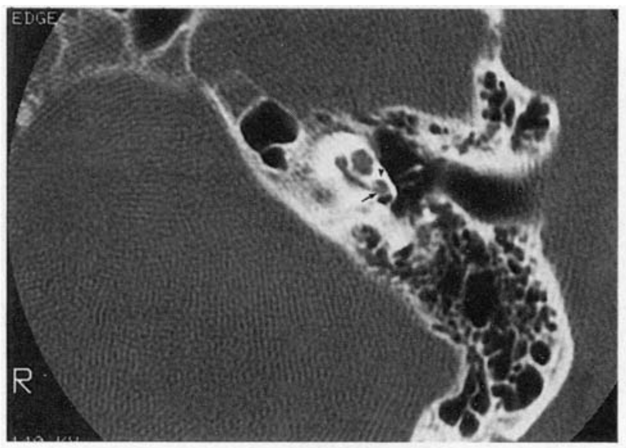

Fig. 3.
Definite narrowing (C2). Small amount of bone along the wall of the scala tympani (arrow). Bone-free scala vestibuli (arrowhead). (Reprinted with permission of the House Ear Institute).

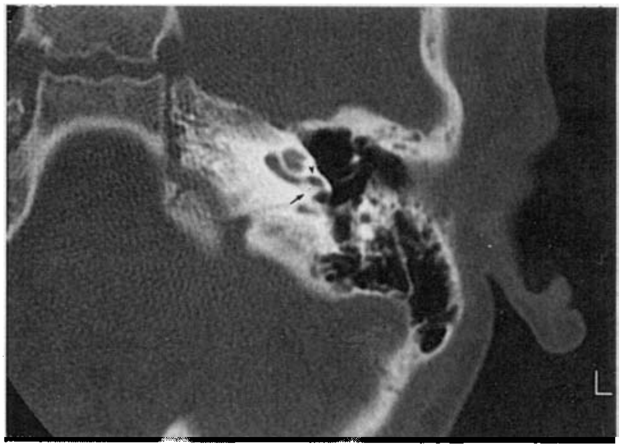

Fig. 4.
Bony obliteration (C3). Ossified scala tympani behind the round window membrane (arrow). Bone-free scale vestibuli (arrowhead). The extension of the ossification is 3 mm. (Reprinted with permission of the House Ear Institute).

radiologist reports. Of the 59 cases in which no bone was observed on the HRCT, a patent scala tympani was found at surgery in 48: true negatives. However, in the remaining 11 cases that were negative on HRCT, partial ossification (nine cases) or soft tissue (two cases) was found at surgery: false negatives. All 20 cases in which partial scala tympani obliteration was reported by the attending radiologist had partial ossification present at surgery; a case with complete ossification of the basal turn and a case with complete cochlear ossification reported on radiology had complete ossification found at surgery: true positives. In no case in which cochlear ossification was reported by the attending radiologist was the scala tympani found to be patent at surgery: no false positive cases.

The data in Table V are based on the re-review of the

TABLE II
MILLIMETERS (MM) DRILLED AT SURGERY DUE TO OSSIFICATION

Millimeters drilled	No of patients (%)
0 mm	49 (60.5)
1 mm	3 (3.7)
2 mm	10 (12.3)
3 mm	5 (6.2)
4 mm	2 (2.5)
5 mm	2 (2.5)
6 mm	7 (8.6)
8 mm	2 (2.5)
9 mm	1 (1.2)

TABLE III
NUMBER OF ELECTRODES INSERTED IN THE COCHLEA AT SURGERY

No of electrodes	No of patients (%)
3M House single-channel cochlear implant	
1	23 (100.0)
Nucleus 22-channel cochlear implant	
8	1 (1.7)
12	2 (3.4)
14	1 (1.7)
18	1 (1.7)
19	2 (3.4)
20	2 (3.4)
22	13 (22.4)
>22*	36 (62.1)

*1 to 10 stiffening rings were inserted.

