ABSTRACT
Bipolar 250 pulses/s electric stimuli applied via a scala tympani electrode pair located in the high CF region of the cochlea evoke responses from a population of low characteristic frequency Inferior Colliculus (IC) units. This is observed for ipsilateral and contralateral electric stimulation of a neomycin deafened cochlea. Modiolar stimulation is used to explain this finding. At low stimulus levels modiolar stimulation is observed.

INTRODUCTION
Cochlear implants are used to provide hearing sensation to the sensoneurally deaf. Bipolar electrical stimulation of a scala tympani cochlear implant produces a localised stimulus which has been measured to diminish at about 9dB/octave [1]. Blamey et al. (1994) describes both a perceived low frequency shift by cochlear implant patients in response to high stimulus levels and a perceived lower pitch for place of electrical stimulation when compared with acoustic stimulation on the opposite side. Modiolar stimulation is likely the cause. Frijns (1995) and Briaire (2000) have modeled the field excitation patterns for scala tympani bipolar electrical stimulation and predicted excitation of the modiolus at higher current levels.

This preliminary study aims to quantify the extent of modiolar stimulation as a function of current level as recorded in a population of IC units driven by scala tympani bipolar charge balanced stimulation.

METHODS
Cats (2-4kg) were anaesthetised with KetamineTM (40mg/kg, i.p) and RompunTM (30mg/kg, i.p). The anaesthetic level was maintained by supplementary doses of Nembutal (5-10mg/kg, i.v). Feline versions of the multichannel bipolar Melbourne/Cochlear scala tympani electrode array were implanted into a NeomycinTM deafened cochlea. The contralateral cochlea was Neomycin deafened, implanted and electrically stimulated whilst the ipsilateral cochlea was left intact. A craniotomy was carried out rostral to the tentorium, and the inferior colliculus exposed by aspirating the overlying occipital lobe. Recording microelectrodes were placed in the inferior colliculus. Stimuli were 40ms bursts of biphasic charge balanced (100µs/phase) electric pulses (125-4000 pulses/s). Electric stimuli were presented as pulse trains at constant current levels.

Unit threshold was established. If no driven response was detected at a particular current level the current was increased in 1 dB steps up to a maximum of 2.5mA. If a driven response was detected the current level was decreased in 1 dB step to establish response threshold. At each threshold point the measurement was repeated until two reproducible threshold values were obtained. Threshold determining stimuli were bursts of electric pulses or a single electric pulse. The firing rate in the interval 0-120 ms post stimulus onset was compared with the firing rate in the 120 ms prior to stimulation. These firing rates were summed over the 10 bursts in each stimulus packet. A driven response was defined, either as a 10 % increase in firing in the driven interval compared to the non driven interval or, for very low or zero spontaneous rate units, an increase of 5 spikes per stimulus packet for the driven region as compared to the non driven region of the response. For a small number of units the automated program failed. In such cases a manual procedure, based on a visual assessment of an increase in firing rate, was used. Automated threshold measurements were checked manually for each unit and recorded to an accuracy of ±1 dB respectively.

The care and use of animals reported on in this study were approved by the University of Melbourne Animal Experimentation Ethics Committee and the Royal Victorian Eye and Ear Hospital Animal Research Ethics Committee.

RESULTS
Figure 1 upper plot shows the number of units expressed as a population percentage (n=66) of contralaterally driven units that show a driven response to the applied electrical stimulus versus their CF. Stimulus level is measured as a dB attenuation relative to a 2.5mA current level. Electrodes were located in the 2-5kHz bin. For attenuation levels greater than 12dB there is evidence of modiolar stimulation in the 0.5-1 kHz CF bin. The contralateral acoustic plot was obtained from 116 IC units recorded.

A Modiolar Stimulation map measured in the Inferior Colliculus
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using contralateral acoustic stimulation of an intact cochlea. For electrical stimulation there is a relatively localized stimulation up to 6-9dB of attenuation (with some localized modiolar stimulation). At higher stimulus levels most IC units representing most of the cochlea or its projections are being driven by either modiolar stimulation or by stimuli local to the electrode pairs. Figure 1 shows the number of units expressed as a population percentage (n=66) of contralateral (upper plot n=66) and ipsilateral (lower plot n=24) driven units that show a driven response to the applied electrical stimulus versus their CF.

Figure 1 (lower plot) shows the number of units expressed as a population percentage (n=24) of ipsilaterally driven units that show a driven response to the applied electrical stimulus versus their CF. For attenuation levels greater than 12dB there is evidence of modiolar stimulation in the 0.5-1 kHz CF bin. The ipsilateral acoustic plot was obtained from 53 IC units recorded using ipsilateral acoustic stimulation of an
intact cochlea. For electrical stimulation there is a relatively localized stimulation up to 9-12dB of attenuation (with some localized modiolar stimulation). With the exception of the 1-2kHz CF range at higher stimulus levels most IC units representing most of the cochlea or its projections are being driven by either modiolar stimulation or by stimuli local to the electrode pairs. The ipsilateral interpretation is confounded by smaller sample size and the fact that nearly all ipsilateral driven IC units are EE units which have a predominantly low CF distribution.

Figure 3 shows the average and minimum latency of low CF units to be as short as or shorter than middle CF units. Finally, compared to the C(acoust)I(acoust) unit type distributions, there is a more pronounced peak located in a lower CF bin (0.5-1 kHz) in the C(elect)I(acoust) EE and new sharp peak (0.5-1 kHz bin) in the EO unit CF distribution. Each peak corresponds to the immediate cochlear turn above the stimulating electrode pair.

DISCUSSION

There are short distance relatively low impedance current paths, for example, via the habena perforata from the stimulating electrodes to the modiolus in which are located spiral ganglion cells from lower CF upper turns of the cochlea (Figure 3). In the modiolus the spiral ganglion cells of the immediate cochlear turn above the stimulating electrodes are nearest the stimulating electrodes [5]. If modiolar stimulation was responsible for generating a driven response from low CF units, cochlear implant patients would note a low frequency shift at high current levels, the average latency of these low CF units might be shorter than middle to high CF units and, for electrically driven units, there might be a modiolar stimulation evoked peak in the unit distribution as a function of CF. This peak should correspond to the immediate cochlear turn above the stimulating electrode pair. All these observations are seen in figures 1 and 2 and from Blamey et al. [2].

CONCLUSION

Modiolar stimulation can evoke responses in IC units at low stimulus levels.

REFERENCES


