An audit of outcomes of cochlear implantation in patients following temporal bone fracture

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Background: Temporal bone fractures may cause a number of pathological changes in the temporal bone, which may influence potential cochlear implantation. In this retrospective study, we examine the impact of previous temporal bone fracture on outcomes and adverse events with cochlear implantation.

Methods: Retrospective case series of 14 adult patients with unilateral or bilateral temporal bone fracture undergoing cochlear implantation. Audiological outcomes [consonant-vowel-consonant (CVC) word and phoneme speech perception scores], ongoing implant use and adverse events were recorded. Audiological outcomes were compared to a control group of 1,414 adult patients undergoing cochlear implantation for post lingual deafness. All patients were discussed in the Cochlear Implant Multidisciplinary Meeting prior to implantation. Computed tomography (CT) petrous temporal bone and magnetic resonance imaging (MRI) scans were performed in all patients for workup and operative planning.

Results: Successful implantation (phoneme ≥55% with ongoing use) was recorded in 8 of 14 patients (57%). Cochlear implantation in otic capsule violating fractures results in worse CVC phoneme scores than both the control group (mean 33.8% *vs.* 63.7%, P=0.0005), and the otic capsule sparing group (mean 33.8% *vs.* 78.8%, P=0.002). There is a statistically significant strong correlation between age at implantation and both CVC word (r=–0.763; P=0.001) and phoneme scores (r=–0.773; P=0.001), with audiological scores reducing with advancing age.

Conclusions: Cochlear implantation following temporal bone fracture is safe, and while technical difficulties may be encountered, implantation may provide significant hearing and communication benefits, even when occurring several years post injury. Implantation in the setting of an otic capsule violating fracture may provide poorer audiological outcomes and has higher complication rates.

Keywords: Cochlear implant; temporal bone fracture; otic sparing; violating

Introduction

Temporal bone fractures are a common occurrence in trauma, present in 3% of all trauma patient (1). High-energy blunt head trauma causes the majority of temporal bone fractures, with half of fractures due to motor vehicle crashes, a third due to falls, and ~10% due to assault (2).

Temporal bone fractures were classically described as either longitudinal (80%) or transverse (20%) (3), however

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this classification failed to correlate well with clinical sequelae. The preferred contemporary classification system nowadays is to instead classify a fracture as either otic capsule sparing or otic capsule violating, which more accurately predicts the outcomes of temporal bone trauma (2). Up to 10% of patients may sustain bilateral fractures (4).

Sensorineural hearing loss occurs in 14–23% of temporal bone fractures, with 20–55% having mixed hearing loss (5). Otic violating fractures have a rate of sensorineural hearing loss 7 to 25 times greater than otic sparing fractures (2,6). Interruption of the otic capsule often causes a complete sensorineural hearing loss, occurring in 14% of all temporal bone fractures (5). In the setting of a unilateral fracture, the resulting single sided deafness affects sound localisation, speech comprehension in noisy environments, spatial awareness and can have significant quality of life, vocational and social impacts. Those patients unfortunate enough to have bilateral otic capsule violating fractures with hearing loss clearly suffer a profound quality of life imposition.

Temporal bone fractures may cause severe loss of hair cells, ganglion cells and other supporting cells in the inner ear (7). Head trauma may still cause sensorineural hearing loss even in the absence of a temporal bone fracture, with similar histopathological findings of hair cell loss, atrophy of the stria vascularis, cochlear hydrops and reduced spiral ganglion cell counts following trauma (8).

Delayed sensorineural loss may also occur in the form of sympathetic hearing loss, affecting up to 10% of patients (9). This represents an autoimmune reaction, due to exposure of inner ear antigens following trauma, and may result in hearing loss in months to years after trauma.

