Int. Adv. Otol. 2009; 5:(2) 229-236

ORIGINAL ARTICLE

Intraoperative Electrocochleography for Monitoring During Stapes Surgery

Simon RM Freeman, Halit Sanli, William PR Gibson

The Sydney Cochlear Implant Centre, Sydney, NSW, (SRMF) Australia.
Department of Otolaryngology, Manchester Royal Infirmary, (SRMF, WPRG) Manchester, UK.

Objective: To describe the results from utilising intraoperative electrocochleography to measure cochlear potentials during stapedectomy.

Materials and Methods: Patients undergoing stapedectomy with intraoperative electrocochleography monitoring were reviewed. Correlation of results from pure tone audiometry and intraoperative electrocochleography including threshold and waveform changes, was sought.

Results: Thirty-nine operations were included with no revision cases. Electrocochleography was measurable in all patients with a mild to moderate hearing loss. It could not be measured initially in 3 of 9 patients with a severe preoperative hearing loss but in only 1 patient following piston insertion. Preoperative air conduction thresholds correlated well with electrocochleography following raising of the tympanomeatal flap ($p<0.001$). Deterioration in electrocochleography threshold following stapedotomy and changes to the waveform, including a halving in action potential amplitude, an increase in the summating potential/action potential ratio and a W-shaped waveform, all occurred to some extent with patients who had sensorineural hearing loss postoperatively. These changes also occurred, albeit less commonly, to some patients who had a good postoperative outcome indicating that it is not possible to differentiate permanent from temporary threshold shifts at the time these changes occur. Improvement in electrocochleography following piston insertion correlated well with change in air conduction thresholds performed 6 weeks postoperatively ($p<0.001$).

Conclusions: Intraoperative electrocochleography provides good prognostic information during stapedectomy. Changes in threshold and waveform can be a useful indicator that inner ear trauma has occurred, particularly when training, but can not be relied upon to provide protection.

Submitted : 22 March 2009 *Revised : 23 April 2009* *Accepted : 03 May 2009*

One of the most serious complications of stapes surgery is sensorineural hearing loss. To overcome this some surgeons prefer to perform it under general anaesthetic as the slightest movement from a patient at a crucial moment has the potential to be catastrophic. Others argue that when performed under local anaesthetic the patient can monitor their own hearing.

Electrophysiological tests are usual when operating around the facial nerve but are rarely used to monitor hearing. Evoked response audiometry gives robust, repeatable measurements. It is widely used to provide objective hearing thresholds in many situations including newborn hearing screening, non-organic hearing loss and animal research. Electrocochleography (ECochG), in particular when recorded from the round window using click stimulation, gives a large stable response that requires only a few averages and is theoretically ideal for monitoring an anaesthetised patient.

Most reports regarding intraoperative ECochG focus on use for hearing preservation during surgery for cerebellopontine angle tumours. A recent paper

Corresponding address:
Mr SRM Freeman,
Department of Otolaryngology,
Manchester Royal Infirmary, Oxford Road, Manchester M13 9WL, United Kingdom.
Phone: +44 161 276 4426; Fax +44 161 276 5003; Email: simonfreeman71@gmail.com
Source of financial support: The Graham Fraser Foundation (UK) supported the fellowship of SRM Freeman with Professor Gibson.

highlighted the usefulness of ECochG in this regard and found an excellent correlation with postoperative pure tone audiometric thresholds[1]. There are very few reports of using ECochG to monitor middle or inner ear surgery.

Gibson has reported several studies on intraoperative ECochG for middle and inner ear surgeries, detailing the changes that occur to the waveform from different stimuli and insults[2-4]. He has used this monitoring technique for various procedures including stapes surgery, endolymphatic sac surgery, perilymph fistula repair and the cochleostomy procedure. No change in response was found upon fenestrating the inner ear (either through oval or round window) but suctioning caused a dramatic decrease in the action potential (AP) and, in most cases, an increase in the summating potential (SP). This appeared as either a broad single waveform or a W-shaped waveform where the initial part was considered to be formed by a sharply peaked SP. With continued damage the entire waveform was lost either immediately or gradually over several minutes. Raising intrathoracic pressure quickly refilled the cochlea following suction in about half the cochleostomy cases, allowing the waveform to return to normal.

