Effect of Cochlear Implantation on Vestibular Function: An Intertwined Phenomena

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***Abstract*—Cochlear implantation (CI) is a well-established treatment modality for individuals with severe hearing loss or deafness. While the procedure has shown significant success in restoring auditory function, its impact on vestibular function remains an area of concern. This cross-sectional study aims to investigate the frequency of disturbed vestibular function after cochlear implantation by utilizing caloric testing. The study was conducted at the Auditory Implant Centre (ENT) of Capital Hospital, Islamabad, Pakistan. The study spanned from 4 July 2021 till 3 January 2022 and had a sample size of about 70 patients. Primary cochlear implantation was performed on the right side using a conventional full-length electrode insertion. The assessment of vestibular function (VF) was carried out in the preoperative and postoperative phases through caloric testing. Follow-up evaluations were conducted after one week and one month simultaneously. Analysis of the data revealed a frequency of disturbed vestibular function after cochlear implantation of 8.57% (n = 08). Notably, the prevalence of vestibular disturbed function was higher in males (9.38%) compared to females (7.89%). These findings suggest that the incidence of vestibular dysfunction following cochlear implantation by caloric testing is relatively low. Based upon these results, it is recommended that meticulous attention be paid during cochlear implantation procedures to improve hearing outcomes while minimizing the risk of vestibular dysfunction. Furthermore, Generative Artificial Intelligence (GenAI) is paving its way through rehabilitative procedures and can produce groundbreaking results in Cochlear Implantation. This study highlights the importance of a comprehensive evaluation of vestibular function in patients undergoing cochlear implantation and also provides a future research directive towards GenAI.**

***Index Terms*—Cochlear implantation (CI), Vestibular function (VF), Caloric testing, Hearing loss, Rehabilitation Otology, Caloric Testing, Cross-sectional study, Generative AI (Gen AI).**

I. Introduction

Cochlear implantation(CI) leads to a significant risk for both peripheral vestibular receptors and cochlear function. Nowadays, the preservation of vestibular function is of utmost concern. Traumatic labyrinthine damage during surgery is a pertinent risk factor which leads to disturbed vestibular function in post-operative period [1] [2]. Cochlear implantation is an advanced surgical procedure performed at specialized auditory centers. Due to its better audilogical outcomes, it is gaining popularity in developing countries. Figure 1 shows procedure is carried out through a postaural round window approach via cortical mastoidectomy under general anesthesia. Criteria for cochlear implantation include candidates with congenital or acquired hearing loss. Moreover, patients who have post-lingual hearing loss of severe to profound type (an ability to hear sounds louder than 90 dBHL at 2 kHz and at 4 kHz) without amplification of hearing aids and patients with bilateral severe to profound sensorineural hearing loss since birth, who are not gaining any benefit from hearing aids are eligible for cochlear implant surgery [3]. Besides disturbed vestibular function, other complications of cochlear implantation includes facial nerve palsy, meningitis, vertigo, tinnitus, CSF leak, device failure or extrusion, flap necrosis and wound hematoma or dehiscence may occur in the postoperative period [4]. Congenital inner ear anomalies also play a vital role in delayed presentation of hearing loss in developing countries like Pakistan [5]. A study by Konrad et al. [6] shows that 79.2% patients have preserved vestibular function after cochlear implantation. Hence, the present study aims to determine the vestibular function before and after the cochlear implantation. Moreover, it further evaluates the frequency of disturbed vestibular function following cochlear implant surgery. The study will be fruitful in the future suggesting that cochlear implantation may not disturb vestibular function and is beneficial for patient. Furthermore, it signifies the potential of Generative AI (GenAI) which has specialized algorithms for early pathognomonic screening and hence can potentially aid interventional surgical procedure like CI.

