The criteria of suitability for a cochlear implant have been extended from total deafness to include some individuals with residual hearing. The aim of the initial hearing evaluation is to define whether the speech discrimination is good enough to justify perseverance with a hearing aid. In adults, usually the pure tone audiogram and speech audiometry are accurate and consistent. In children, however, to achieve accuracy, free field testing must be complemented by repeated aided conditioned responses and objective evoked response audiometry. When a child has residual hearing it is more difficult to assess the potential for habilitation using an aid. For both adults and children, it is necessary to make a selection from a battery of tests on the basis of the subjects experience. This development highlights the need for otologists and audiologists to become familiar with the battery of tests used in evaluating severe deafness (Plant 1984) and to review decisions made about the management of people with severe to total deafness.

In suitable people, the aim of treatment with the Cochlear multichannel implant and its multipeak speech processor is a significant score for open set speech discrimination tests using hearing alone. This cannot always be achieved but as long as the evaluation protocol has been used to warn patients before the operation, they will be satisfied with a result where the implant complements lip reading resulting in discrimination of running speech and detection of environmental sounds.

Criteria for Referral to a Deafness Clinic

There are several clear requirements to be met before referring a person with deafness to a clinic managing severe to total deafness:
— People over eight years of age, whether they are aidable or not, should have had experience with aural communication if they are to use the (re)habilitation for more than sound awareness.
— If there is no response to sound then the pathology, the learning skills and the system of (re)habilitation must allow for a physiological and attentive response to electrical stimulation.
— If there is residual hearing the open set speech discrimination should be less than 20% for either CID sentences (Owens 1981), or AB word lists scored phonemically (Boothroyd 1968). These scores correspond to an audiogram with no responses to frequencies of 2000Hz and above, and thresholds of 90dB or worse for 250 to 1000Hz (Fig.1). The corresponding thresholds for an aided free field audiogram are set out in Figure 2 but are subject to alteration by the strategy used in the individuals hearing aid fitting. The important point is to see that the aided thresholds fall within the speech range.

FIG. 1. Where there is an average hearing threshold of 90dB or more for the frequencies 500 to 2000Hz and no aidable hearing above 2000Hz the patient is said to have profound deafness and may have better hearing with a Cochlear multichannel implant.

In the state of Victoria, according to National Acoustic Laboratory annual figures, there are about ten new children with deafness of this degree identified each year.

Pure Tone Audiometry in Total and Profound Deafness

There are several details relevant to the preparation of the pure tone audiogram of a person with profound or total deafness:
Assessment of Residual Hearing in Profound and Total Deafness

The first people given a cochlear implant were selected for their total absence of hearing. The performance of the Cochlear Multichannel device has shown that even certain people with residual hearing are suitable for the device. There are several tests available to assess the hearing skills of people with severe deafness. These tests have been selectively adopted and expanded to assess three aspects of aural communication. In the diagnostic aspect, word detection is used to confirm the pure tone bone conduction thresholds, and to help in the detection of retrocochlear disease. In the phonetic aspect, words and phonemic contrasts from the PLOTT test are used to measure speech discrimination skills particularly with a view to habilitation with an aid and speech therapy. In the phonetic aspect, words and sentences are used to measure lip reading, listening, pronunciation and vocabulary skills.

The choice of tests to be applied to the individual will depend on the presentation. For instance a post linguistically deafened person, even if there was a congenital onset, will have AB word lists, CID sentence tests and speech tracking as the aim is to confirm the retention of mature listening, lip reading and communication. The young children's group of tests is restricted to attempts at imitation of phonemic contrasts (heed/hard) or identification of pictures where the name of the object differs only in contrasting phonemes (key/car). In the group for prelinguistic people between eight and seventeen years it is important to establish whether it is possible to discriminate voicing, duration and accent clues through the PLOTT test, as these could be provided by the implant and assist lip reading. It may, however, take many months of perseverance for these people to use the tonotopic aspect of the implant for spectral contrasts. The PLOTT tests are discussed amongst the children's group because of their value in confirming the audiogram but they are included in the adult tests to help the measurement of hearing where there will be only a small benefit from the implant. Similarly, in the group of tests for people where the implant may not be able to work at its best, as in individuals with ossification of the cochlea, the postoperative results may be limited to significant scores on the PLOTT test.