Filipo et al[5] studied changes to AP amplitude and latency in a series of stapes surgery patients with normal bone conduction hearing. They found a highly variable relationship between these two outcomes both following stapedotomy and following placement of the prosthesis suggesting they could not be relied upon to predict audiological outcomes.

Wazen et al[6] studied intraoperative ECochG threshold changes during stapes surgery. They found that improvement in ECochG thresholds occurred in 19 of 22 patients but this did not correlate with the degree of postoperative audiometric improvement.

We aimed to assess the prognostic value from using intraoperative electrocochleography during stapes surgery and in particular correlate the changes that occurred to both the threshold and the waveform in relation to changes in pure tone audiometry.

Materials and Methods

This is a retrospective case series analysis of all patients undergoing stapes surgery with intraoperative ECochG monitoring by the senior author between May 2001 and May 2007. During this time all traces performed were routinely recorded to a hard disk. Ethics approval was obtained from South West Area Health Service in 1992. A report stating it was a safe procedure was filed in 1994 and since then it has been accepted as a clinical procedure. Further approval for this review was also obtained.

Surgery was performed under general anaesthetic through a standard endaural approach. Following bone removal to allow adequate visualisation, a stapedotomy was perfomed using Fisch picks to a size of 0.5mm. The stapes superstructure was then removed. A 0.4mm Fisch prosthesis was used.

ECochG was performed using a malleable silver ball electrode placed in the round window following raising of the tympanomeatal flap. This could be readily secured to the skin using a steristrip where it remained stable and did not obscure access. Reference and ground needle electrodes were inserted on the ear lobe and forehead respectively. Acoustic stimulation was provided by a TDH-39 earphone attached to the operating microscope using velcrose. This ensured that, with the microscope in focus, the earphone was always the same distance from the ear throughout the operation. Comparisons at this distance with those at ear level found thresholds deteriorated by 10 dBHL. The Medelec Synergy was used to coordinate the stimuli and record the potentials. A custom built amplifier was used to increase the intensity maximum by 30dbHL. A 100 μs click stimulus of 128 sweeps at a rate of 15 per second was used with bandpass filters of 3Hz for the high pass filter with a roll off of 12dB/octave and a low pass filter of 3kHz. Threshold measurements were obtained starting at an intensity of 110 dBHL (equivalent to approximately 100 dBHL at ear level) and reducing by 10 dBHL increments until no response was seen. They were routinely performed at several stages during the operation including following raising of the tympanomeatal flap (baseline), the stapedotomy and after insertion of the prosthesis. Examples are shown in Figures 1 - 4.

Postoperatively pure tone thresholds were obtained at six weeks. Threshold averages were calculated including: air conduction (AC) and bone conduction (BC) 4-frequency averages (500Hz, 1kHz, 2kHz, 3kHz), preoperative air bone gap (ABG) (preoperative AC average minus preoperative BC average), postoperative ABG (postoperative AC average minus postoperative BC average), closure of ABG (preoperative minus postoperative ABG) and overclosure (preoperative minus postoperative high BC 3-frequency average including 1kHz, 2kHz and 4kHz).

The correlation between ECochG and pure tone audiometric thresholds were calculated using Pearson's correlation coefficient. Using a Bonferroni Correction to account for the multiple frequencies analysed, the significant p-value was considered to be <0.003125 (0.05/16). Waveform patterns were evaluated using the trace from the 110dBHL stimulus. The SP/AP ratio and the N1 amplitude were evaluated as well evidence of a "W" waveform.

