Role of HRCT and MRI of the Temporal Bone in Predicting and Grading the Degree of Difficulty of Cochlear Implant Surgery

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Abstract This study proposes a grading system based on a 10-point scoring chart of high resolution computed tomography (HRCT) and magnetic resonance imaging (MRI) imaging findings in patients being assessed preoperatively for cochlear implantation. This system helps in objectively assessing the degree of difficulty of the surgical procedure and alerts the surgeons to any potential intraoperative complications. This is a prospective study carried out at a tertiary referral center where 55 patients with bilateral profound sensorineural hearing loss were evaluated by HRCT and MRI and subsequently underwent cochlear implantation. HRCT examinations were performed on a 64 slice multidetector CT scanner. MRI examinations were performed on a 3.0 Tesla MRI scanner. A 10—point scoring chart was devised based on specific imaging findings and all patients were assigned potential difficulty scores (PDS) based on HRCT and MRI findings. Surgical times were documented in each case and each imaging point on the

scoring chart was correlated with the surgical times. Eight out of the ten points in the scoring chart proved to be statistically significant in predicting the degree of difficulty of the surgical procedure. After grading the pre-operative imaging examinations based on the 10-point scoring chart we concluded that patients who have PDS between 0 and 3 (Grade 1) have uneventful and uncomplicated surgery with the lowest intraoperative times. Patients with PDS between 4 and 7 alert the surgeon to moderate surgical difficulty and longer intraoperative times. PDS of 8 and above indicate prolonged and difficult surgery.

Keywords Cochlear implant · High resolution computed tomography · Magnetic resonance imaging · Surgery

Introduction

Evolving candidacy criteria have resulted in an increasing number of infants and children undergoing implantation. More patients with residual hearing are being considered for cochlear implantation to improve hearing. This has had an impact on the surgical techniques employed during cochlear implantation. Advances in imaging technology today enable us to visualize precise anatomical details of the temporal bone using high-resolution computed tomography (HRCT) and high-resolution magnetic resonance imaging (MRI). This enables a preoperative diagnosis of important surgical landmarks, surgically relevant anatomical variations and the entire spectrum of congenital/acquired abnormalities.

This manuscript discusses a grading system for objectively assessing the challenges a cochlear implant surgeon is likely to encounter based on HRCT and MRI findings.

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The authors conclude that this imaging based grading system, using a structured, 10-point scoring chart, would prove useful to a trainee and experienced implant surgeon. It would alert them about potential intraoperative issues and provide a reliable estimate of the actual intraoperative time.

Study Design

Prospective study.

Setting

Tertiary referral center.

Patients

Fifty-five patients underwent pre-cochlear implant imaging using HRCT and MRI after approval of the study protocols by the institutional review board.

Inclusion Criteria

Patients with bilateral severe to profound sensorineural hearing loss being assessed for cochlear implantation.

Exclusion Criteria

Active middle ear disease, congenital aural dysplasia and patients medically unfit for undergoing cochlear implantation.

Written consent was obtained from all patients before imaging.

Materials and Methods

All patients in the study were evaluated by HRCT and MRI of the temporal bone. Imaging for the pediatric population was performed under sedation or short acting general anesthesia. Low-dose pediatric HRCT protocols are used to keep radiation doses to a minimum. Cone Beam CT (CBCT) was not available at our imaging center and, hence, pediatric patients could not avail of this low radiation modality [1]. All HRCT examinations were performed on a multi-detector, 64-slice CT scanner with the following parameters: collimation: 64×0.625 , slice thickness: 0.67 mms, increment: 0.33 mms, reconstruction algorithm: 360° , rotation time: 0.5 s, pitch factor: 0.426 and image display matrix: 768×768 MRI examinations were performed on a 3.0 Tesla MRI scanner with 10.0 cm coverage, dual element, flexible surface coils positioned

over the external auditory canal. A 32-channel head coil was placed over the surface coils for additional cerebral imaging, the ‘concentric coil technique’ [2]. MRI imaging protocol included the following sequences:

1. DRIVE i.e., Driven Equilibrium in Steady State[®] (Philips Medical Systems, Amsterdam, North Holland, Netherlands) [3]: a heavily, T2 Weighted, Turbo Spin Echo (TSE) 3D sequence (TR: 1500 ms; TE: 163 ms; echo-train length (ETL): 40; slice thickness: 0.3 mms; FOV: 150×150 mms; pixel size: $0.5 \text{ mm} \times 0.5 \text{ mm}$; image reconstruction matrix: 512×512). This sequence is acquired in standard axial and coronal planes, and reformatted in sagittal oblique planes perpendicular to both VII-VIIIth nerve complexes.
2. T2 weighted (T2 W)/Fluid attenuation inversion recovery (FLAIR) sequence to assess the brainstem and auditory pathway (TR: 3029 ms; TE: 100 ms; FOV: 230 mm; slice thickness: 2 mms).
3. Contrast enhanced fat suppressed sequences whenever required after a rapid bolus intravenous injection of gadobenatedimeglumine[®] (Bracco Diagnostics, Milan, Italy) in a dose of 0.1 mmol/kg body weight, followed by a 5 ml saline flush. T1 weighted, Fast Field Echo (FFE), 3D images are obtained (TR: 25 ms; TE: 5.3 ms; slice thickness 0.7 mm; FOV: 160×160 mm; pixel size: $0.7 \text{ mm} \times 0.7 \text{ mm}$; image reconstruction matrix: 256×256).

All HRCT and MRI images were studied in axial planes reconstructed parallel to the long axis of the lateral semi-circular canals. Coronal sections were viewed perpendicular to the plane of the axial images. All the preoperative imaging examinations were evaluated by an experienced head and neck imaging specialist.

Results

Fifty-five patients were evaluated in the study. The population included 27 female subjects (49.1 %) and 28 male subjects (50.9 %) with a mean age of 6.8 years (9 months to 13 years). Table 1 shows the age and gender distribution of the study sample. Table 2 outlines the 10-point chart based on specific imaging findings used to score each patient. This scoring system uses data based on the principle of allocating points for individual risk factors

Table 1 Age and gender distribution of study sample (n = 55)

Sr. no	Age group	Number of patients
1	Less than 5 years	32 (17 females, 15 males)
2	5–10 years	15 (5 females, 10 males)
3	More than 10 years	8 (5 females, 3 males)

Table 2 10-point scoring chart based on HRCT and MRI imaging findings

1. Degree of mastoid pneumatisation	
Well pneumatized	0
Hypo/non-pneumatized	1
2. Facial recess anatomy	
Narrow (< 3 mm)	2
Wide (> 3 mm)	0
3. Descending segment of facial nerve canal	
Normal	0
Overhanging the round window	2
4. Position of the jugular bulb	
Normal	0
High riding/dehiscent	1
5. Posterior wall of external auditory canal/sigmoid sinus lines	
Favourable	0
Not favourable	1
6. Posterior wall of external auditory canal/long axis of the basal turn line	
Favourable	0
Not favourable	1
7. Relative position of the basal turn of cochlea to the malleoincudal joint in axial plane	
Favourable	0
Not favourable	1
8. Lines along the anterior margin of the IACs (rotated cochlea)	
Parallel lines	0
Angulated and intersecting	1
9. Associated congenital anomalies of the temporal bone	
Not present	0
Isolated LVAS/Mondini/Bulbous IAC	1
IP-I, IP-III, Common cavity	4
10. Associated acquired abnormalities of the temporal bone (Labyrinthitis ossificans [LO] and otosclerosis)	
Not present:	0
LO, Balkany grade 1	2
LO, Balkany grade 2, otosclerosis	4
LO, Balkany grade 3	6
Total score	20

thought to increase the level of surgical difficulty. The points are then summated to provide an overall score for each case pre-operatively i.e., a 'potential difficulty score' (PDS). Table 3 depicts the incidence of the risk factors based on imaging findings within the study group as per the 10-point scoring chart. All fifty-five patients subsequently underwent cochlear implantation by the same implant surgeon. The surgical time required in each case was documented from skin incision to skin suture completion. The surgical time for all fifty-five patients ranged from 60 to 150 min. Each imaging point was correlated with the