II. MATERIALS AND METHODS

A. Patient Population

This cross-sectional study included patients aged between 2-60 years with prelingual, perilingual or postlingual hearing loss. Both genders were included. They had been audiological proven bilateral profound sensorineural hearing loss. The exclusion criteria included children with congenital inner ear anomalies and patients with developmental and behavioral disorders which includes attention deficit hyperactivity disorders (ADHD) and mental retardation. In addition to this, exclusion included patients with any other co-morbidities like hypertension, diabetes mellitus, asthma and ischemic heart diseases (IHD) and patients with history of vestibular disorders e.g., Benign paroxysmal positional vertigo (BPPV),

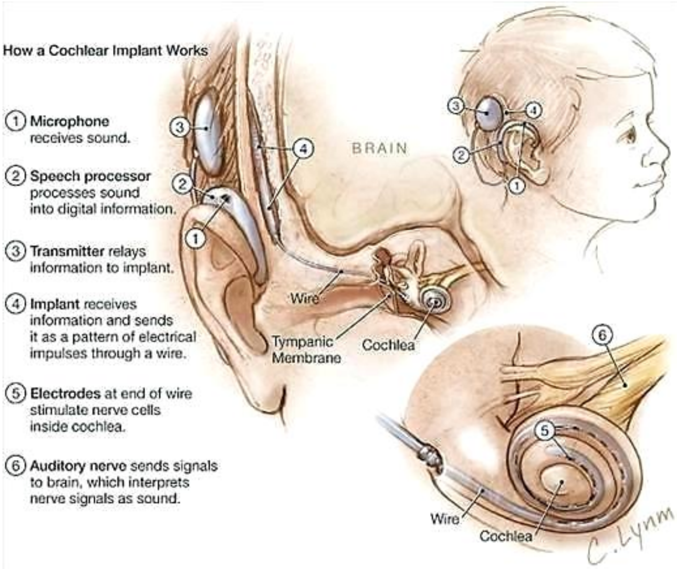

Fig. 1: How cochlear implant works, Image Courtesy [7].

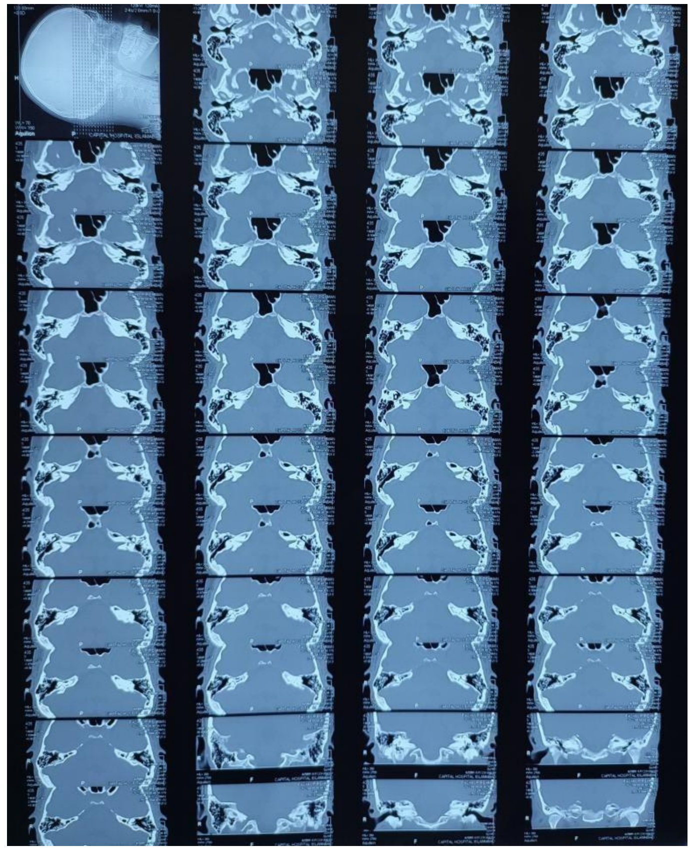

Fig. 2: Pre-operative evaluation of cochlear implant candidate by CT scan temporal bone without contrast showing the patency and number of cochlear turns, pneumatization of mastoid air cells,level of sigmoid sinus and juglar bulb,semicircular canal position and level of internal carotid artery.

labyrinthitis or vestibular neuritis, Meniere's disease were also excluded.

B. Audiological evaluation by Caloric Testing and Brain Evoked Response Audiometry (BERA)

It is a useful clinical test to assess and quantify the functional status of vestibular system and it evaluates the peripheral lesions. Vestibulo-ocular reflex that involves irrigating the external auditory canal with cold and warm water respectively is a means of detecting vestibular disturbance. It testifies the lateral semicircular canal and their afferents and rules out central causes of vertigo [8] [9]. Other evaluation tests includes Xray, CT scans temporal bone and BERA (Brain stem evoked response audiometry) in figure 2,3,4.