Results

Thirty-nine operations were performed on 38 patients where ECochG was performed intraoperatively. There were no revision operations. There were 19 women and 19 men with a mean age of 49 years (range 19 - 83). The closure of ABG and overclosure of high bone conduction are displayed in Figure 5. Patients are identified (ID: 1-39) in order of preoperative AC threshold average. In 7 cases preoperatively and 4 cases postoperatively, the BC thresholds were beyond the limits of the audiometer at some frequencies so these were calculated as 75 dBHL. Patient ID 8 suffered a dead ear. This was displayed in figure 5 for graphical purposes as no closure of ABG but was otherwise excluded from the ABG results. For purposes of analysis all postoperative AC thresholds for this patient were considered to be 120 dBHL. The results of overclosure and the ABG are given in Table 1. Patient ID 35 only had measurable BC thresholds at 500 Hz and so was omitted from the overclosure results. One case (ID 21) had deterioration in high BC threshold average of 40 dBHL and 2 cases (ID 3 and 26) deteriorated by 17 and 20 dBHL respectively.

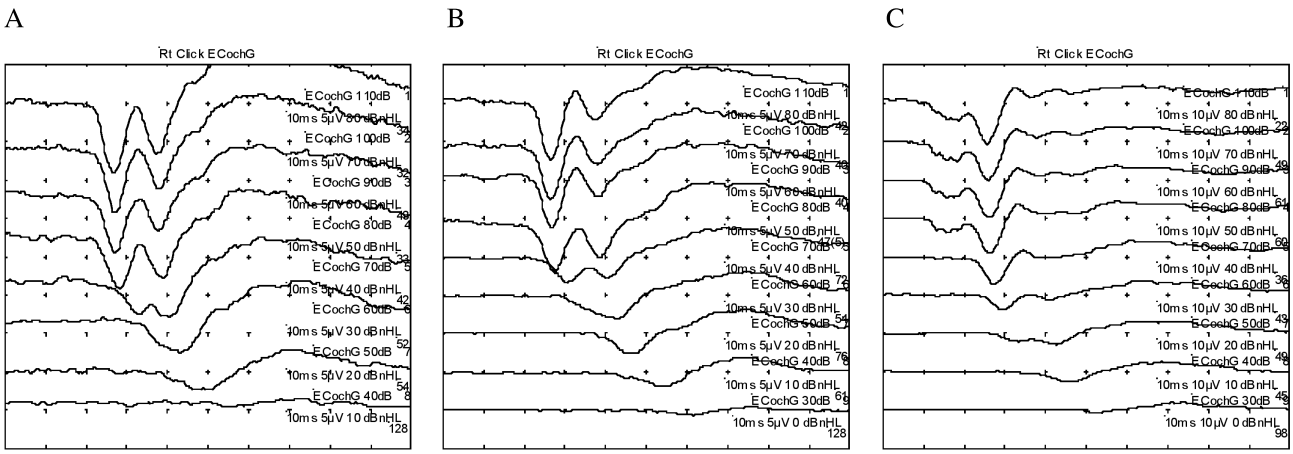

Figure 1. Electrocochleography of patient (ID 6) at baseline (a) and following stapedotomy (b) and prosthesis insertion (c) showing a good result.
(a): Clear waveform and threshold demonstrated at baseline albeit with prominent N2 waveform.
(b): The clear waveform remains and the threshold has improved by 10dBHL following stapedotomy.
(c): Improvement is maintained following prosthesis insertion. This patient had a 26 dBHL improvement in AC with a 2 dBHL loss in high BC postoperatively.

