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High Resolution Computed Tomography and Magnetic Resonance Imaging in the Preoperative Assessment for Cochlear Implantation Candidacy

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Abstract

Background: High Resolution Computed Tomography (HRCT) and magnetic resonance imaging are regularly used for cochlear implant preoperative evaluation for the evaluation of inner ear malformations, surgical planning, and especially the imaging of the VIIIth nerve. In children, these imaging procedures are especially important due to the high incidence of inner ear malformations.

Aim of Work: To study the role of high resolution computed tomography and magnetic resonance imaging in classifying 70 patients with profound deafness for possible absolute contraindications for surgery, relative contraindications for surgery (difficult surgery) or easy surgery for cochlear implant.

Subjects and Methods: We performed a cross sectional descriptive study on 70 patients with profound SNHL for possible cochlear implantation surgery followed-up by Helwan University Teaching Hospitals between January 2016 and December 2017.

All patients were subjected to high resolution CT scan (64 mutlislice) and 3D T2 MRI of the temporal bone to delineate condition of the mastoid, vascular anomaly, internal auditory canal, cochlear nerve, size of the cochlea, status of the endo-and perilymphatic fluid, round window niche and variation of the facial nerve.

All Patients were Classified into: Absolute contraindications to cochlear implant surgery, relative contraindications to cochlear implant surgery and their complicating factor in making surgical intervention with relative difficulty, otherwise easy surgical intervention is assumed.

Results: We studied a total of 70 patients with profound deafness planned for cochlear implantation surgery and our results showed 5.7% (n=4) of the study group would not benefit and cochlear implantation surgery is contraindicated for these patients as well as 41.4% (n=29) of the patients have had complicating criteria that possibly make surgical intervention difficult in comparison 52.9% (n=37) with anticipated straight forward surgical intervention which were statistically significant.

Conclusion: The correct classification of cochlear conditions and a clear description of such abnormalities by means of multislice CT and 3D MRI are determining factors in the surgical planning developed by the cochlear implantation team, with direct impact on the success of the surgical intervention. Thus the radiologist experienced in the evaluation of the temporal bone plays a major role in the course of this disorder.

Key Words: *Cochlear implantation difficulties – Cochlear implantation contraindications – HRCT – MRI in CI.*

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Introduction

COCHLEAR implant device provides a direct stimulation of the residual spiral ganglion cells of the cochlear nerve by bypassing the destroyed hair cells. In normal persons, the sound waves coming from the oval window pass to the scala vestibuli up to the helicotrema and then, go down towards the round window by the scala tympani. The hair cells are excited by the variations of pressure waves transmitted to the scala media [1].

Cochlear implant device include an electrode array inserted into the scala tympani of the basal turn via the round window for a distance of 20-24 mm, the sound waves received by the external microphone are transduced into electric signals. These electric signals are then digitally encoded by an external speech processor, and then transmitted as electromagnetic waves across the skin by a transducer to the receiver which reconverts radiowaves into elementary electric signals to stimulate sequentially each slot of the implanted electrode array. Excited slot sequentially excites spiral ganglion cells or axons in the cochlea [2].

Cochlear implant candidates should usually be over two years of age, have bilateral profound or severe hearing loss, receive no enough benefit from external hearing aid with less than 30% of intelligibility, and have a high motivation for rehabilitation. A lot of factors are considered to select cochlear implant candidates: Age, mental and physical health, audiologic testing, cause and duration of the deafness, capacity and ability to be reeducated, social status [3].

Imaging findings are crucial in identification of absolute contraindication factors, as well as complicating factors and factors with relative contraindication for surgery [4].

Some criteria such as cochlear nerve aplasia, labyrinthine and/or cochlear aplasia are still considered as absolute contraindications, in spite of studies bringing such criteria into question. Cochlear dysplasias constitute relative contraindications, among them labyrinthitis ossificans. Other alterations may be mentioned as complicating agents in the temporal bone assessment, namely, hypoplasia of the mastoid process, aberrant facial nerve, otomastoiditis, otosclerosis, dehiscent jugular bulb, enlarged endolymphatic duct and sac [5].