1) Mechanics of the test: When endolymph is warmed at 44 degrees Celsius, an artificial current is generated which moves causing ampullopetal endolymph flow creating an imbalance between right and left vestibul-ocular reflex generating horizontal nystagmus in the same direction. In addition to this, when cold water irrigation is applied it generates horizontal nystagmus in opposite direction due to ampullofugal flow.

2) Equipment: 250cc distilled water, stopwatch, thermometer, 60 cc syringe with removed needle and catch basin.

3) Procedure: Elevate the patient's head at 30 degrees which places the horizontal semicircular canal in vertical plane. Then, irrigate the external auditory canal with 250 cc of warm water for 20-30 seconds and note the nystagmus in for 30-45 seconds. Wait for 5 minutes and repeat the test in opposite ear [10] [11] Vestibular function is considered preserved when the caloric test shows minimum10 nystagmus beats between 30-60 seconds at the end of bithermal water irrigation at pre and post operative phase of CI [6]. If the caloric test results show more than 10 nystagmus beats between 30 to 60 seconds, then it will be considered as disturbed vestibular function. These medical tests are commonly used to evaluate the function of the auditory nerve and brainstem in cochlear implant patients. These tests help to determine the presence of any hearing loss and provide an estimation of the patient's hearing threshold level. BERA (Brain stem evoked response audiometry) or ABR (Auditory brainstem response) is a non-invasive procedure, which involves the placement of electrodes on the scalp and earlobes to record the electrical activity generated by the auditory nerve and brainstem in response to clicks or tone bursts. The electrical signals are then analyzed and displayed on an oscilloscope or computer screen to evaluate the hearing function. In cochlear implant patients, BERA or ABR is used pre-operatively to evaluate the functioning of the residual auditory nerve and brainstem, and post-operatively to assess the success of the cochlear implant surgery. This test provides important information on the extent of hearing loss and helps to determine the appropriate candidacy for cochlear implantation. In addition to evaluating the auditory nerve and brainstem, BERA or ABR can also help to identify any abnormalities in the inner ear and brainstem, such as vestibular schwannoma (acoustic neuroma), which can impact the success of the cochlear implant surgery. There are several advantages of BERA or ABR over other traditional

Fig. 3: Post-operative X-ray skull bone transorbital view showing 2.5 turns of cochlear implant electrode.

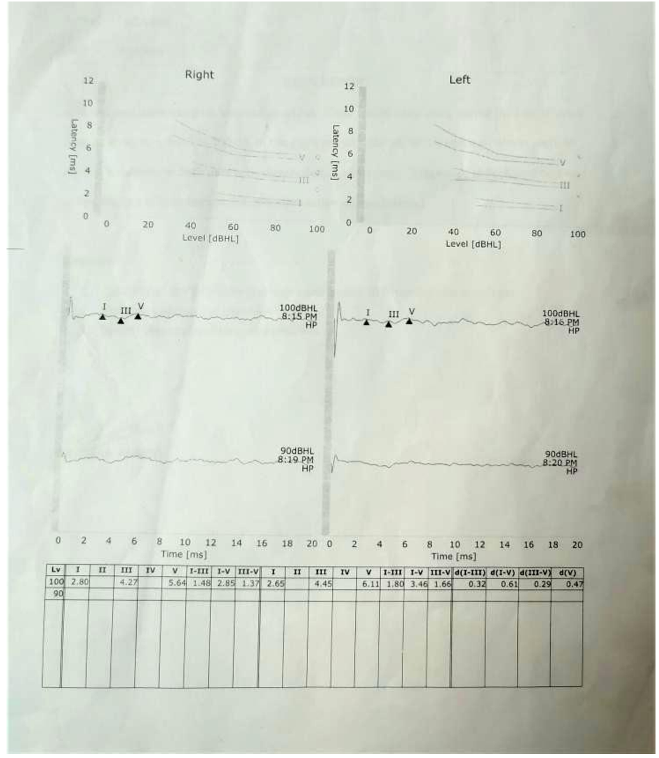

Fig. 4: Brain evoked Response audiometry TABLE I:

Distribution of patients according to Age (n=70)

Age (in years)	No. of Patients	%age
2-15	69	98.57
16-60	01	1.43
Mean ± SD = 4.18 ± 2.94 years		

hearing tests such as pure-tone audiometry. For example, BERA can provide objective information on hearing function even in patients who are unable to respond to traditional hearing tests, such as young children or patients with cognitive or communicative difficulties.