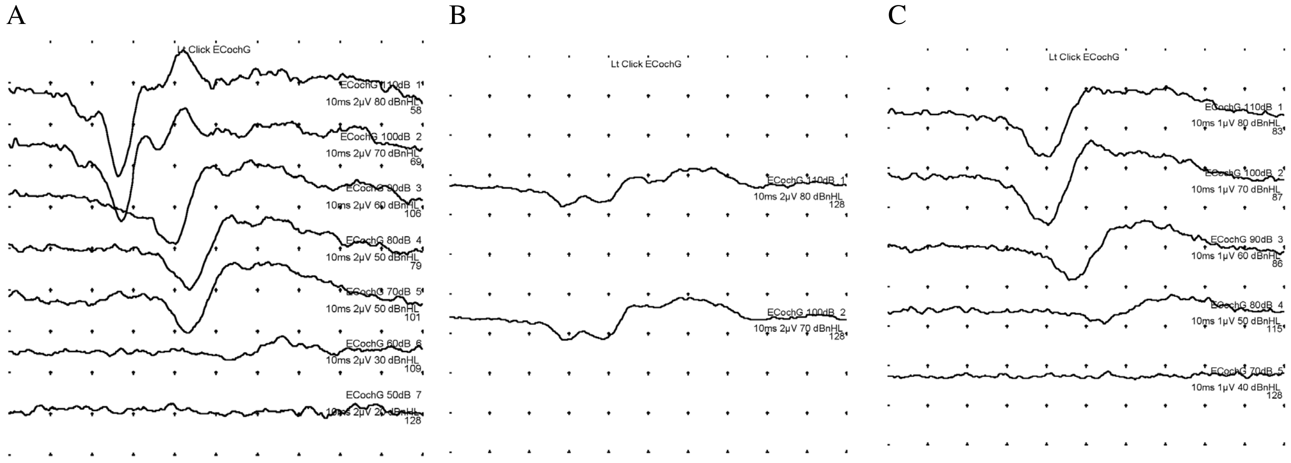

Figure 2. Electrocochleography of patient (ID 8) at baseline (a) and following stapedotomy (b) and prosthesis insertion (c) showing development of the "W" waveform with overall loss of threshold.
(a): Clear waveform and threshold demonstrated at baseline.
(b): Loss of N1 amplitude with "W" waveform and deterioration of threshold following stapedotomy. Downward displacement of the footplate had occurred.
(c): Partial recovery of waveform and threshold following prosthesis insertion. This patient was well initially but developed clinical signs of labyrinthitis 2 days postoperatively and was subsequently found to have a dead ear.