In patients with severe to profound or complete sensorineural hearing loss, cochlear implantation represents an opportunity for hearing rehabilitation. However, implantation in this group poses challenges, given the fracture of the temporal bone may distort the normal anatomy, and cause intracochlear fibrosis and osteoneogenesis, making implantation difficult. The aim of this study is to evaluate cochlear implantation in this group, to determine whether audiological outcomes and adverse events are affected by the presence of a previous temporal bone fracture. We also examined the effect of factors including fracture type, evidence of ossification on pre-operative imaging, age at implantation, and timing to implantation on these outcomes. We present this article in accordance with the STROBE reporting checklist (available at https://www.theajo.com/article/view/10.21037/ajo-23-12/rc).

Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This retrospective study was approved by the Human Research Ethics Committee (No. 18/1367HS). Because of the retrospective nature of the research, the requirement for informed consent was waived. The Cochlear Implant clinic at the Royal Victorian Eye and Ear Hospital serves all Victorian patients.

The Cochlear Implant database was analysed for implantation in patients with an indication reported as head injury or trauma which yielded 48 patients. A chart review was performed, to determine clear evidence of temporal bone fractures on pre-operative imaging. A total of 14 adult patients with post lingual hearing loss were identified to have had cochlear implantation following temporal bone fracture between January 2000 to June 2020, with audiological data available for analysis for 13 patients.

A control group was also identified from the database, with 1,414 adult patients with post lingual hearing loss implanted from January 2000 to June 2020 with otherwise normal cochlear anatomy. Patients were excluded from the study if they had documented otosclerosis as aetiology, were non-English speakers, patients with psychiatric or medical conditions precluding formal testing, and those patients that received a research device.

All patients were discussed in the Cochlear Implant Multidisciplinary Meeting prior to implantation. Computed tomography (CT) petrous temporal bone and magnetic resonance imaging (MRI) scans were performed in all patients for workup and operative planning. Follow up was performed at 3 and 12 months to assess audiological outcomes and ongoing use.

Patients underwent speech perception assessment before and after the procedure. Testing included open-set monosyllabic word testing in quiet [consonant-vowel-consonant (CVC) words] scored on the basis of phonemes and words correct. Pure tone audiograms, CVC word and phoneme scores were recorded pre-operatively. Post operative assessment included CVC word and phoneme scores, and was recorded at 3 and 12 months post implantation. Speech perception testing was performed at 65 dB. Hearing status in the contralateral ear, pre-implantation duration of deafness, and ongoing use at last review were also recorded.

Patient charts were reviewed to identify the type of device implanted, as well as any intraoperative and post

operative adverse events.

Successful implantation was defined as a CVC phoneme score of 55% or greater at 65 dB, with ongoing utilisation of the implant. In 2016 our centre published data from a large cohort of patients (n=382 patients), and found that 75% (n=288 patients) of adults met this definition of success after 12 months of use (10).

An intermediate outcome was recorded in those patients with an improvement in phoneme score of greater than 10%, but overall score less than 55%, with ongoing use. An unsuccessful outcome was defined as no ongoing use or improvement in phoneme score of less than 10% from baseline.

Student's two sample t-test was used to compare audiological outcomes between groups, and Pearson pairwise correlation was used to test for correlation between time to implantation or age at implantation and audiological outcomes. For pairwise comparisons, r value of >0.5 was considered strong, 0.3–0.5 moderate and 0.1–0.3 weak correlation. Statistical analysis was performed using XLStat software.

Results

A total of 14 patients were identified having undergone implantation in the setting of a previous temporal bone fracture, with subsequent post lingual hearing loss. The results are summarised in *Table 1*. Patient age at insertion ranged from 21 to 80 years old. Unilateral temporal bone fractures were present in nine patients, due to fall (3 patients), motor vehicle accident (2 patients), train accident (2 patients), bicycle accident (1 patient) and unknown cause (1 patient). Five patients had bilateral fractures, due to assault (2 patients), fall (1 patient) and motor vehicle accident (2 patients). Three of five (60%) patients with bilateral fractures underwent bilateral implantation.

Of a total of 19 temporal bone fractures, eight were otic capsule sparing, while eleven were otic capsule violating. There was evidence of cochlear involvement of the fracture line in eight of the otic capsule violating fractures. A total of 17 implantations were performed.