surgical timing. Table 4 shows the statistical correlation of the imaging findings with surgical timings. A linear relationship was observed between increasing PDS and correspondingly increasing operative times. It was observed that patients with a PDS of 0 to 3 had surgical timings within the range of 60–90 min (mean: 75 min). Those with a PDS of 4 to 7 had surgical timings within the range of 91–120 min (mean: 105.5 min). Those with a PDS between 8 and 9 had surgical timings ranging from 121 to 150 min (mean: 135.5 min). The patients were categorized into three groups i.e., Grade 1 (patients with a PDS of 0 to 3), Grade 2 (patients with a PDS of 4 to 7) and Grade 3 (patients with a PDS of 8 and above), with increasing grades corresponding to a predictably increased degree of difficulty of the surgery. Table 5 shows degree of surgical difficulty grading based on PDS and surgical timings.

Statistical Analysis

Data was analyzed using statistics package EpiInfo™ 7.1.3.3 version for windows. Descriptive data are represented as mean $\pm$ SD for numeric data and percentages and proportions for categorical data. Appropriate tests of significance were used depending on the nature and distribution of data. We used Pearson's correlation and a linear regression to assess relationships and quantify the effect on surgical timings based on the 10-point scoring system. Values of $p < 0.05$ were considered statistically significant. An analysis of the data based on the above imaging criteria and findings was performed (Table 6). Eight out of the 10 points in the scoring system were observed to have significant p values ($p < 0.05$) and a bearing on the surgical timings, which ultimately correlate with the degree of surgical difficulty.

Discussion

The surgery for cochlear implantation is beyond the scope of this text, and the reader is referred to numerous texts in medical literature. In brief, cochlear implantation is usually performed through a transmastoid facial recess approach. Electrode insertion into the scala tympani is done either via the round window or a cochleostomy made anteroinferior to the round window. Surgical approaches may need to be altered based on the anatomical variants and pathologies of the temporal bone [4]. Patients who have specific anatomical variations/associated abnormalities are likely to have more difficult surgeries with increased intraoperative times as compared to patients with normal anatomy.

A 10-point scoring chart was devised based on specific imaging findings and all patients were allotted PDSs based

Table 3 Incidence of the risk factors based on imaging findings

Sr. no	Imaging findings	%
1.	Hypopneumatized mastoid	36.36
2.	Narrow facial recess	30.90
3.	Descending segment of facial nerve canal overhanging the round window	21.81
4.	High riding jugular bulb	03.63
5.	Unfavourable posterior canal wall—sigmoid sinus lines	36.36
6.	Unfavourable posterior canal wall—long axis cochlear basal turn lines	18.18
7.	Unfavourable position of the basal turn of cochlea to the malleo-incudal joint in axial plane	01.81
8.	Intersecting lines along the anterior margin of the IACs	03.63
9.	Associated congenital anomalies of the temporal bone	58.17
10.	Associated acquired abnormalities of the temporal bone	05.44

Table 4 Statistical correlation of the imaging findings with surgical timings

Sr. no	Imaging findings in the scoring chart	Pearson correlation (r value)	P value
1.	Degree of mastoid pneumatization	0.284	0.036
2.	Facial recess anatomy	0.548	0.0001
3.	Descending segment of facial nerve canal	0.341	0.011
4.	Position of the jugular bulb	0.160	0.242
5.	Posterior wall of external auditory canal/sigmoid sinus angle	0.295	0.029
6.	Posterior wall of external auditory canal/long axis of the basal turn line	0.232	0.088
7.	Relative position of the basal turn of cochlea to the malleo-incudal joint in axial plane	0.299	0.027
8.	Lines along the anterior margin of the IACs	0.427	0.001
9.	Associated congenital anomalies of the temporal bone	0.403	0.002
10.	Associated acquired abnormalities of the temporal bone	0.598	0.0001
Total score		0.892	0.0001