Pre-operative imaging High Resolution Computed Tomography (HRCT) and magnetic resonance imaging are regularly used for cochlear implant pre-operative evaluation for the evaluation of inner ear malformations, surgical planning, and especially the imaging of the VIIIth nerve. In children, these imaging procedures are especially important due to the high incidence of inner ear malformations [6].

High resolution computed tomography is able to evaluate bony structures. An accurate analysis of the cochlear labyrinth is important for a precise surgical planning. After analyzing the malformation, the proper electrode has to be chosen by the surgeon since worldwide manufacturers provide various electrodes (like short, long, preformed, straight, perimodiolar) [6].

Patients and Methods

We performed a cross sectional descriptive study on 70 patients; 27 females and 43 males with mean 4 years old and patients' ages ranged from 6 months to 48 years, with profound SNHL as evidenced by audiological evaluation; PTA, speech audiometry, ABR and otoacoustic emission for possible cochlear implantation surgery followed-up by Helwan University Teaching Hospitals between January 2016 and December 2017.

Inclusion criteria:

All ages and sexes were included.

Exclusion criteria:

Any patient with possible identifiable wave on ABR or pass by transient evoked otoacoustic emission.

Image analysis and evaluation:

All patients were subjected to high resolution CT scan (64 mutlislice) and 3D T2 MRI of the temporal bone to delineate:

- Aeration of the mastoid and of the middle ear.
- Anomaly of the pathway of the:
  - Carotid artery.
  - Sigmoid sinus.
- Size of the internal auditory meatus.
- Cochlear nerve presence.
- Malformation of the membranous labyrinth.
- Status of the endo- and perilymphatic fluid.
- The bony labyrinth and status of the round window niche.
- Variation of the pathway of the facial nerve.

The previous structures were assessed on both 3D MRI and CT exams and rated as pathologic or normal. Special attention was given to the cochlea, the vestibule, the three semicircular canals, the endolymphatic duct and sac, and the internal auditory canal and the appearance of the bony labyrinth on CT and the membranous labyrinth on MRI. Finally, an overall diagnosis inclusive of all findings was stated and categorized as pathologic or normal.

Cochlear dysplasias were graded according to its size and imaging criteria as hypoplastic, mondini malformation, absent or dysplastic. The term dysplasia was assigned to abnormalities that spanned from an isolated modiolar deficiency to an absence of the apical turn of the cochlea, single turn of the cochlea to complete aplasia of the cochlea. The cochlear nerve size and Internal Auditory Canal (IAC) size were all measured. A normal cochlear nerve was considered equal to or greater in diameter to the facial nerve as visualized by direct and/or reconstructed sagittal oblique images of the IAC. A deficient cochlear nerve was considered if it is smaller than the adjacent facial nerve. If the cochlear nerve was not visualized, the nerve was considered to be absent. On the oblique sagittal T2-weighted images, the IAC was measured at its mid portion. The IAC was considered normal if it measured 4mm or greater in 1 dimension on the oblique sagittal image [4].

Patients analysis and evaluation:

All patients were classified into:

Absolute contraindications to cochlear implant surgery.

Relative contraindications to cochlear implant surgery and their complicating factor in making surgical intervention with relative difficulty [7].

Otherwise easy surgical intervention is assumed. According to the following key.

Statistical methods:

Data management and analysis was performed using Statistical Package for Social Sciences (SPSS) vs. 23. Numerical data were summarized as median and range, categorical data were presented as numbers and percentages. Chisquare test of goodness of fit was used to test the hypotheses that all categories of each characteristic are equal. All p-values were two-sided. p-values <0.05 were considered significant.

Table (1): Key of classification of CT & MRI findings for the study.

	Easy surgery	Difficult surgery	Contraindicated surgery
Mastoid areation	Normal or effusion	Hypopnematized	Non
Vascular anomaly sigmoid	Normal or lateral position	Prominent or high jugular bulb	Non
Size of IAC	Adequate	Widened	Narrowed
Labrinth size right	More then 8	From 6.5 to 7.9	Absent
Labrinth size left	More then 8	From 6.5 to 7.9	Absent
Cochlear malformation	Normal	Calcified or mondini or hypoplastic or dysplastic	Absent
Vestibular aqueduct size	Normal	Large	Absent
Round window niche	Normal	Narrowed	Absent
Facial recess	Normal	Narrowed	Non

Results

Table (2): Range of age of patients involved by the study.