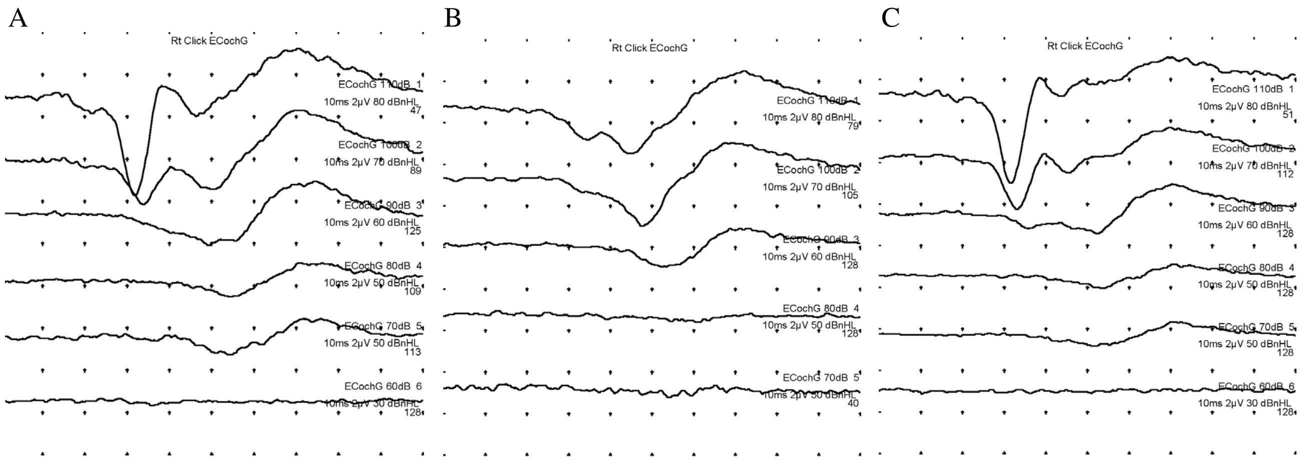

Figure 3. Electrocochleography of patient (ID 9) at baseline (a) and following stapedotomy (b) and prosthesis insertion (c) showing development of "W" waveform but with good recovery.
(a): Clear waveform and threshold demonstrated at baseline.
(b): Loss of N1 amplitude with "W" waveform and deterioration of threshold following stapedotomy.
(c): Good recovery of waveform and threshold to baseline levels following prosthesis insertion. This patient had a 22dBHL improvement in AC with 2 dBHL loss in high BC postoperatively.

Intraoperative ECochG thresholds were unobtainable in 3 cases at baseline (ID: 30, 32 and 35) and 1 case (ID: 35) at the end of the procedure. All these cases had a severe to profound hearing loss. For the purposes of analysis, these ECochG thresholds were recorded as 120 dBHL. All other patients gave clear, repeatable waveforms. In 6 patients, all of whom had ECochG thresholds of 100 dBHL or greater, the waveform was too small to allow accurate interpretation of morphology.

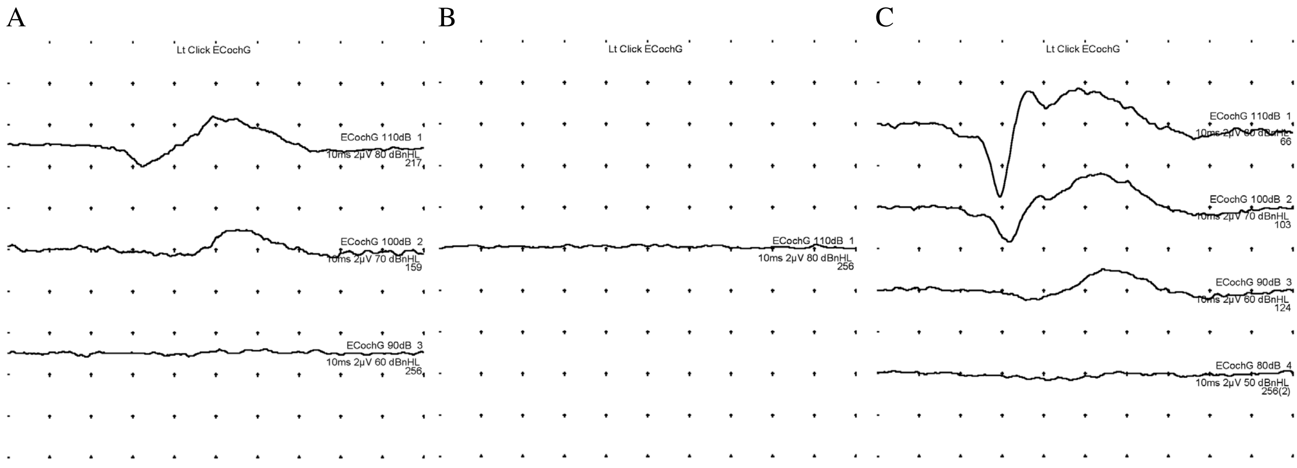

Figure 4. Electrocochleography of patient (ID 21) at baseline (a) and following stapedotomy (b) and prosthesis insertion (c) showing an initial severe loss with temporary deterioration but good recovery.
4 (a): Initial severe hearing loss with associated poor ECochG waveform but clear threshold.
4 (b): Loss of threshold following stapedotomy.
4 (c): Good recovery with improvement in both waveform and threshold. Unfortunately this patient suffered an 18dBHL loss of AC that was due to a 40 dB loss of high BC. It was not clear if this was caused intraoperatively or because of exercise-induced barotrauma 3 days postoperatively.