The duration of pre-implantation deafness varied greatly from 6 months to 50 years, with a median of 16 years. Two patients were implanted for single side deafness, the remainder had bilateral hearing loss.

Pre-curved Contour advance electrodes were preferred for the majority of insertions [Cochlear CI 24 RE (CA) or CI 512 electrodes] implanted in 13 patients (16 insertions).

The remaining patient received a Cochlear CI 522 straight slim electrode.

Adverse outcomes only occurred in the presence of an otic capsule violating fracture. One patient with bilateral fractures (patient 4) had an initial failed unilateral implantation, due to false insertion into the hypotympanic cell tract in the presence of ossification of the basal turn. This patient was successfully reimplanted ipsilaterally, requiring a drill out of the basal turn and proceeded to subsequent contralateral implantation. Two patients (patients 5 and 14) required scala vestibuli insertion due to ossification of the scala tympani. Pre-operative MRI demonstrated fibrosis of the scala tympani in both patients that underwent scala vestibuli insertion. A further two patients (patients 3 and 13) only had partial insertion, also due to ossification which was evident on pre-operative imaging.

Two patients experienced facial nerve stimulation initially. With implant programming this was able to be alleviated in both patients. Interestingly, in one patient this occurred in the tip electrodes, while in the other patient it was the basal electrodes causing facial nerve stimulation. Both patients were implanted with CI 512, with a perimodiolar electrode array which is known to be protective against facial nerve stimulation (11). In one patient (patient 14), there was fibrosis of the basal turn on preoperative MRI which required scala vestibuli insertion, while the other patient (patient 12) had standard insertion with a fluid filled cochlear on preoperative MRI.

Audiological outcomes were available for 13 of 14 patients, with one patient lost to follow up immediately, with no ongoing use of their implant. Four patients only had 3-month data available, with two patients lost to follow up and two patients no longer using their implant at 12 months.

The control group mean CVC word scores were 36% at 3 months and 44% at 12 months. The control group mean CVC phoneme scores were 58% at 3 months and 65% at 12 months. The mean post implantation CVC word score for patients with temporal bone fractures was 34% (range, 0–88%), while the mean CVC phoneme score was 53.54% (range, 0–95%).

CVC word and phoneme scores at last follow up were compared to the control group mean (see *Table 2*). There was no statistical difference in the phoneme scores between implantation in otic capsule sparing fractures compared to the control group (mean 78.8% *vs.* 63.7%, P=0.097). Otic capsule violating fractures had worse phoneme scores than

Table 1 Demographic and outcome data

Patient	Age at implantation (years)	Hearing loss	Fracture location	Imaging features	Implantation	Side	Time to implantation (years)	Adverse event	CVC word scores		CVC phoneme scores	
									3 months (%)	12 months (%)	3 months (%)	12 months (%)
1	64	Bilateral	Sparing	Nil significant	Unilateral	Left	20	None	28	34	55	60
2	41	Bilateral	Sparing	Nil significant	Unilateral	Left	15	None	40	LTFU	70	LTFU
3	63	Bilateral	Violating	Fracture line involving basal turn	Unilateral	Right	16	Partial insertion	14	8	39	29
4	36	Bilateral	Bilateral: right, violating; left, sparing	Right: fracture line involving basal turn	Bilateral	Right	0.5	Failed initial insertion. Basal turn drill out required	Not recorded†			
						Left		None	64	60	80	82
5	67	Bilateral	Violating	Scala tympani fibrosis	Unilateral	Right	35	Scala vestibuli insertion	0	Non-user	11	Non-user
6	47	Bilateral	Bilateral: right, violating; left, sparing	Left: calcification of basal turn involving scala tympani on CT	Unilateral; right	Right	26	None	26	52	51	77
7	80	Bilateral	Violating	Nil significant	Unilateral	Right	1.5	None	0	Non-user	4	Non-user
8	56	Bilateral	Bilateral: right, violating; left, violating	Nil significant	Bilateral	Left	0.5	None	12	38	8	39
						Right		None	14	16	40	43
9	40	Bilateral	Bilateral: right, sparing; left, sparing	Nil significant	Unilateral	Right	18	None	70	88	83	95
10	23	Single sided deafness	Sparing	Nil significant	Unilateral	Right	1	None	56	65	77	84
11	74	Bilateral	Violating	Nil significant	Unilateral	Right	18	None	40	42	66	69
12	71	Bilateral	Violating	Nil significant	Unilateral	Right	50	Facial nerve stimulation	0	0	0	0
13	21	Bilateral	Bilateral: left, violating; right, sparing	Left: fracture line involving cochlear	Bilateral	Left	1	Partial insertion	50	LTFU	76	LTFU
						Right		None	68		84	
14	23	Single sided deafness	Violating	Fracture line involving basal turn, scala tympani fibrosis	Unilateral	Right	8	Scala vestibuli insertion. Facial nerve stimulation	Non-user	Non-user	Non-user	Non-user