	Mean	Standard deviation	Median	Minimum	Maximum
Age (years)	5.8	7.2	4.0	5.0	48.0

The above table showing the age distribution of the study group which showed that the median of age were 4 years old and patients' ages ranged from 6 months to 48 years.

Table (3): Sex distribution of patients involved in the study.

	N	%
Sex:		
Female	27	38.6
Male	43	61.4

The above table shows the sex distribution of the study group which comprised 27 (38.6%) females and 43 (61.4%) males.

Table (4): CT & MRI findings for the study group.

	Easy surgery		Difficult surgery		Contrain-dicated surgery		p-value
	N	%	N	%	N	%	
Mastoid areation	58	82.9	12	17.1	0	0.0	<0.001
Vascular anomaly sigmoid	57	81.4	13	18.6	0	0.0	<0.001
Size of IAC	67	95.7	1	1.4	2	2.9	<0.001
Labrinth size right	63	90.0	5	7.1	2	2.9	<0.001
Labrinth size left	62	88.6	6	8.6	2	2.9	<0.001
Cochlear malformation	60	85.7	8	11.4	2	2.9	<0.001
Vestibular aqueduct size	62	88.6	6	8.6	2	2.9	<0.001
Round window niche	67	95.7	1	1.4	2	2.9	<0.001
Facial recess	63	90.0	7	10.0	0	0.0	<0.001

All the above p-values are <0.001, the % of cases requiring easy surgery is significantly more than those with difficult or contraindicated surgeries.

Table (5): Variation of labyrinth size in the study group.

	Mean	Standard deviation	Minimum	Maximum
Labrinth size right	8.5	0.4	7.5	9.6
Labrinth size left	8.5	0.4	7.6	9.4

The above table showing variation in labyrinth size in the study group which revealed that the mean size of the cochlea whether right or left were 8.5mm ±0.4mm.

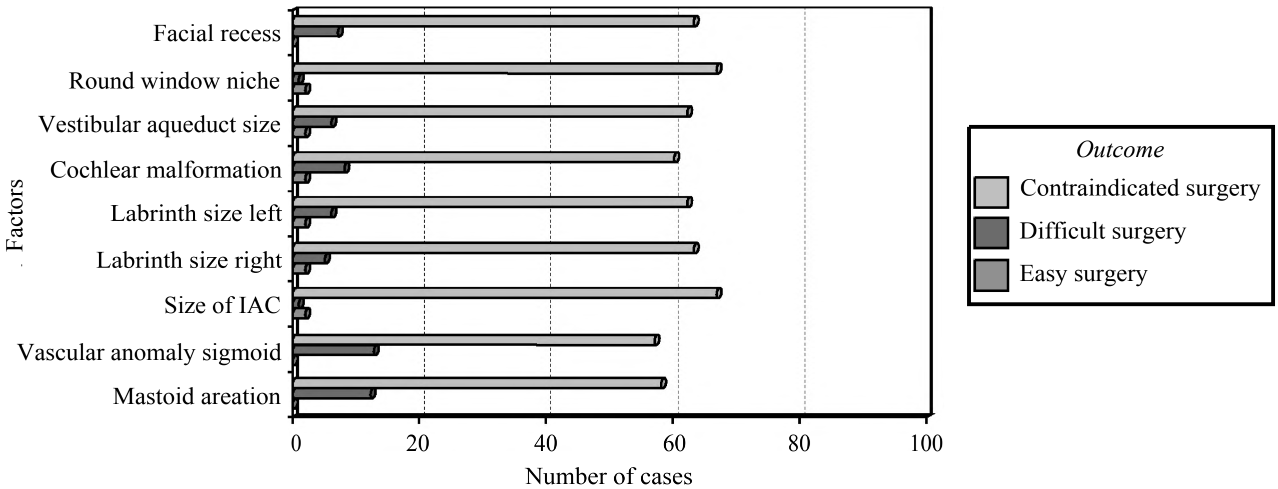


Fig. (1): Showing number of cases with factors that delineate easy surgical intervention, suspected difficult surgical intervention and contraindicated for surgical intervention.