A significant correlation was found between baseline ECochG thresholds and all preoperative AC thresholds measured as well as the 4-frequency average (Table 2). Scatter graphs confirmed the strength of these associations.

The change in ECochG threshold following stapedotomy was variable. Ten patients had an improved threshold by 10 dBHL (example given in Figure 1) and in 15 patients there was no change. Seven patients deteriorated by 10 dBHL but all of these

Table 1. Results for overclosure and air-bone gap (dBHL).

	Mean (95% CI)	SD	Range	<-20	-20-11	-10-1	0-10	11-20	>21
Overclosure+	2 (-2 - +6)	12	-40 - +24*	1	2	9	19	6	1

	Mean (95% CI)	SD	Range	0-10	11-20	21-30	31-40	>40
PreopABG	30 (27-33)	9	18 - 49		7	14	11	7
PostopABG*	8 (6-10)	6	0 - 28	32	4	2		
Closure ABG*	23 (20-26)	8	8 - 41	3	12	18	4	1

**Patient with dead ear excluded.*
+Patient with no measurable bone conduction at 1,2 or 4 kHz excluded.

Table 2. Pearson correlations between electrocochleographic thresholds after raising the tympanomeatal flap (baseline) with preoperative audiometry.

Preoperative AC audiometry	4-frequency average	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz
ECochG Pearson correlation	0.759	0.646	0.695	0.780	0.741	0.709	0.611	0.541
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001

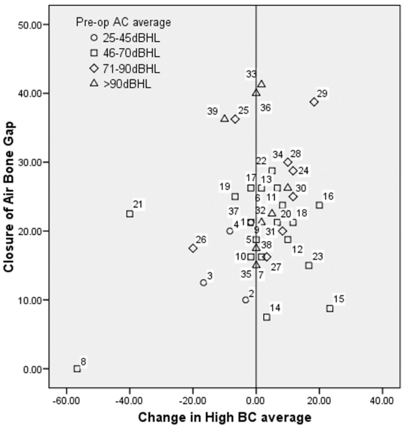

Figure 5. Scatterplot comparing change in conductive hearing (air bone gap) with change in sensorineural thresholds (overclosure of high bone conduction average) following stapedectomy.
Patients are categorised by their preoperative AC hearing thresholds. For "Change in High BC average": negative values signify a sensorineural hearing loss postoperatively whereas positive values demonstrate improvement in bone conduction postoperatively (overclosure) that is principally due to the Carhart phenomenon.

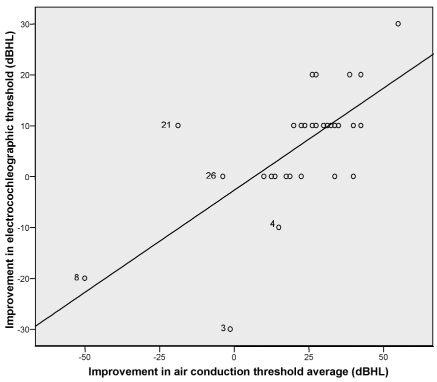

Figure 6. Scatterplot comparing improvement in electrocochleographic threshold with improvement in air conduction threshold average following stapedectomy. For "Improvement in air conduction threshold average": negative values signify a sensorineural hearing loss that is greater than any improvement in the conductive loss (air-bone gap). Conversely a positive value means the improvement in air-bone gap is greater than any concommittent sensorineural loss that may have occurred.
The ID numbers of the 5 patients with the largest postoperative sensorineural loss are marked with two of these (ID 3 and 21) being outliers.