TABLE IV
COCHLEAR OSSIFICATION AS FOUND IN THE REPORTS BY ATTENDING RADIOLOGISTS COMPARED TO SURGICAL FINDINGS

Radiological findings	Surgical findings			
	Patent	Partial ossification	Complete ossification	Soft tissue
None	48	9		2
Partial ST ossification		20		
Full ST + SV ossification			1	
Total ossification			1	

TABLE V
COCHLEAR OSSIFICATION AS FOUND IN THE SENIOR RADIOLOGIST'S REVIEW COMPARED TO SURGICAL FINDINGS

Radiological findings	Surgical findings			
	Patent	Partial ossification	Complete ossification	Soft tissue
C0	43	3		
C1	3	3		
C2	1	3		2
C3	1	20	2	

scans by the senior radiologist, blinded to the history and to the surgical results and using the Dreisbach and Balkany (1988) classifications. When indistinctness of the endosteum of the basal turn (C1 finding) as a positive finding is included, the prevalence of false negatives (three cases) is lower, while that of false positives (five cases) is higher than results from the attending radiologists. Four of the five false positive scans were performed with the GE 8800 equipment and the fifth was performed with the GE 9800 at 100 mA. All of these cases had aetiologies other than meningitis.

If the data are collated into radiological findings of 'no ossification' or 'some ossification' and surgical findings of 'patent' or 'ossification/tissue', diagnostic values can be calculated. The senior radiologist and attending radiologist reviews were also further divided to examine the subsets of cases evaluated with the GE 8800 and GE 9800 scanners separately. All of the resulting diagnostic values are presented in Table VI. The overall accuracy of the interpretation as reported by the attending radiologists is 86.4 per cent. Because there are no false positives by the attending radiologist, specificity and positive predictive value (PPV) are both 100 per cent. However, there were false negatives by the attending radiologist so sensitivity is only 66.7 per cent. Negative predictive value (NPV) is 81.4 per cent. Accuracy, sensitivity, and NPV were better when examining just those cases scanned with the newer GE 9800 equipment, with accuracy of 93.0 per cent, sensitivity of 76.5 per cent, and NPV of 90.9 per cent.

Sensitivity and NPV were improved when the scans were evaluated by the senior radiologist. Best results were obtained with the newer scanner, with accuracy of 94.7 per cent, sensitivity of 88.2 per cent and NPV of 95.1 per cent. On the other hand, the senior radiologist had more false positives than the attending radiologist, yielding specificity and positive predictive values (PPV) of less than 100 per cent (97.5 and 93.8 per cent, respectively, for the GE 9800 scanner).

Within the group evaluated using the GE 9800 scanner, there was little difference in false positive or negative rates between use of 100/120 mA (children/adults) and use of 140/170 mA, although radiologist interpretation was slightly more accurate with the higher amperage.

TABLE VI
DIAGNOSTIC VALUES FOR RADIOLOGICAL FINDINGS BY SCANNER TYPE AND RADIOLOGIST STATUS

		HRCT scanner type	
	Overall	GE 8800	GE 9800
Attending radiologists			
Accuracy	86.4%	70.8	93.0%
Sensitivity	66.7%	56.3%	76.5%
Specificity	100.0%	100.0%	100.0%
PPV*	100.0%	100.0%	100.0%
NPV†	81.4%	53.3%	90.9%
Senior radiologist			
Accuracy	90.1%	79.2%	94.7%
Sensitivity	90.9%	93.8%	88.2%
Specificity	89.6%	50.0%	97.5%
PPV*	85.7%	78.9%	93.8%
NPV†	93.5%	80.0%	95.1%

* Positive predictive value; † negative predictive value.