Table (6): Radiological findings in classifying study group.

	N	%
Contraindicated surgery	4	5.7
Difficult surgery	29	41.4
Easy surgery	37	52.9
p-value		<0.001

The above table showing that the % of cases requiring easy surgery and difficult surgery are significantly more than those with contraindicated surgeries denoting that implantation is possible is almost all deaf mute patients.

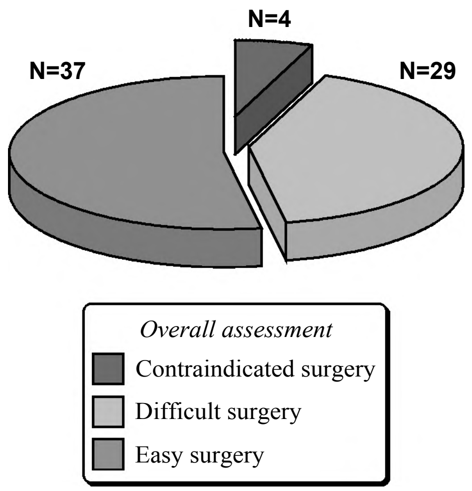


Fig. (2): Presenting comparisons between patient whom shall have an easy surgical intervention in comparison to anticipated difficult surgical intervention and contraindicated surgery.

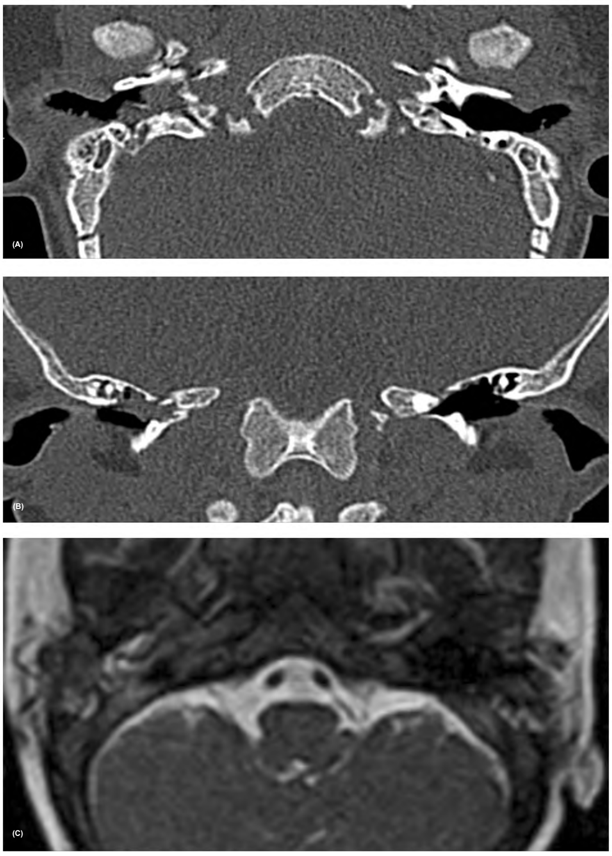
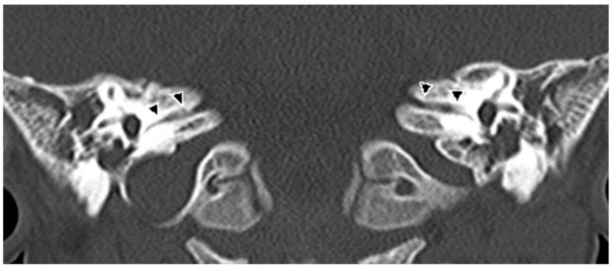