Table 5 Degree of surgical difficulty grading based on PDS and surgical timings

Score	Surgical time (min)	Grade	Imaging based prediction
0–3	60–90	Grade 1	No anticipated surgical difficulty
4–7	91–120	Grade 2	Anticipated surgical difficulty
8 and above	121–150	Grade 3	Prolonged and difficult surgery

Dependent variable: surgical timing in minutes

$P < 0.05$: statistically significant

on the HRCT and MRI examinations. The imaging scoring chart included the following:

1. Degree of mastoid pneumatisation.
2. Facial recess anatomy.
3. Anatomy of the descending segment of the facial nerve canal.
4. Position of the jugular bulb.
5. Posterior wall of external auditory canal/sigmoid sinus angle.
6. Posterior wall of external auditory canal/long axis of the cochlear basal turn lines.
7. Relative position of the basal turn of the cochlea to the malleo-incudal joint in the axial plane.
8. Lines along the anterior margin of the internal auditory canals (IACs).
9. Associated congenital anomalies of the temporal bone.
10. Associated acquired anomalies of the temporal bone.

The normal and abnormal imaging findings and scores assigned with each of the above points are discussed below under individual headings. Specific standardized imaging planes/anatomical levels and techniques of measurement

Table 6 Multiple linear regression showing predictors of surgical timings

Independent variable	Regression coefficient	95 % Confidence interval for regression coefficient		P value
		Lower bound	Upper bound	
Associated acquired abnormalities of the temporal bone	24.598	19.221	29.974	0.0001
Descending segment of facial nerve canal	16.437	8.473	24.401	0.011
Lines along the anterior margin of the IACs	69.382	33.445	105.319	0.001
Associated congenital anomalies of the temporal bone	15.803	9.040	22.566	0.002
Relative position of the basal turn of cochlea to the malleo incudal joint in axial plane	69.642	20.661	118.623	0.027
Facial recess anatomy	12.728	4.996	20.459	0.0001
Posterior wall of external auditory canal/sig sinus angle	14.370	0.559	28.180	0.029
Degree of mastoid pneumatization	30.143	2.082	58.203	0.036
Position of the jugular bulb	43.774	−30.454	118.002	0.242
Posterior wall of external auditory canal/long axis of the basal turn line	53.389	19.986	86.792	0.088

are also outlined with actual demonstration on the relevant HRCT images.

Degree of Mastoid Pneumatization

In children younger than 2 years, the tympanic ring is underdeveloped, the mastoid pneumatization is incomplete and the stylomastoid foramen is quite shallow; hence, the facial nerve is vulnerable to injury [5]. In experienced hands, this reduced degree of mastoid pneumatization is adequate for clear access and successful electrode insertion [6]. However, a hypo pneumatized mastoid indicates a limited surgical exposure to the facial nerve recess [7]. The authors assign a score of '0' for a well pneumatized mastoid, and a score of '1' for a non/hypo pneumatized mastoid (see Figure, Online Resource 1, ESM_1, which shows scoring for mastoid pneumatization).

Anatomy of the Facial Recess

The facial recess is completely developed at birth [8] and is measured as the distance between the facial nerve and the annulus. It is measured in the axial plane at the level where the round window and the basal turn of the cochlea are seen. At birth, the facial recess reaches 3.04 mm at the round window [9]. The authors term the facial recess as wide and normal if it measures more than 3 mms, and assign it a score of '0'. If the facial recess measures less than 3 mms, it is labeled as narrow with a score of '2' (Fig. 1).

Anatomy of the Descending Segment of the Facial Nerve Canal

Most surgeons prefer round window insertion via posterior tympanotomy approach for electrode insertion for

preservation of residual hearing. An anteriorly placed descending segment of the facial nerve canal can significantly hamper the surgeons' view of the round window [4, 7]. A normally positioned descending facial nerve is assigned a score of '0'. If the descending segment of the facial nerve canal overhangs the round window niche, a score of '2' is assigned (see Figure, Online Resource 2, ESM_2, which shows scoring for descending facial nerve canal). A large percentage of patients undergoing cochlear implantation have inner ear anomalies like cochleovestibular dysplasias. These patients have an aberrant anterior and laterally located descending facial nerve [10].