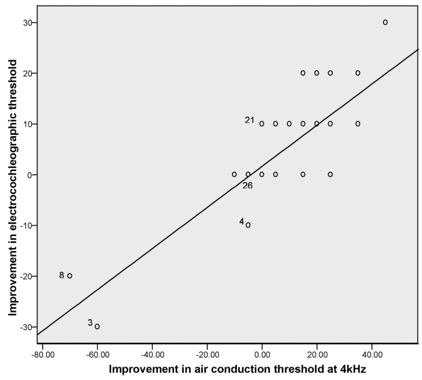

Figure 7. Scatterplot comparing improvement in electrocochleogrphic threshold with improvement in air conduction threshold at 4kHz following stapedectomy.
For "Improvement in air conduction threshold average": negative values signify a sensorineural hearing loss that is greater than any improvement in the conductive loss (air-bone gap). Conversely a positive value means the improvement in air-bone gap is greater than any concommittent sensorineural loss that may have occurred.
The ID numbers of the 5 patients with the largest postoperative sensorineural loss are marked. The two patients (ID 3 and 21) who were outliers in figure 2 are no longer so.

had recovered by the end of the procedure except one (ID 4). Three patients deteriorated by 20 dBHL (ID 9 (Figure 3), 14 and 21 (Figure 4)) but then recovered and 2 patients deteriorated by 40dBHL (ID 3 and 8 (Figure 2)) with neither fully recovering to baseline levels.

A significant correlation was found between improvement in ECochG thresholds following piston insertion and improvement in AC thresholds measured at 6 weeks postoperatively at all frequencies except 6 and 8 kHz (Table 3). The scatter graphs of these correlations at the 4-frequency average and at 4kHz are shown in Figures 6 and 7 respectively.

The SP/AP ratio was greater than 40% in 2 patients at baseline (ID 4 and 5) and became so in 3 patients during the procedure (ID 8, 9 and 23). In 3 patients (ID 4, 8 (Figure 2b) and 9 (Figure 3b)) this developed as a "W" shaped waveform that in each case was associated with a decrease in threshold (by 10, 40 and 20 dBHL respectively). At the end of the procedure the SP/AP ratio had returned to less than 40% with a normal waveform in patients ID 5, 9 and 23.

Great variability was seen in the N1 amplitude. Significant changes were felt to have occurred if the amplitude halved. This occurred at the time of

Table 3. Pearson correlations between improvement in electrocochleographic threshold with improvement in air conduction audiometry following stapedectomy.

Preoperative AC audiometry	4-frequency average	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz
ECochG Pearson correlation	0.659	0.504	0.529	0.638	0.770	0.818	0.283	0.416
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01

stapedotomy in 12 patients (ID 1, 3, 4, 8, 9, 11, 13, 14, 16, 17, 21, 26) with some recovery made in all patients.

Discussion

This study found that ECochG was measurable in all patients with a mild to moderate hearing loss as well as in 6 of 9 patients with a severe preoperative hearing loss and a further 2 of the remaining [3] following piston insertion. Preoperative AC pure tone audiometric thresholds correlated well with those found by ECochG following raising of the tympanomeatal flap. Deterioration in ECochG threshold following stapedotomy and changes to the waveform including a halving in AP amplitude, an increase in SP/AP ratio and a W-shaped waveform all occurred to some extent with patients who had sensorineural hearing loss postoperatively suggesting these are indicators of inner ear trauma. These changes also occurred to some patients who had a good postoperative outcome indicating that it is not possible to differentiate permanent from temporary threshold shifts at the time these changes occur. Improvement in ECochG following piston insertion correlated well with change in AC thresholds performed 6 weeks postoperatively.

The process of recording the ECochG was straight forward and added no more than 5 minutes to the whole procedure. The application of the speaker to the microscope allowed precise control over the distance from the ear and the silver ball electrode could be left in-situ without obscuring access. The additional use of a custom amplifier allowed sound generation up to 110 dBHL which was useful in those patients with a severe hearing loss.