The open set word tests requiring a vocabulary are:

- **The AB word lists** (Fig 3) are familiar tests and can be used to assess profound deafness particularly if they are scored phonemically, but for the result to be significant the score should be greater than 10% in a test of 10 words to exclude the possibility of identifying vowel sounds by chance.
- **The Picture vocabulary** test is the corresponding speech test for a child (Fig 4) but is a closed set test.
- **The CID test** has been adopted by this clinic for several reasons. It provides plenty of open set material for statistics.

\[ \text{ship, rug, fan, cheek, haze, dice, both, well, jot, move} \]

**FIG. 3.** The words selected for the AB lists are not only phonetically balanced but also chosen for their ability to be scored as three parts (a vowel and first and final consonant).

**FIG. 4.** The words chosen for Picture Vocabulary are objects found in a young person's receptive vocabulary and can be pointed out in a book on request. They have important vowel and consonant contrasts.

It is managed by nearly all the postlinguistic patients postoperatively, and yet difficult enough to provide a comparison of individual performance. It is scored on the
This truck weighs half a ton.
What time does your watch say?
Good morning.

FIG. 5. The CID everyday sentences are scored according to the correct identification of the critical words in the sentence. They are presented in lists of 25.

number of key words imitated correctly in two sets of 10 sentences (Fig 5).

— The **BKB test** is similar and has a vocabulary more appropriate for children. In the preoperative protocol, after a six month training period using an appropriate hearing aid and speech therapy, these speech tests are performed with listening alone, with listening aided by lip reading, and with lip reading alone. An implant may be considered if the CID score in the better ear is less than 20%. In the ear to be implanted, the score should be less than 10%. A CID score of 40% may allow for the discrimination of running speech as in conversation. This is true particularly if the contextual clues in running speech can be used to provide top-down assistance. With practice and confidence this sort of score can be turned to successful use of the telephone.

— **Speech tracking** (Defillipo 1978) is easier than the other sentence tests and can even be performed by some deafened people using lip reading alone. This test measures the number of words per minute accurately repeated by the listener. It has been a particularly effective way of demonstrating the improvement in hearing ability from week to week in the months after an implant.

The closed set tests are used to confirm the preservation of residual hearing and to evaluate the patient’s ability to detect and discriminate features of speech differing in spectral content, duration of vowels, stress pattern as in question/statement, gender of the speaker, and presence of voicing. Note that the tests include words which differ in place and manner. These discriminations cannot be made by the group of people we are considering without the help of lip reading, an implant or a Tickle Talker (Cowan 1991).

— The **five sound test** described by Ling (1976) is an example of a speech test which is independent of vocabulary. The subject is asked to imitate ‘a’ (cat), ‘i’ (bit), ‘u’ (boot), ‘s’ and ‘sh’. This test is appropriate for the daily evaluation of a hearing aid and to confirm whether the cochlear implant is providing spectral information across the whole speech range.

— another nonsense test is the **11 vowel test** from the Minimal Auditory Capabilities battery in which the vowel is preceded by ‘h’ and followed by ‘d’ to make up a nonsense word. This test is scored on whether the vowel was correctly identified or merely classified as to short or long. For instance hid and head have short vowels whereas heed is long. The other words are who’d, hood, had, hard, heard, hud, hod and hide.

— The **PLOTT test** (Erber 1979, Plant 1984) assesses speech discrimination by forcing the subject to make choices between words differing in vowel duration or place (Fig 6a), differing in consonant voicing, place, or manner (Fig 6b), and differing in syllable number or structure (Fig 6c). These tests may be used to confirm the pure tone audiogram or assess the development of speech discrimination in the face of deafness. Where hearing is present in the 125 to 500Hz range it should be possible to perform speech tests with voiced/unvoiced discriminations and prosody (duration/length/stress) discriminations. It requires hearing above 2000Hz to hear the difference in speech features differing in place or manner of articulation.