Anatomy of the Jugular Bulb

The superior margin of the jugular bulb normally does not extend above the floor of the ipsilateral internal auditory canal or above the level of the basal turn of the cochlea: these cases are assigned a score of '0'. If the jugular bulb extends above these anatomical landmarks, it is termed as a high riding jugular bulb and assigned a score of '1' (see Figure, Online Resource 3, ESM_3, which shows scoring for the jugular bulb). A similar score is also assigned to a jugular bulb with a deficient/thin bony covering (dehiscent jugular bulb) [11].

The Posterior Canal Wall/Sigmoid Sinus Lines

These lines are drawn on the axial HRCT image where the tympanic annulus and the handle of malleus are visible in the same plane. The posterior canal wall line is drawn along the posterior wall of the external auditory canal and the second line is drawn tangential to the sigmoid sinus. Normally, the basal turn of the cochlea lies between the angles subtended by these two lines (Fig. 2a). Such cases

Fig. 1 The facial recess is the distance between the descending facial nerve canal and the tympanic annulus (bidirectional arrows and green lines). Axial HRCT images showing a normal facial recess measuring 3.60 mm (a) and a narrow facial recess measuring 2.51 mm (b)

Fig. 2 The posterior canal wall/sigmoid sinus lines: Lines drawn along the posterior wall of the external auditory canal (AB) and tangential to the sigmoid sinus (CD). Scored as favourable if the basal turn of cochlea (arrow) lies between the two lines (a) and unfavourable if the basal turn/or any part lies outside the two lines (b)

are assigned a score of '0'. In these cases, the surgeon has easy access to the round window niche. If the basal turn lies outside this angle, a score of '1' is assigned (Fig. 2b) due to the difficulty in accessing the round window.

The Posterior Canal Wall/Cochlear Basal Turn Lines

These lines are drawn on the axial HRCT image depicting the entire basal turn of the cochlea. The posterior canal wall line is drawn along the posterior wall of the external auditory canal, as mentioned earlier, and the second line is drawn along the center of the long axis of the basal turn of cochlea. Normally, these two lines run parallel to each other (Fig. 3a). If the basal turn line is angulated posteriorly (towards the occiput), the surgeon does not encounter any difficulty in electrode insertion: these cases are assigned a score of '0'. If the lines intersect (i.e., the basal turn line is angulated more anteriorly away from the occiput), as in Fig. 3b, an easy, uncomplicated sliding insertion is not possible: such cases are assigned a score of '1'.

Relative Position of the Basal Turn of the Cochlea to the Malleoincudal Joint

The part of the ossicular chain visualized in the axial HRCT image of the temporal bone at the level of the basal cochlear turn is represented by two parallel lines. The anterior line consists of the neck and manubrium of the malleus and the cochleariform process. The posterior line consists of the lenticular process of the incus, the incus-stapes connect and the stapes. The superior segment of the malleoincudal joint (traditionally referred to as the 'ice-cream cone'), consisting of the head of the malleus and the short process/body of the incus, is usually never identifiable in the same axial HRCT image that depicts the basal cochlear turn. These cases are termed normal and assigned a score of '0'. If the cochlea is rotated away from its normal, inferolaterally directed long axis, the superior malleo-incudal joint (i.e., 'ice-cream cone') is identified in the same axial section as that of the basal cochlear turn and these cases are assigned a score of '1' (see Figure, Online Resource 4, ESM_4, showing scoring for likely cochlear rotation). Access to the round window niche in these cases is difficult.