C. *Evaluation and Statistical Analysis*

Data will be entered and analyzed in Statistical Package for the Social Sciences version (SPSS) 23. Descriptive statistics will be calculated for quantitative and qualitative variables. Quantitative variables like age, gender and residual hearing will be measured by mean and standard deviation. Qualitative variables like disturbed vestibular function, prelingual, lingual and post lingual candidates, inner ear defects, syndromic or nonsyndromic patients, vertigo will be measured by frequency for percentage. Effect modifiers like age, gender, prelingual, lingual and postlingual cochlear implantation cases will be controlled by stratification. Post-stratification Chi-square test will be applied. P-value less than 0.05 will be considered significant.

III. RESULTS

In this study, we evaluate the effect of implantation on vestibular system's function. The age range in this study was from 2 to 60 years with a mean age of 4.18 ± 2.94 years. Most of the patients 69 (98.57%) were between 2 to 15 years of age as shown in Table I. Out of 70 patients, 32 (45.71%) were male and 38 (54.29%) were females with male to female ratio 1:1.2 as shown in Table VII. Distribution of patients according to type of deafness, inner ear defects and syndromic or non-syndromic patients are shown in Table II, III, IV respectively. In our study, frequency of disturbed vestibular function after cochlear implantation by caloric testing was found in 08 (8.57%) patients as shown. Stratification of disturbed vestibular function with respect to age groups, gender and type of deafness is shown in Table V, VI, VII respectively. Pie charts in Figure 5 and 6 shows distribution of patients according to gender and frequency of disturbed vestibular function after cochlear implantation by caloric testing sequentially.

IV. DISCUSSION

When cochlear implantation began worldwide a large group of individuals was concerned regarding post-surgical vertigo.

TABLEII: Distribution of patients according to type of deafness (n=70).

Type of deafness	No. of Patients	%age
Prelingual	33	47.14
Lingual	21	30.0
Post-lingual	16	22.86
Lingual	16	22.86

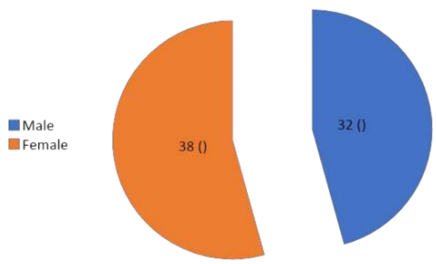

Fig. 5: Distribution of patients according to gender (n=70).

TABLE III: Distribution of patients according to inner ear defects (n=70).

Inner ear defects	No. of Patients	%age
Yes	09	12.86
No	61	87.14

Infact, symptoms of dizziness and imbalance were commonly reported following CI surgery. However, symptoms are often short-lived, and it is not clear whether symptoms are due to vestibular damage secondary to surgical intervention or due to other vestibular causes. Candidates with disturbed vestibular function can lead to detrimental consequences, such as falls and injuries such as elderly patients [12]. The study conducted by Dagkiran et al. [1] of 42 patients showed that 12 (28.5%) had significant impairment of vestibular function on the side of implantation. The study concludes that vertical, horizontal semicircular canal and otolith functions can be damaged in postoperative phase of cochlear implantation. A meta-analysis by Ibrahim et al. [13] of vestibular function after cochlear implantation reported that caloric and VEMP testing in adults was disturbed. This study included individuals of adult age group having sensorineural hearing loss who underwent unilateral or bilateral cochlear implantation.

A retrospective cohort study conducted by Nayak et al. [14] shows reduced vestibular function in postoperative period of the implanted ear. The objective of the study was to identify the prevalence of preoperative vestibular weakness in CI candidates and identify any risk factors for postoperative vertigo. It was conducted in 149 patients and used videonystagmography (VNG) in pre and postoperative period. The prevalence of vestibular dysfunction in CI candidates was evaluated in preoperative VNG revealed that 71/149 patients (47.7%) had normal vestibular function, reduced vestibular response was found in 46 patients (30.9%) and bilateral vestibular hypofunction was found in 32 patients (21.5%). This study validates that all postoperative cochlear implant candidates were found to have

TABLE IV: Distribution of patients according to syndromic or nonsyndromic patients (n=70).