Discussion

The reported accuracy of computed tomography in detecting cochlear ossification ranges from 54 to 91.9 per

TABLE VII
GUIDELINES FOR HIGH-RESOLUTION COMPUTED TOMOGRAPHY IN COCHLEAR IMPLANT PRE-EVALUATION

Technical
- 1.5 mm sections at 1 mm intervals
- 4000 HU display window width
- 500 to 900 HU level
- Edge enhancement algorithm
- 140 mA in children and 170 mA in adults
- + 30° or 0° plane from Reid's baseline
- Inferior tympanic annulus to superior semicircular canal

Interpretation check list
- Cochlea: presence, malformations, patency of the scalae
- Modiolus: patency
- Internal auditory canal: width
- Round window: presence, patency
- Cochlear aqueduct: width, relation to scala tympani
- Carotid canal: relation to cochlea
- Jugular bulb: relation to round window
- Facial nerve: course, size of facial recess
- Mastoid pneumatization: development, hypotympanic cells
- Temporal squama: thickness

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cent (Jackler *et al.*, 1987c; Balkany *et al.*, 1988; Laszig *et al.*, 1988; Wiet *et al.*, 1990). In our series, an accuracy of 86.4 per cent was obtained according to the reports of the attending radiologists for HRCT from both old and new scanners. With re-review by the senior radiologist, blinded to history and surgical findings and using the Dreisbach and Balkany (1988) classification, accuracy was 90.1 per cent overall and 94.7 per cent for scans using a GE 9800 machine. The difference between attending and senior radiologists in sensitivity and NPV narrowed considerably with use of the newer equipment. Interestingly, all the false positives were in patients deafened by causes other than meningitis.

The presence of ossification or fibrosis in the cochlea in profoundly deaf cochlear implant candidates is not unusual. In this study, 32 out of 81 (39.5 per cent) cases had ossification or fibrous tissue found at surgery. When the aetiology of deafness is meningitis, this prevalence increases to 78 per cent. Since nearly two-thirds of the children who received cochlear implants were deafened by meningitis, a high index of suspicion for bone growth in the cochlea of children presenting for implant evaluation is warranted. Although ossification is not a contraindication to implantation, knowledge of its presence and extent is important to the surgeon and for patient counselling. Fibrous tissue was found at surgery in two patients deafened by meningitis who had had HRCT four months after the onset of meningitis and were implanted after four and six months, respectively. Both scans were read as negative by the attending radiologist, but as C2 in the re-review by the senior radiologist. A definitive narrowing of the scala tympani, representing the early stage of labyrinthitis ossificans, can be appreciated on HRCT, a finding also reported by others (Novak *et al.*, 1990).

HRCT played a decisive roll in the choice of side of implantation in 10 (12.3 per cent) of the patients in this review, where more ossification was present on one side than the other. In the presence of identical audiological results and HRCT appearance on both sides, the side for implantation is usually chosen by the patient.

From our experience, we have developed some simple guidelines for the radiological assessment of the cochlear implant candidate. These technical guidelines and a check list for interpretation of results can be found in Table VII.

Newer magnetic resonance imaging (MRI) techniques permit visualization of the liquid-filled membranous labyrinth and allow detection of fibrosis not visualized by HRCT (Brogan *et al.*, 1991; Tien *et al.*, 1992; Casselman *et al.*, 1993). Selected cases of patients deafened by meningitis may benefit from these techniques. However, MRI does not furnish the bony anatomical details necessary for surgical planning, complicates sedation and monitoring of children undergoing evaluation, and adds cost to an already expensive procedure. Furthermore, in our experience, fibrosis undetected by HRCT did not appear to have compromised surgical success or eventual outcome of the implantations. Thus, the routine use of MRI in the radiological assessment of cochlear implant candidates is not necessary, and its future role is likely to remain limited. HRCT evaluated by an experienced radiologist and surgeon is sufficient for the radiological assessment of cochlear implant candidates.

Pre-operative knowledge of the anatomy of the cochlea and the presence of new bone formation becomes especially important given the significant number of centres that perform only a few cochlear implants per year (Tucci *et al.*, 1990). Radiological findings not only influence a decision regarding candidacy and play a role in the choice of ear to be operated, but also provide information that can assist the surgeon in better preparation for surgery.