<table>
<thead>
<tr>
<th>Vowel contrasts (PLOTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENGTH</td>
</tr>
<tr>
<td>ball cart sheep heart</td>
</tr>
<tr>
<td>bull cut ship but slip</td>
</tr>
<tr>
<td>IDENTITY</td>
</tr>
<tr>
<td>key bin bee black cat</td>
</tr>
<tr>
<td>car bun boo block cut</td>
</tr>
</tbody>
</table>

FIG. 6a

<table>
<thead>
<tr>
<th>Consonant contrasts (PLOTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOICING</td>
</tr>
<tr>
<td>pin peas pear coat path</td>
</tr>
<tr>
<td>bin bees bear goat bath</td>
</tr>
<tr>
<td>PLACE</td>
</tr>
<tr>
<td>four tie tea fox bun</td>
</tr>
<tr>
<td>saw pie key socks gun</td>
</tr>
<tr>
<td>MANNER</td>
</tr>
<tr>
<td>one tea tall mat red</td>
</tr>
<tr>
<td>sea knee sail bat bed</td>
</tr>
</tbody>
</table>

FIG. 6b. Words selected to discriminate vowel (6a) or consonant contrasts (6b) may be used to confirm the pure tone hearing thresholds and to check for the presence of the skills of discriminating sounds differing in duration or formant structure. The test is scored by counting either correct words or by the correct contrast category.

<table>
<thead>
<tr>
<th>M.S.T.P. (PLOTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MONOSYLLABLE</td>
</tr>
<tr>
<td>dog car fish</td>
</tr>
<tr>
<td>TROCHEE</td>
</tr>
<tr>
<td>table rabbit apple</td>
</tr>
<tr>
<td>SPONDEE</td>
</tr>
<tr>
<td>football toothbrush icecream</td>
</tr>
<tr>
<td>POLYSYLLABLE</td>
</tr>
<tr>
<td>helicopter butterfly kangaroo</td>
</tr>
</tbody>
</table>

FIG. 6c. The M.S.T.P test may be used with people who have profound deafness to assess whether the ability to detect rhythm and duration features in speech. The test is scored by counting either correct words or by the correct contrast category.

Those people with residual hearing up to 3000Hz should be able to discriminate the spectral phonetic features of the vowel test, but hearing up to 4000Hz is required to detect the sibilant sounds in the Ling test. The Cochlear MSP speech processor is programmed to detect sound in this band and to transmit this information to the two most basal electrodes. The remaining electrodes are in two sequences, the next most basal code for the second formant (2-3kHz) on the basis of place, and the apical sequence code for the first formant (300 to 1500Hz). These features have been reliably reproduced by the multichannel implant especially in the ideal case who has the array inserted over 20mm inside the cochlea and a small proportion of missing spiral ganglion cells. It is still possible to provide some spectral information when there has been only 5 of the 22 electrodes working. Examples of this include a fractured cochlea, deafness from irradiation to the postnasal space, and most cases of an ossified cochlea treated with an extracochlear multiple electrode array.
Medical Assessment

The medical assessment is based on the history of the deafness disease process, the history of the deafness as it affects communication and social factors, the general medical history and examination. These are important factors to be considered before referral to an implant clinic but a surprising variety of conditions have been helped significantly by the multiple channel device.

Deafness from ototoxic drugs have better than average results whereas deafness from viral labyrinthitis and congenital causes (Nadol 1989) may have poor results. Complete congenital deafness not implanted until after 8 to 10 years of age is associated with failure to develop language comprehension and syntax. Well motivated teenagers and young adults with congenital deafness have gained assistance with lip reading. In 20% of patients with retinitis pigmentosa there is progressive sensorineural deafness (Usher's syndrome). If these children become totally deaf and blind a cochlear implant would only provide language perception if they had acquired aural communication skills previously.

Ossification in the cochlear spiral is seen in meningitis, otitis media and otosclerosis but not always to the point of total obliteration (Gantz 1988).

Medical problems such as balance disturbance, medical diseases constituting an anaesthetic risk, maladaptation to deafness, congenital syphilis and congenital brain damage require separate specialist assessment. Otitis media should be brought under control before the definitive audiogram is made, and definitely before implantation. It may be possible to perform the procedure in the presence of a mastoid cavity (Scrivener 1987).