	No. of Patients	%age
Syndromic	26	37.14
Non syndromic	44	62.86

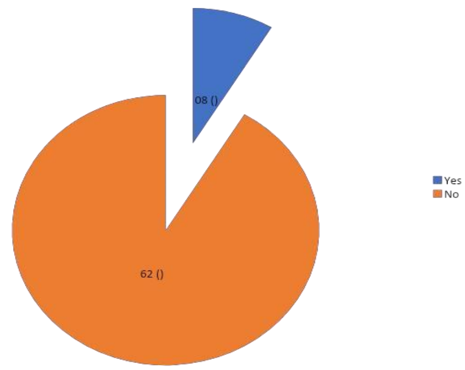

Fig. 6: Frequency of disturbed vestibular function after cochlear implantation by caloric testing (n=70).

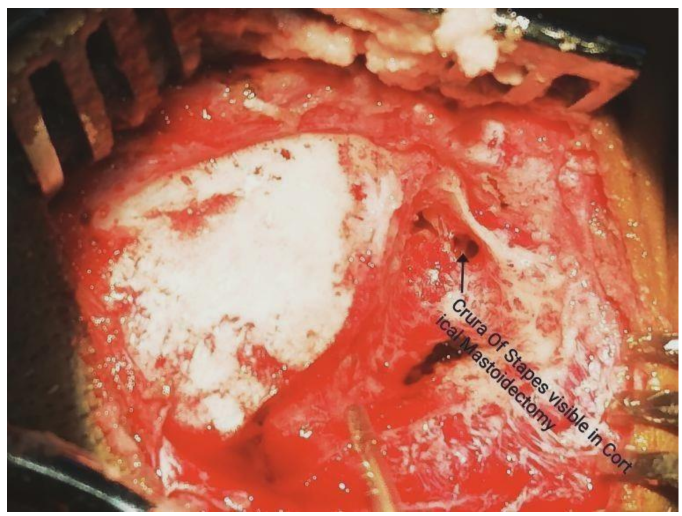

Fig. 7: Steps in cochlear implant surgery clear identification at cortical mastoidectomy with crura of stapes visible after Fisch flap elevation.

a decrease in caloric response, on average from 28.4 degrees/s to 6.4 degrees/s ($p = 0.02$). The vestibular sequalae can include dizziness, imbalance, vertigo, or disequilibrium.

The study by Konrad et al. [6]reports that the incidence of post cochlear implant newly developed compensated vestibular dysfunction was 16.6%. Dizziness occurs after CI frequently, with a reported incidence between 2 and 60Another research meta-analysis by Hansel et al. [15] showed that vertigo existed in 9.3% patients with continuous increase in patient age at the time of surgery. Younger patients compensate better following vestibular dysfunction. In addition to this, surgical approach is also a strong determinant for vestibular disturbance. This study showed that cochlear implant by cochleostomy lead to 8.8% significant increase in postoperative vertigo as compared to round window approach. The risk of vertigo as a postoperative complication is reported to range from 12 to 74%. The study by Weinmann et al. [16] shows that the incidence of new vertigo after CI was 45.8% (11/24 patients). The symptoms

TABLE V: Stratification of disturbed vestibular function with respect to age groups.

Age (Years)	Disturbed vestibular function	Disturbed vestibular function	p-value
	Yes	No	
2-30	05 (7.25%)	64 (92.75%)	0.001
31-60	01 (100.0%)	00 (0.0%)	0.001

TABLE VI: Stratification of Disturbed vestibular function with respect to gender.

Gender	Disturbed vestibular function	Disturbed vestibular function	p-value
	Yes	No	
Male	03 (9.38%)	29 (90.62%)	0.826
Female	03 (7.89%)	35 (92.11%)	0.826

TABLE VII: Stratification of Disturbed vestibular function with respect to type of deafness.