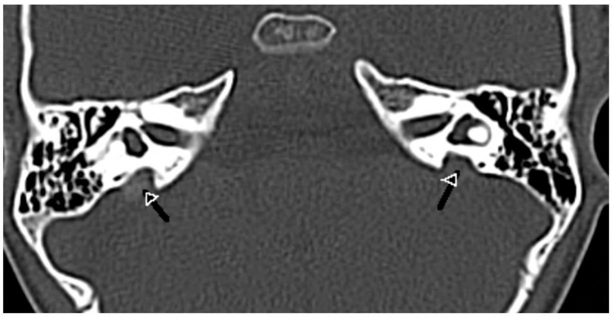
Fig. (3): (A & B) Axial and coronal CT images bone window sitting & [C] Axial T2WI: Complete absence of inner ear structures with non-visualized cochlea, vestibule or semicircular canals on either side. Note obliterated right middle ear cavity by high density inflammatory material which appreciates intermediate signal in T2WI, a pattern suggestive of congenital cholesteatoma. This inflammatory material is surrounding the middle ear ossicles with erosion of the scutum and bulging into the tympanic membrane. The ossicles are small and could be eroded by the inflammatory debris while the left ossicular chain is clearly identified.



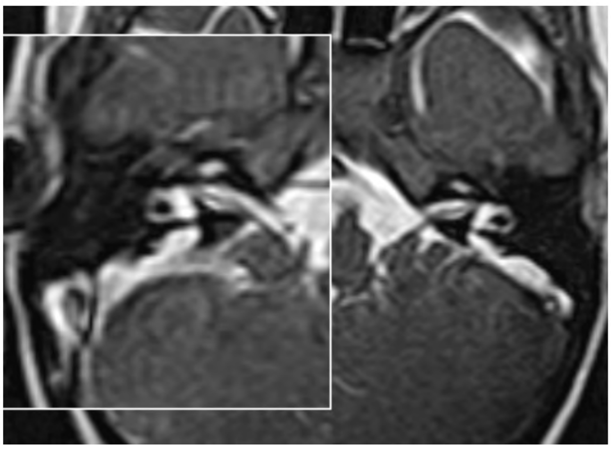
(A)

(B)

Fig. (4): (A) Thin axial CT cuts bone window revealed bilateral hypoplastic internal auditory canals [arrow heads] more on the right side, measuring about 2.4 mm on the right and 3mm on the left. (B) Corresponding 3-D-coronal GR T2 WIs of the same patient confirms bilateral IAC hypoplasia.



(A)



(C)

Fig. (5): (A) Bilateral enlargement of the bony vestibular aqueducts [arrows] reaching 6 and 5.5mm on the right and left sides respectively [measured at mid-point]. (B) Corresponding axial T2WIs of the same patient confirm large bright endolymphatic sacs on both sides [magnified on the right side].

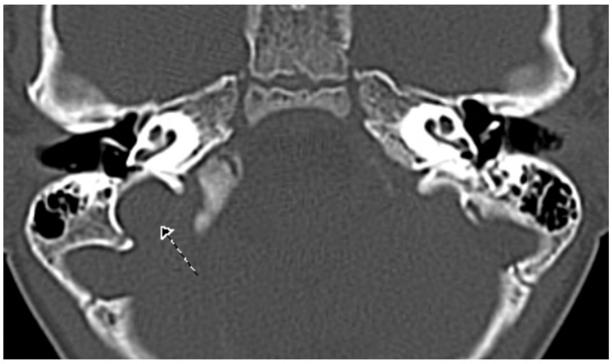


Fig. (6): Axial CT cut bone window revealed prominent high riding right jugular bulb [arrow] reaching the level of the basal cochlear turn.

Discussion

Cochlear implant is the method of choice in the treatment of deep sensorineural hypoacusis, particularly in patients where conventional amplification devices do not imply noticeable clinical improvement. The incidence of Sensorineural Hearing Loss (SNHL) in children is about 1,000. Today screening tests as part of newborn evaluations facilitate the early detection of congenital hearing impairment [8].

Our study was a cross sectional descriptive analytical study that studied a total of 70 patients with profound deafness planned for cochlear implantation surgery and our results showed 5.7% (n=4) of the study group would not benefit and cochlear implantation surgery is contraindicated for these patients as well as 41.4% (n=29) of the patients have had complicating criteria that possibly make surgical intervention difficult in comparison 52.9% (n=37) with anticipated straight forward surgical intervention which were statistically significant.