Fig. 3 The posterior canal wall/cochlear basal turn lines: Lines drawn along the posterior wall of the external auditory canal (AB) and along the long axis of the basal turn of cochlea (CD). Scored as favourable if the lines run parallel (a), or if the basal turn line is inclined posteriorly (anatomically towards the occiput; in which case the lines diverge medially). Scored as unfavourable if the basal turn line is inclined anteriorly and the lines converge/intersect medially (b)

Lines Along the Anterior Margin of the Internal Auditory Canals

In normal cases, the lines drawn along the anterior margins of the internal auditory canals are parallel to each other and do not intersect. These cases are assigned a score of '0'. If the internal auditory canals are mal-angulated anteriorly, these lines will intersect one another. Such cases are assigned a score of '1'. The cochlea is likely to be rotated in these cases, resulting in difficult electrode insertion (see Figure, Online Resource 5, ESM_5, showing variation in the lines drawn along the anterior margins of the internal auditory canals).

Associated Congenital Anomalies of the Temporal Bone

Patients with congenital inner ear anomalies are prone to surgical complications of CSF leaks (intra and post-operative), facial nerve stimulation/injury and internal auditory canal insertion of the electrode [4]. Reports in the literature show that cochlear implantation in cochlear malformations/other inner ear anomalies can be achieved with the same degree of safety as that seen with normal cochlear anatomy, provided the anomalies and associated malformations are accurately identified preoperatively [12–14].

The authors follow the classification proposed by Senaroglu in 2010 [10], which includes: Michel deformity (Labyrinthine aplasia), cochlear aplasia, common cavity, cochlear hypoplasia and Incomplete Partition (IP): IP-Type I (cystic cochleovestibular malformation); IP-Type II (Mondini deformity if associated with enlarged vestibular aqueduct) and IP-Type III (X-linked Deafness). Additional imaging findings like enlarged vestibular aqueduct (LVAS), enlarged endolymphatic sac/duct, bulbous internal auditory canals (IACS) and thin lamina cribrosa also need to be

identified preoperatively, as these conditions are associated with an increased incidence of an intraoperative CSF gusher [10, 15, 16]. A score of '0' was assigned to normal cases without inner ear anomalies. Patients with isolated LVAS, Mondini deformity (see Figure, Online Resource 6, ESM_6, showing Mondini deformity) and bulbous IAC were assigned a score of '1'. Patients with IP-Type I (see Figure, Online Resource 7, ESM_7, showing IP-Type I), IP-Type III and common cavity were assigned a score of '4' due to the higher incidence of intraoperative complications.

Associated Acquired Abnormalities of the Temporal Bone

Two important acquired pathologies affecting the surgical procedure in our study were labyrinthitis ossificans and otosclerosis.

Extensive cochlear ossification is no longer considered a contraindication to cochlear implantation, as studies have shown that patients with as little as 10 % of the normal complement of spiral ganglion counts demonstrate average, post-operative outcomes [17]. It is important to grade the severity of the ossification. To do so, the authors follow the Balkany Grading system [19] estimated on HRCT:

- Grade 0 Normal cochlea without any ossification
- Grade 1 Ossification affects only the basal turn of the cochlea (see Figure, Online Resource 8, ESM_8, showing Balkany Grade 1 labyrinthitis ossificans)
- Grade 2 Ossification affects two turns of the cochlea
- Grade 3 Ossification affects three turns of the cochlea

A variety of surgical approaches and techniques have been used by many groups based on the grade of the cochlear ossification [4, 15, 20, 21]. Bacterial meningitis causing

cochlear ossification is more extensive than when it is caused by otosclerosis [18].

Otosclerosis is a disorder of bone reabsorption of the temporal bone followed by replacement with dense irregular sclerotic bone. It occurs mainly around the oval window (the fenestral otosclerosis) and, in 10 % of patients, in the peri-cochlear location of the otic capsule (the retro-fenestral otosclerosis) [22]. The mainstay of treatment for patients with otosclerosis is a stapedotomy. In advanced otosclerosis where patients have associated sensorineural hearing loss, a stapedotomy is often unsatisfactory for the hearing goals of the patient, and cochlear implantation results in excellent hearing outcomes. Preoperative grading of the otosclerosis is important and the Rotteveel classification system [23], based on HRCT imaging, can be used for this purpose. Grade 1 otosclerosis is solely fenestral. Grade 2a is retro-fenestral otosclerosis, which presents as a double ring or halo effect on imaging (see Figure, Online Resource 9, ESM_9, showing fenestral and retrofenestral otosclerosis). Grade 2b is a narrowed basal turn and Grade 2c is both retro-fenestral and a narrowed basal turn. Grade 3 otosclerosis is a diffuse confluent retro-fenestral involvement [24].