†, independent hearing outcomes were not scored for the right ear in patient 4, rather they were assessed with the left implant and bilateral implants. CVC, consonant-vowel-consonant; LTFU, lost to follow up; CT, computed tomography.

Table 2 CVC word and phoneme scores (%) by fracture type

Audiological outcome	Otic capsule sparing fracture, %	Otic capsule violating fracture, %	Control group, %	P_1	P_2	P_3
Mean CVC word score at last follow up	58.1	15.5	41.9	0.091	0.003*	0.001*
Mean CVC phoneme score at last follow up	78.8	33.8	63.7	0.097	0.0005*	0.002*

P_1: otic capsule sparing fractures compared to control group; P_2: otic capsule violating fractures compared to control group; P_3: otic capsule sparing fractures compared to otic violating sparing fractures. *, P values reach statistical significance. CVC, consonant-vowel-consonant.
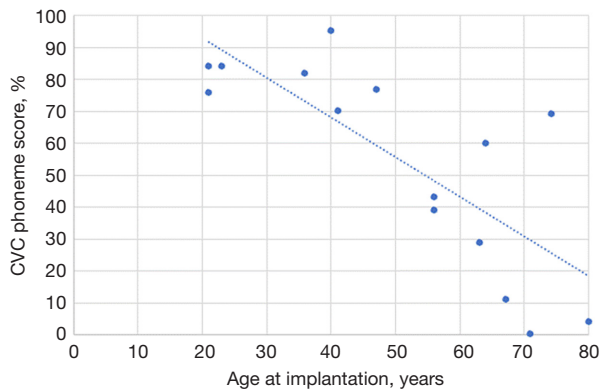
Figure 1 CVC phoneme scores (percentage) by age at implantation. CVC, consonant-vowel-consonant.
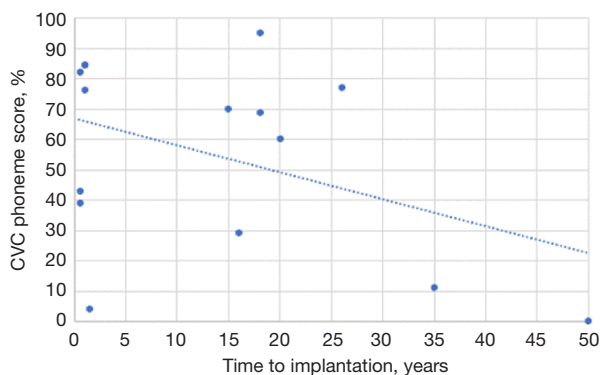
Figure 2 CVC phoneme scores (percentage) by time to implantation (years). CVC, consonant-vowel-consonant.

both the control group (33.8% *vs.* 63.7%, P=0.0005), and the otic capsule sparing group (33.8% *vs.* 78.8%, P=0.002).