And that signifies the important role that radiological investigations (high resolution CT and MRI) are of utmost importance in pre-operative work up for patients planned for cochlear implantation surgery.

Another issue is that possible difficult intraoperative criteria for cochlear implantation surgery is not uncommon and that should warn surgeons that adequate training and expertise is required for every cochlear implantation patient to face challenges that could occur intraoperatively.

Actually no studies to date revealed such results as our study yet only few reports have been published about inner ear anomalies in SNHL and those dealing with cochlear implantation surgery are even fewer. And so an important part of this study was the depiction of a variety of etiologies that cause difficulties that could face the cochlear implantation surgeon.

However, the value of CT in the qualitative and quantitative evaluation of patients with sensorineural hearing loss has been reported earlier. Our study totally agrees with Krombach et al., 2008 [9] in that MRI and CT have become essential parts of the diagnostic work-up in patients with symptoms related to the inner ear. Both imaging modalities are complementary. The strength of CT lies in the better delineation of the osseous otic capsule. The soft-tissue components cannot be evaluated. The fluid-containing labyrinth, the nerves and soft-tissue components can be excellently delineated on MR images.

Difficulties arising in surgery of cochlear implant are important to be studied and assessed its impact on surgery and possibly on outcome of implant. Congenital dysplasia require thorough evaluation, careful operative planning, and a candid discussion with the parents due to increased risk of perilymph fistula, facial nerve injury, partial electrode insertion and less than op timum benefit from the implant. The obliterated cochlea, usually the result of meningitis and labyrinthitis ossificans, also represents a challenge as finding of patent scala tympani may be difficult [10].

Cochlear implantation of congenitally deaf children with inner-ear malformations may involve difficulties in pre-operative evaluation, surgical approach and post-operative follow-up. Cochlear nerve aplasia and hypoplastic cochleas are among the most difficult cases and sometimes children are considered unsuitable for cochlear implantation. However, there is always the possibility that hypoplastic cochleas may include ganglion cells and the only nerve in the internal auditory canal (facial nerve) may contain auditory fibres as well [10].

Both CT and MR are mandatory to guide the choice of the cochlear device, the side to implant by looking for cochlear patency, round window niche access, degree of mastoid aeration. The main role of radiological studies are to determine patients with absolute contraindications, relative contraindications and complicating factors for cochlear implantation [11].

Well-aerated mastoid cavity indicates easier surgical intervention across the facial nerve recess. Inflammation of the mastoid cells or presence of a middle ear cholesteatoma increases the risk of post-operative sepsis and failure [11].

Hypoplastic mastoid process is included in the range of complicating factors: When unilateral, such a finding favors the contralateral placement of the implant, in the spared side. Hypoplastic mastoid bones and decreased of mastoid cell aeration increase the difficulty of performing a facial recess approach. Venous variants such mastoid emissary veins could be faced [11].

Inflammation of middle ear mucosa and middle ear effusion also add difficulty to the surgery as round window niche may be obscured by inflamed mucosa and granulation tissue which may be difficult to be removed [12].

Facial nerve with an abnormal course through the mastoid cells is at significant risk during implantation. The pre-operative detection of aberrant or dehiscent facial nerve may prevent possible facial palsy secondary to the procedure, as the nerve would be out of its pathway and the surgeon would be aware of this abnormality prior to the procedure. Such surgical difficulty could be avoided if cochlear implant surgeons have adequate preoperative radiological imaging to evaluate the anatomy of the temporal bone. HRCT is the only modality that can detect this abnormality preoperatively [13].

An Internal Auditory Meatus (IAM) less than 2mm in diameter increases the risk of a congenital absence or of severe hypoplasia of the acoustic nerve. Similarly, patients with an absent or narrow modiolus are at risk of absence of cochlear nerve [14].

Exploration of the IAM by MRI allows the measurement of the diameter of the cochlear nerve in relation to the facial nerve taken as reference. Normally, the cochlear nerve lays on the inferior part of the internal auditory meatus and is larger than the facial nerve. Its diameter is approximately of 0.4mm [14,15].