Type of deafness	Disturbed vestibular function	Disturbed vestibular function	p-value
	Yes	No	
Prelingual	03 (9.09%)	30 (90.91%)	0.303
Lingual	03 (14.29%)	18 (85.71%)	0.303
Post-lingual	00 (0.0%)	16 (100.0%)	0.303

indicated an otogenic etiology of vestibular dysfunction in 72.7% of all the cases with new vertigo after cochlear implantation surgery. A study conducted by Sosna et al. [17] upon fifty-fve patients was included in the study (30 females, 25 males, age 11–80, mean 41.8±19.35). cVEMP and oVEMP were performed preoperatively and 1–3 months after cochlear implantation. Caloric and vHIT tests were conducted preoperatively and 4–6 months after cochlear implantation. The partial deafness treatment–electro acoustic stimulation at postoperative phase of cochlear implant was determined. It gives a rate of saccular damage of 15.79%, utricular damage of 19.04%, and a horizontal semicircular canal response reduction of 15.79%. There was no vestibular loss in cases of perimodiolar electrode insertion. The results suggest that age predisposes the patients to postoperative vestibular loss after cochlear implantation.

The caloric test assesses the functional integrity of the horizontal semicircular canal (SCC) and is the most utilized test of vestibular function in post-CI patients [18]. A recent literature review with the sample of cochlear implant recipients shows that the caloric test was more sensitive in detecting vestibular disability than vHIT at a rate of 1.8:1. Vestibular disability occurs not only in patients who had a normal balance status before the CI but also in those with preoperative vestibular hypofunction. It is well known that residual vestibular function is essential for postural control in patients with vestibular disturbance. Therefore, maintaining residual vestibular function is crucial for minimizing balancing disabilities after the CI procedure [11].

However, there are studies which support the idea that cochlear implantation does not affect the vestibular function.

A study conducted by Kaczmarczyk et al. [19] shows that cochlear implantation does not impair gait stability, contrary to what might be expected. Rather, it was found that gait stability improved in most subjects after cochlear implantation, thereby reducing the risk of falling. In the experimental group, the gait stability ratio (GSR) improved in 17 subjects after cochlear implantation, by an average of 6%. We have speculated that the observed improvement in gait stability after cochlear implantation may plausibly be due to an improved "spatial sense" resulting from auditory recovery and to motoric learning. Patki et al. [20] used temporal bone modeling to estimate anatomical contributions to the caloric response and demonstrated that 69% of the variability of the caloric responses is accountable for anatomical differences in temporal bone only.

This would suggest that alterations to the mastoid would alter the heat transfer properties of the caloric test. These factors are magnified in patients with surgical ears, specifically CI patients, because most undergo mastoidectomies. Additionally, patient alertness can affect the caloric test results, and the test is conducted in the dark where visual cues are removed. Vertigo is basically an illusion of directional motion (spinning or non-spinning) of an individual or the environment [15]. It might be followed by cochlear implantation surgery due to secondary injury while electrode insertion, intraoperative loss of perilymphatic fluid, post-cochleostomy labyrinthitis, endolymphatic hydrops, implant linked electrical stimulation or foreign body induced labyrinthitis [21]. For knowledge and better understanding Figure 7-11 shows the steps of CI procedure. The objective of this study is to check the correlation between cochlear implantation and vestibular function. It is conducted to determine the frequency of disturbed vestibular function after cochlear implantation by

Fig. 8: Per-operative examination and placement of mastoid retractor in right ear after raising anterior based Fisch flap.