ECochG using click stimulation is known to correlate best with pure tone audiometry between 3 - 4kHz[7] so it is no surprise that this study found both preoperative and postoperative changes were best correlated around these frequencies. However we still found an excellent correlation with the lower frequencies as well (Tables 2 and 3) confirming the validity of the test. While tone pips may potentially correlate better with the lower frequencies, these give a less robust stimulation of the cochlea because of the narrow bandwidth and we have found them to be less reliable. Keith et a[18] reported using preoperative ECochG to evaluate cochlear reserve prior to stapes surgery in patients with severe hearing loss. We also found it useful in this situation. However [3] of our patients had no response at baseline and one of these still had no response following stapes surgery even though all had useful gains postoperatively. Therefore the absence of a response can not be used to conclude a pure sensorineural hearing loss.

The alterations in waveform previously reported by Gibson[2-4] were noted in some patients. However no consistent finding occurred to indicate definite damage. Two 2 patients with the worst ECochG results (ID 3 and 8 (Figure 2)) both suffered downward displacement of the footplate during fenestration with immediate deterioration in threshold and alteration of the waveform. They both showed some improvement after several minutes of inaction but clearly some damage had already occurred. Patient ID 8 was discharged the following day with no problems but developed severe vertigo 2 days postoperatively. When he presented back on day 5 he had already developed a dead ear. Several other patients were also found to have either a reduced threshold or an altered waveform after either fenestration or prolonged manipulation of the piston. Following several minutes of inaction this usually returned to baseline levels and often improved after completing the piston insertion. In these cases the improvement was reflected in the postoperative audiogram indicating any inner ear trauma sustained was temporary. The main exception to this was patient ID 21 (Figure 4). A temporary threshold deterioration occurred following fenestration but otherwise the surgery for this patient was uneventful. Interestingly this patient gave a history that, despite advice to the contrary, he had played a hard game of tennis 3 days after the operation during which he had felt a loud “pop” in his ear. It is not clear whether the damage occurred intraoperatively or due to subsequent barotrauma.

Unlike Wazen et al[6], we found an excellent correlation between the amount of improvement in ECochG thresholds and AC audiometry. Both studies used a similar technique except that they used an inset earphone so it is not clear why this difference should have occurred.

Intraoperative ECochG can provide useful prognostic information during stapes surgery. Changes in threshold and waveform can be a useful indicator that inner ear trauma has occurred, particularly when training, but can not be relied on to provide protection.

References

1. Morawski KF, Niemczyk K, Bohorquez J, et al. Intraoperative monitoring of hearing during cerebellopontine angle tumor surgery using transtympanic electrocochleography. Otol Neurotol 2007; 28:541-5.

2. Gibson WP. Electrocochleography in the diagnosis of perilymphatic fistula: intraoperative observations and assessment of a new diagnostic office procedure. Am J Otol 1992; 13:146-51.

3. Gibson WPR, Arenberg IK. The scope of intra-operative electrocochleography. Surgery of the Inner Ear. Amsterdam/New York: Kugler Publications, 1991. 295-303.

4. Aso S, Gibson WP. Perilymphatic fistula with no visible leak of fluid into the middle ear: a new method of intraoperative diagnosis using electrocochleography. Am J Otol 1994; 15: 96-100.

5. Filipo R, Bertoli GA, De Seta E, Cordier A, Barbara M. Initial experience of peroperative electrocochleography monitoring in stapes surgery. Rev Laryngol Otol Rhinol (Bord) 1993; 114: 161-3.

6. Wazen JJ, Emerson R, Foyt D. Intra-operative electrocochleography in stapes surgery and ossicular reconstruction Am J Otol 1997; 18: 707-13.

7. Brackmann DE, Selters WA. Electric response audiometry: clinical applications. Otolaryngol Clin North Am 1978; 11: 7-18.

8. Keith RW, Kereiakes TJ, Willging JP, Devine J. Evaluation of cochlear function in a patient with “far-advanced” otosclerosis. Am J Otol 1992; 13: 347-9.