There was a statistically significant strong correlation between age at implantation and both CVC word (r=−0.763; P=0.001) and phoneme scores (r=−0.773; P=0.001) on Pearson correlation, with audiological scores reducing with advancing age (see *Figure 1*). While there appeared

to be a similar trend of reducing audiological scores with increased time to implantation, this did not reach statistical significance [CVC word (r=−0.314; P=0.254), CVC phoneme scores (r=−0.422; P=0.117)]. A number of patients with delayed implantation performed poorly on both CVC word and phoneme scores (see *Figure 2*). Notably however, there was still benefit seen for patients implanted up to 26 years post onset of hearing loss.

Successful implantation (phoneme ≥55% with ongoing use) was recorded in 8 of 14 patients (57%). The rate of successful implantation was 100% for otic capsule sparing fractures. Implantation in otic capsule violating fractures was successful in 30%, had an intermediate outcome in 20% and was unsuccessful in 50%. All patients with an unsuccessful outcome had an otic violating fracture in the implanted ear, with four having bilateral hearing loss. Four patients ceased implant use, while one still found benefit from their implant, despite reduced speech perception scores.

Of the four patients which ceased implant use, in one patient (patient 12) this was likely due to the prolonged duration of deafness, with his temporal bone fracture having occurred 50 years earlier. This patient was implanted in the setting of new moderate-profound contralateral sensorineural hearing loss secondary to sudden sensorineural hearing loss. At 12 months their CVC word and phoneme scores in the implanted ear were 0% and 0% respectively. They have since returned to using a Bi-CROS hearing aid with reasonable satisfaction. The second patient (patient 5) underwent scala vestibuli insertion, experienced facial nerve stimulation, and unfortunately also had a poor audiological outcome, with 0% word scores and 11% phoneme scores at the 3-month follow up. They had a 35-year interval between fracture and implantation, and as such neural atrophy may be the primary cause of the poor outcome rather than the scala vestibuli insertion itself. They were implanted in the setting of progressive presbyacusis in the contralateral ear. Despite consistent use for 9 months,

they were unable to adjust to the new sound quality, did not receive any perceptible benefit and discontinued use. The third patient that ceased implant use (patient 7) also had a poor audiological outcome, with CVC word and phoneme scores of 0% and 4% respectively, and they did not persist with use in the setting of advancing dementia. The fourth patient failed to attend any follow up appointments after moving interstate, with no post-op audiological assessment performed.

Discussion

The data from our centre demonstrates a significant difference in the outcomes between otic capsule sparing and otic capsule violating fractures. Our study demonstrates a higher rate of success when the fracture does not violate the otic capsule, which is consistent with a systematic review by Cowan *et al.* (12). Audiological outcomes in the setting of an otic capsule violating fracture are significantly worse than the general implant population. Implants inserted into a fractured otic capsule were still utilized in 50% of cases, suggesting that as these patients have profound or total hearing loss, even suboptimal audiological outcomes may provide significant quality of life benefits in the setting of bilateral hearing loss.

There was a statistically significant negative correlation between age at implantation and audiological outcomes, in the absence of a significant correlation between time to implantation and outcomes. Hearing assessment may often be delayed in these patients, as ~90% have concurrent intracranial injuries, 9% have cervical spine injuries, and are often associated with other severe injuries (13). While delays to implantation may limit efficacy in the setting of neural atrophy, a number of patients with prolonged time to implantation still had significant benefit. Advancing age may reduce audiological outcomes, but hearing rehabilitation is still valuable in these patients for protecting neurocognitive functioning (14).

All insertions which were complicated by facial nerve stimulation, failed or partial insertion, or required scala vestibuli insertion, occurred in otic capsule violating fractures. Imaging was predictive in all cases of insertion difficulty, with evidence of cochlear involvement by fracture or ossification evident.