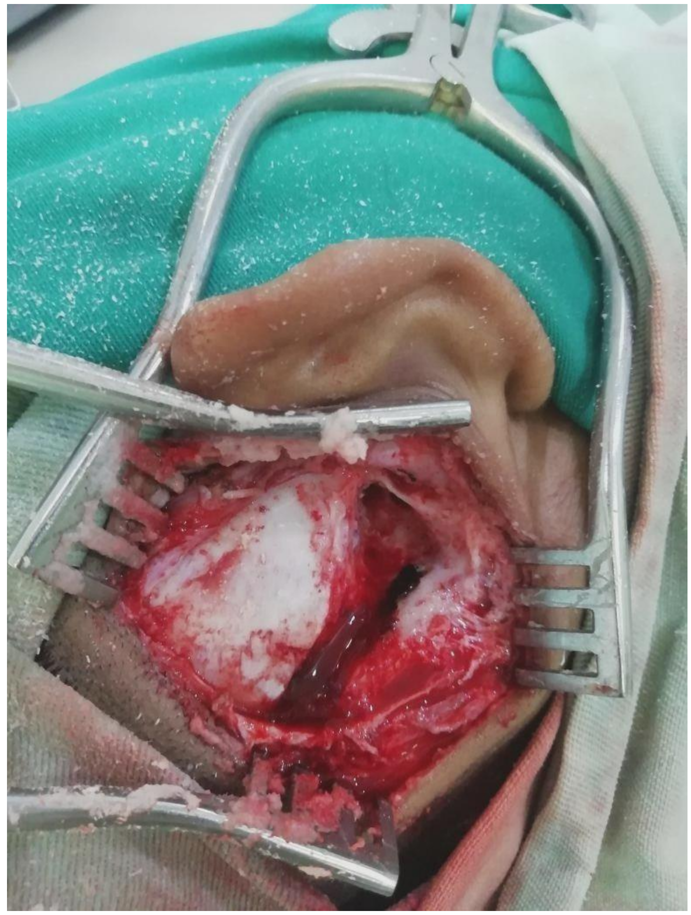

Fig. 9: Drilling at Macevan's triangle and preseving the facial nerve from damage with water irrigation.

caloric testing. The age range in this study was from 2 to 60 years with a mean age of 4.18 ± 2.94 years. Most of the patients 69 (98.57%) were between 2 to 15 years of age. Out of 70 patients, 32 (45.71%) were male and 38 (54.29%) were females with male to female ratio 1:1.2. In our study, frequency of disturbed vestibular function after cochlear implantation by caloric testing was found in 08 (8.57%) patients. This becomes evident that vestibular disturbance follows cochlear implantation; however, it can be minimized by careful evaluation and surgical techniques.

V. Conclusion

This study concludes that frequency of disturbed vestibular function after cochlear implantation by caloric testing is quite low. The prevalence of vestibular disturbed function is higher in male gender 9.38% as compared to female 7.89%. Therefore, it is recommended that great care should be taken during cochlear implantation to improve hearing in patients. This study aims to inform ENT professionals about potential risks associated with surgical procedures and to promote proactive measures that enhance patient safety by minimizing these risk factors.

Fig. 10: Closure of cortical mastoidectomy in triple layers to prevent hemostasis and for better healing and scar formation.

Fig. 11: Auditory implant team performing cochlear implant surgical procedure.

VI. Future Directions

Current study provides important insights into the impact of cochlear implantation on vestibular function. However, there is still additional need to dive deep into this topic. One avenue for future research is to conduct, a more comprehensive study that includes a larger sample size and more detailed metrics for vestibular function. This could involve conducting a longitudinal study that follows patients over a long period to assess the impacts of cochlear implantation on vestibular functioning. In addition to this, study can be done collaborating Generative Artificial Intelligence (GenAI), which is significantly changing healthcare from decision making to clinical diagnostics and having personalised treatment regimens. One such example is demonstrated as Doodle Me application which is an AI-powered mobile app that aids individuals with speech and communication disabilities and has a 92.6% accuracy level. It provides real-time auditory feedback, which supports rehabilitation process and has a potential to aid in autism and post-lingual hearing loss patients [22]. By developing GenAI based personalized rehabilitation programs that address the specific vestibular challenges faced by cochlear implant recipients, it is possible to further improve patient care and minimize the risk of errors. Finally, future research could incorporate Agentic Artificial Intelligence (AAI) which is a more robust and advanced automated system for CI. By early audiological screening and GenAI/AAI based CI, quality of life can be significantly improved [23]. Overall, there exists a significant gap in understanding how to responsibly implement GenAI algorithms for vestibular functional assessment. A multidisciplinary collaboration can bridge this gap by including a team of computer scientists and medical professionals which is much needed in this era of new technologies evolving at an enormous rate. It can transform millions of lives everyday by early diagnosis and better prognosis in patients suffering from ongoing hearing loss.

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ETHICAL CONSIDERATION

Ethical approval was obtained from the Ethical Committee of Capital Hospital, Islamabad, Pakistan. All patients included in this study provided written informed consent for their participation and for the use of preoperative photographs for research and publication purposes. Care was taken to ensure that all images used were anonymized to protect patient privacy and confidentiality. The inclusion of operative images and team image was solely integrated for educational and scientific dissemination and did not compromise patient dignity.

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