References

Balkany, T., Gantz, B., Nadol, J. B. Jr. (1988) Multichannel cochlear implants in partially ossified cochleas. *Annals of Otology, Rhinology and Laryngology* **97 (suppl. 135):** 3–7.

Brogan, M., Chakeres, D. W., Schmalbrock, P. (1991) High-resolution 3DFT MR imaging of the endolymphatic duct and soft tissues of the otic capsule. *American Journal of Neuroradiology* **12:** 1–11.

Casselman, J. W., Kuhweide, R., Diemling, M., Ampe, W., Dehaene, I., Meeus, L. (1993) Constructive interference in steady state-3DFT MR imaging of the inner ear and cerebellopontine angle. *American Journal of Neuroradiology* **14:** 47–57.

Dreisbach, J. N., Balkany, T. J. (1988) The imaging evaluation of the cochlear implant candidate. In *American Academy Otolaryngology Head-Neck Surgery Instructional Courses*. vol 1. (Johnson, J. T., Blitzer, A., Ossoff, R., Thomas, J. R., eds.), Mosby Year Book, St Louis, pp 175–184.

Eisenberg, L. S., Luxford, W. M., Becker, T. S., House, W. F. (1984) Electrical stimulation of the auditory system in children deafened by meningitis. *Otolaryngology – Head and Neck Surgery* **92:** 700–705.

Fayad, J., Moloy, P., Linthicum, F. H. Jr. (1990) Cochlear otosclerosis: does bone formation affect cochlear implant surgery? *American Journal of Otology* **11:** 196–200.

Green, J. D. Jr., Marion, M. S., Hinojosa, R. (1991) Labyrinthitis ossificans: histopathologic consideration for cochlear implantation. *Otolaryngology – Head and Neck Surgery* **104:** 320–326.

Jackler, R. K., Luxford, W. M., House, W. F. (1987a) Congenital malformations of the inner ear: a classification based on embryogenesis. *Laryngoscope* **97 (suppl. 40):** 2–14.

Jackler, R. K., Luxford, W. M., House, W. F. (1987b) Sound detection with the cochlear implant in five ears of four children with congenital malformations of the cochlea. *Laryngoscope* **97 (suppl. 40):** 15–17.

Jackler, R. K., Luxford, W. M., Schindler, R. A., McKerrow, W. S. (1987c) Cochlear patency problems in cochlear implantation. *Laryngoscope* **97:** 801–805.

Laszig, R., Terwey, B., Ratimer, R. D., Hesse, G. (1988) Magnetic resonance imaging (MRI) and high-resolution computer tomography (HRCT) in cochlear implant candidates. *Scandinavian Audiology* **17 (suppl. 30):** 197–200.

Novak, M. A., Fifer, R. C., Barkmeier, J. C., Firsz, J. B. (1990) Labyrinthine ossification after meningitis: its implications for cochlear implantation. *Otolaryngology–Head and Neck Surgery* **103:** 351–356.

Shelton, C., Luxford, W. M., Tonokawa, L. L., Lo, W. W. M., House, W. F. (1989) The narrow internal auditory canal in children: a contraindication to cochlear implants. *Otolaryngology – Head and Neck Surgery* **100:** 227–231.

Tien, R. D., Felsberg, G. J., Macfall, J. (1992) Fast spin-echo high resolution MR imaging of the inner ear. *American Journal of Roentgenology* **159:** 395–398.

Tucci, D. L., Lambert, P. R., Ruth, R. A. (1990) Trends in rehabilitation after cochlear implantation. *Archives of Otolaryngology, Head and Neck Surgery* **116:** 571–574.

Wiet, R. J., Pyle, G. M., O'Connor, C. A., Russell, E., Schramm, D. R. (1990) Computed tomography: how accurate a predictor for cochlear implantation? *Laryngoscope* **100:** 687–692.

Wolff, A. B., Brown, S. C. (1987) Demographics of meningitis-induced hearing impairment: implications for immunization of children against *Hemophilus influenzae* type B. *American Annals of the Deaf* **132:** 26–30.

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