CT imaging may overlook ossification. Seidman *et al.* (15) found intraoperative ossification that was not identified on high-resolution computed tomography (HRCT) in 22% of cases. In 5 of 18 cases in their experience, the round window membrane was found to be ossified with a patent cochlear lumen. In 7 of 18 cases, ossification was found to extend for up to 2 mm into the cochlear lumen. In 6 cases, 3–9 mm of the basal turn was occluded. In all of these cases, the cochlear lumen appeared patent on HRCT. As such, pre-operative imaging with both CT and MRI is essential in these patients, as it can predict the occurrence of perioperative adverse events by identifying both bony obstruction and fluid signal abnormalities.

Facial nerve stimulation is reported to occur in 1–14.9% of cochlear implantation across all indications (16). In our group, the rate was 11.7% (2 insertions). Espahbodi *et al.* (17) suggested that fracture lines may provide a lower impedance pathway to the adjacent facial nerve and reduce the threshold for facial nerve stimulation. Fortunately for our patient group, facial nerve stimulation was able to be overcome with programming changes and did not impair ongoing use. For one patient, facial nerve stimulation occurred despite scala vestibuli insertion. Bigelow *et al.* (18), in a study of temporal bone dissection, demonstrated that the scala vestibuli was more distant from the labyrinthine segment of the facial nerve than the scala tympani. Despite this, scala vestibuli insertion does not absolutely protect from facial nerve insertion. A systematic review by Eastwood *et al.* (19), found that 50% of patients with facial nerve stimulation following implantation in the setting of temporal bone fracture did require reimplantation. Facial nerve stimulation has been shown also to be a problem in patients undergoing implantation for advanced otosclerosis, which is another group where aberrant electrical conduction may take place (20). In the presence of otosclerosis, perimodiolar electrodes have been shown to greatly reduce the incidence of facial nerve stimulation (21,22). The incidence of facial nerve stimulation in this group should not be a barrier to implantation, however potential recipients should have informed consent regarding the elevated risk and potential need for reimplantation. Perimodiolar implants should be preferred in the setting of previous temporal bone fracture.

Scala vestibuli insertion was necessitated in two patients due to the previous fracture. A previous study from our centre demonstrated a 10.5% decrease in phoneme scores for scala vestibuli insertion (23), with a mean 12-month phoneme score for planned scala vestibuli recipients of 46.1%. Trudel *et al.* (24) have demonstrated equivalent audiological outcomes for scala vestibuli insertion when compared to scala tympani insertion in the presence of

ossification. In the presence of ossification of the scala tympani, scala vestibuli insertion is a reasonable alternative still providing valuable hearing rehabilitation.

While not observed in our group, it is also important to consider the risk of perioperative meningitis, which may be increased in the setting of a fracture. There were 2 cases of meningitis across 96 implants in the review by Eastwood *et al.* (19), which is significantly higher than the overall rate of post operative meningitis (0.25%) (25).

It is also important to emphasise that not all patients are suitable for cochlear implantation. A thorough pre operative work up, assessment of the patients medical and social status, multidisciplinary imaging review and appropriate pre-counselling regarding the goals and expectations of the patient should be performed for all potential recipients. There is a proportion of individuals with temporal bone fractures that may be ineligible for implantation due to one or more factors.

Implantation in the setting of single sided deafness should be considered cautiously, and may be contraindicated in the presence of an otic capsule violating fracture given the poorer audiological outcomes. Only two patients with single sided deafness were implanted in our study, with one patient with an otic capsule sparing fracture performing well (CVC word score 65% and CVC phoneme score 84% at 12 months), while one patient with an otic capsule violating fracture failed to attend any follow up.

Conclusions

Cochlear implantation following temporal bone fracture is safe, and while technical difficulties may be encountered in the presence of an otic capsule violating fracture, implantation may provide significant hearing and communication benefits, even when occurring several years post injury. In patients with fractures violating the otic capsule, audiological outcomes are worse. Pre-operative imaging is essential to provide a recommendation regarding implantation, and to allow for surgical planning. Where there is evidence of fibrous or bony obstruction on imaging, this indicates a potentially difficult insertion and poorer prognosis, and as such careful assessment needs to be made to determine if implantation is still appropriate.

Acknowledgments

Footnote

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