Enlargement of the ducts and endolymphatic sacs is the most common amongst congenital internal ear abnormalities detectable at imaging studies. Such condition is generally bilateral, associated with cochlear dysplasia and abnormalities of the vestibular system semicircular canals. It is more commonly found in children under the age of ten. CT demonstrates the enlargement of the vestibular aqueduct and MRI demonstrates the enlarged endolymphatic sac on the posterior wall of the temporal bone [14,15].

Relative contraindications for cochlear implantation include cochlear dysplasias, particularly labyrinthitis ossificans, which may be secondary to infection, inflammation, trauma or previous surgery of the internal ear. Labyrinthitis ossificans affects the fluid-filled spaces of the membranous labyrinth, sometimes with ossification in the form of focal or diffuse plates. CT demonstrates high density bone deposition in the membranous labyrinth. On the other hand, MRI is superior to demonstrate the focus that is not yet calcified. Such cochlear calcification does not contraindicate the implantation, but its imaging documentation is required, since such condition could make cochleostomy more difficult to be performed **[16]**.

Absolute contraindications include cochlear nerve aplasia (evidenced by MRI), cochlear and/or labyrinthine aplasia, in spite of reports questioning the two latter contraindications. Labyrinthine aplasia is determined by the complete absence of the internal ear, including the cochlea, the vestibulum and semicircular canals. On MRI T2-weighted sequences, the high signal intensity from the fluid contained in the membranous labyrinth is not observed, with absence of the vestibulocochlear complex. In cases of unilateral labyrinthine aplasia, the implantation is contralaterally performed **[16]**.

Aberrant internal carotid artery results from a congenital vascular abnormality where a small segment of the internal carotid artery is inside the middle ear. CT demonstrates a tubular vascular structure surrounding the cochlear promontory, associated with enlargement of the inferior tympanic canaliculus and absence of the carotid foramen and of the vertical segment of the carotid artery. Jugular bulb dehiscence is a usually as asymptomatic anatomical variant, with superior and lateral extension of the jugular bulb into to the middle ear, through the dehiscent sigmoid plate **[17]**.

In our study, 70 patients were studied using high resolution CT scan and 3D MRI we demonstrated 17.1% (n=12) cases showing hypopnematised mastoid bone, anomalous sigmoid sinus was demonstrated in 18.6% (n=13) either prominent sigmoid sinus with or without a high jugular bulb, regarding the IAC our study showed a single patient 1.4% with a narrowed IAC yet two patients 2.9% revealed absent IAC, cochlear dysplasia was shown in 11.4% (n=8) with two patients 2.9% with cochlear aplasia, large vestibular aqueduct and subsequent CSF gusher difficulty represented 8.6% (n=6) with two patients 2.9% with absent vestibular aqueduct, regarding narrowed round window niche our study showed a single patient 1.4% with 2 patients with absent round window niche (cochlear aplasia), anomalous facial nerve course was demonstrated in 10% of the study sample (n=7).

When we compare with other researches our results comply with a study by Kim et al., 2006 **[5]** who studied 87 patients with severe to profound hearing loss for possible placement of a multichannel cochlear implant hearing device out of which 42 patients were studied by means of HRCT scan were evaluated. CT of the middle and inner ear was normal in 24 patients (57.1%) and showed labyrinthine ossification in 12 (28.6%), cochlear or fenestral otosclerosis (or both) in four (9.5%), and congenital cochlear malformation in two (4.8%). MRI experience in their study was limited.

A retrospective study for possible surgical difficulties by Aldhafeeri and Alsanosi **[10]** on 316 patients who underwent cochlear implanation revealed a total of 24 patients with inner ear. The anomalies included isolated large vestibular aqueducts in 8 (33.3%) patients, isolated semicircular canal dysplasia in 8 (33.3%) patients, classical Mondini malformation in 7 (29.1%) patients, and cochlear hypoplasia in 1 (4.1%) patient.