The authors assign a score of '0' when cochlear ossification and otosclerosis are not present. Patients with labyrinthitis ossificans (Balkany Grade 1) are assigned a score of '2'. Patients with labyrinthitis ossificans (Balkany Grade 2)/otosclerosis are assigned a score of '4'. Patients with labyrinthitis ossificans (Balkany Grade 3) are assigned a score of '6'.

Out of the above mentioned imaging points in the scoring chart determining the PDS, eight were found to correlate significantly with the surgical timings and, hence, had a direct impact on the degree of surgical difficulty. These eight points include:

1. Degree of mastoid pneumatisation.
2. Facial recess anatomy.
3. Descending segment of facial nerve.
4. Posterior wall of external auditory canal/sigmoid sinus angle.
5. Relative position of the basal turn of the cochlea to the malleoincudal joint in the axial plane.
6. Lines along the anterior margin of the IACs (rotated cochlea).
7. Associated congenital anomalies of the temporal bone.
8. Associated acquired abnormalities of the temporal bone (labyrinthitis ossificans[LO] and otosclerosis).

The remaining two points that did not significantly affect the surgical timings are:

1. Position of the jugular bulb.
2. Posterior wall of external auditory canal/long axis of the basal turn line.

Though these two points have not statistically proven to affect the surgical timing, it is the opinion of the authors that, in certain patients, they do have an impact on the surgical steps. An insufficient cohort for this study is likely to be the cause for this observation.

There were 30 patients (54.54 %) classified as Grade 1, 19 patients (34.34 %) classified as Grade 2 and 6 patients (10.90 %) classified as Grade 3. Out of the 30 patients in Grade 1, it was observed that 25 patients had uneventful surgery and five patients had prolonged surgery (sensitivity: 83 %; positive predictive value: 100 %; specificity: 100 %; negative predictive value: 83 %). Out of these five patients, two patients had dense mastoid sclerosis, two had blood dyscrasias that were not identified on routine, pre-operative, haematological investigations and one patient had congested middle ear mucosa.

Out of the 19 patients assigned as Grade 2, 15 patients had minor surgical difficulties as predicted by specific imaging findings on the scoring chart, and four had uneventful surgery (sensitivity: 100 %; positive predictive value: 78 %; specificity: 90 %; negative predictive value: 100 %). Out of these four, two patients (despite having a hypopneumatized mastoid) had an uneventful surgery. One patient with labyrinthitis ossificans Balkany grade 1 had an easy insertion. One patient with narrow facial recess on imaging had easy access to the round window.

All six patients assigned as Grade 3 had prolonged and difficult surgery (sensitivity: 100 %; positive predictive value: 100 %; specificity: 100 %; negative predictive value: 100 %).

Conclusion

Cochlear implant surgery today is one of the most expensive, non-state funded surgeries in developing countries. There are numerous experienced clinicians performing this surgery with a large margin of safety and very low complication rates. However, trainee cochlear implant surgeons would benefit immensely if the potential degree of difficulty of surgery in a specific case were known pre-operatively. With this in mind, the authors have devised a 10-point imaging based scoring chart and a grading system, which alerts and prepares the surgeons for likely problems and difficulties they may encounter during the surgery. After grading the pre-operative imaging examinations based on the scoring system, the authors concluded that patients who have a potential difficulty score between 0 and 3 will have uneventful and uncomplicated surgery with the lowest intraoperative times. Scores between 4 and 7 alert the surgeon to moderate surgical difficulty and longer intraoperative times. Scores of eight and above indicate a high chance of a prolonged and difficult surgery.

Conflicts of interest Nothing to declare.

Informed consent Has been obtained for high resolution computed tomography of the temporal bones.

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