Another study who studied surgical obstacles hypopnematised mastoid bones with secretory otitis media by Gao et al., **[18]** on a total of 120 patients revealed five cases (4.16%) were defined of which four cases proceeded with successful implantation after removal of granulation tissue to identify the round window and underwent cochleostomy. One case associated with failure to complete surgery as a result of a large amount of granulation tissue which impeded the access to the middle ear.

Conclusions:

- The correct classification of cochlear conditions and a clear description of such abnormalities by means of multislice CT and 3D MRI are determining factors in the surgical planning developed by the cochlear implantation team, with direct impact on the success of the surgical intervention. Thus the radiologist experienced in the evaluation of the temporal bone plays a major role in the course of this disorder.
- Cochlear implantation surgery is now well practiced, and difficulties during surgery are infrequent for example: Anterior displaced sigmoid sinus, middle ear granulation tissue, aberrant facial nerve, CSF gusher and intracochlear ossification.
- Most of these difficulties can be effectively managed during surgery and only a small percent associated with failure to implantation.

- Surgical management of certain obstacles encountered during surgery demands expert knowledge and surgical technique for successful implantation. For these reasons we recommend to have preoperative imaging with HRCT and MRI, and to increase skills of the surgeons by attending international meetings and advanced training courses.
- Well preparation of the patient decreases the difficulty during surgery.
- Cochlear implantation for inner ear anomalies can be performed safely. Special attention should be given to pre-operative imaging to anticipate the potential intraoperative risks that can occur in inner ear anomaly cases. Every surgery should be planned with a safe approach and specific requirements.

Future Recommendations:

Following-up the 29 patients with relative contraindications and suspected difficult intervention for intraoperative difficulties and outcome after surgery.

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تقييم مرضى جراحة زرع قوقعة قبل الجراحة بإستخدام الآشعة المقطعية عالية الدقة والرنين المغناطيسى

يتم إستخدام الآشعة المقطعية عالية الدقة والرنين المغناطيسى بصفة روتينية لتقييم زرع قوقعة الآذن قبل الجراحة لتدارك تشوهات الآذن الداخلية، والتخطيط الجراحى فى الآطفال، وهذه الإجراءات لها آهمية قصوى نظرا لإرتفاع معدل تشوهات الآذن الداخلية فى هؤلاء المرضى.

آجرينا الدراسة على ٧٠ مريضا يعانون من ضعف سمع حسى عصبى مخطط لعملية زرع قوقعة الآذن الذين تتابعهم مستشفيات جامعة حلوان بين يناير ٢٠١٦ وديسمبر ٢٠١٧ وقد تعرض جميع المرضى إلى آشعة مقطعية عالية الدقة وتصوير بالرنين المغناطيسى لعظمة الآذن لتقييم تشوهات الآوعية الدموية، القناة السمعية الداخلية، العصب القوقعى، وحجم القوقعة، ووضع العصب السابع الوجهى. تم تصنيف جميع المرضى إلى: موانع مطلقة لجراحة زرع قوقعة الآذن، موانع النسبية لجراحة قوقعة الآذن وعامل تعقيد التدخل الجراحى مع الصعوبة النسبية وإلا يفترض التدخل الجراحى السهل.

درسنا ٧٠ مريضا يعانون من ضعف سمع حسى عصبى مخطط لعملية زرع قوقعة الآذن وآظهرت نتائجنا آن ٥.٧٪ (ن=٤) من مجموعة الدراسة لن تستفيد من الجراحة لوجود تشوهات تمنع التدخل الجراحى وكذلك ٤١.٤٪ (ن=٢٩) من المرضى لديهم موانع نسبية لجراحة قوقعة الآذن وعوامل تؤدى إلى تدخل جراحى صعب نسبيا مقارنة ٥٢.٩٪ (ن=٣٧) لا يعانون من آى تشوهات وبذلك يعتبر التدخل الجراحى سهل ونسبة نجاح عالية للعملية والذى له دلالة إحصائية.

إن التصنيف الصحيح للظروف القوقعة والوصف الواضح لآى تشوهات عن طريق الآشعة المقطعية عالية الدقة والرنين المغناطيسى له دور حاسم فى التخطيط الجراحى الذى يضعه فريق زراعة القوقعة، ولما له تآثير مباشر على نجاح التدخل الجراحى.