Radiography

High resolution computerised tomographic X-ray scans are essential for the definition of the cochlea for implant. The scans are made in the axial and the coronal planes at approximately 1mm intervals. At the least, there should be ten cuts in the coaxial plane from the basal turn to the top of the semicircular canals and about five cuts in the coronal plane from the carotid canal to the vestibule. The images should include the sigmoid sinus, the mastoid emissary vein, mastoid air cell system, facial nerve, internal auditory canal and the middle ear. The coronal cuts require dorsiflexion of the neck and are therefore not performed on subjects requiring a general anaesthetic for the procedure because this posture produces respiratory obstruction. The images should be presented life size so the diameter of the basal turn may be accurately measured and the contrast should be adjusted to demonstrate the presence of intracochlear calcification or fibrosis.

Meningitis, otosclerosis, fractures of the cochlea and the dysplasia described by Mondini in 1791 could cause difficulty with intra-cochlear placement of the electrode array. The appearance of otosclerotic change is typically narrowing of the fluid spaces of the cochlea and radiotranslucency around the cochlea called the double barrel appearance. Meningitis has diffuse opacification in the worst case, patchy change in the case of fibrosis, or no change at all. Both fractures and the Mondini dysplasia are associated with cerebro spinal fluid otorhoea which could lead to meningitis or perilymph gushers during surgery. The deformity in the dysplasia is flattening of the cochlea, widening of the perilymph and endolymph spaces, shortening of the length of the cochlea duct spiral, and enlargement of the vestibular aqueduct. It sometimes presents with stepwise hearing loss which may be surgically preventable. The Scheibe malformation (Schéle 1895), in which there is aplasia of the organ of Corti and saccule, and the Alexander dysplasia involving the hair cells in the basal end of the organ of Corti will not be detectable by X-rays.

Electrical Stimulation of the Inner Ear

Electrical stimulation of the inner by a needle placed through the drum to the region of the round window has become a standard part of the preoperative evaluation performed on all prospective implant patients over 10 years of age (Fig 7,8). The gated square wave stimulus provides a pulsatile auditory percept at thresholds below the pain current threshold. The aims of the evaluation are to measure parameters thought to be affected by the extent of neuronal damage and the presence of retrochlear disease, and to provide the patient with an experience comparable with the sound produced by the implant.

FIG. 7. The needle electrode in the electrical stimulation of the promontory may be secured in the speculum by a rare earth magnet glued into the side wall. The magnet may also be attached to the lead wire.

The circuit for the electrical stimulation includes:

- a needle inserted through the tympanic membrane resting close to the round window. It is not necessary to use an anaesthetic with most patients.
- an active wire attached to the needle by a magnet placed in the speculum, and a common wire attached to the cheek or mastoid.
- an electrical isolation device comparable with the implanted package.
- a stimulator either in the form of a hard wired box, or a computer fitted with a diagnostic programming unit, a microphone and a speech processor.

The tests include:

- listening till the gated square wave is detected. The current ranges from 0-1000microamps and the threshold for a sound percept is between 1 and 100microamps.
pulses per second.
— a record of the patient's description of the percepts
— gap detection over the range 10-300ms
— adaption of the loudness of impulses over 60sec
— use of the speech processor and microphone to assess
the patient's ability to detect speech features that can be
encoded by an FO extractor such as syllable number, pitch
of the voice and stress patterns.

The subjects are suitable for an implant if they use
adjectives to describe the percept which suggests that they
heard rather than felt the stimulus. The quality of the result,
however, may depend on whether they perceived a
difference between the pulse rates without prompting. For
this reason we record the patients description of each
percept. Of those who detected the change, 53% scored over
40% for the CID sentence test without lip reading, using the
Cochlear Multichannel cochlear implant and the WSP
speech processor in the Melbourne series. There was a 78% chanceto score 20% or more for the CID sentence test.
Conversely, if the patient is unable to detect the pulse rate
change and they are over 50 at operation, and/or the total
deafness has been present over 17 years, there was
significantly less chance of discriminating speech well. Tho
people who failed the test were also found to have diffuse
neurological disease. They were not given an implant. One
patient, a 68 year old who had been deaf for 20 years from
an unknown cause was implanted and achieved 6% for the
open CID test. Two people have failed to perceive any
information from the implant after successful EPS.

Assessment by Clinical Team
The decisions to be made are whether the implant is the
appropriate form of assistance or whether an aid, a Tickle
Talker or continued signing is most suitable for the
individual's communication requirements. These matters
require involvement of people from outside the team
including parents, teachers of the deaf and perhaps an
ethics committee where the team is breaking new ground.

Speech pathologists contribute to the assessment of
profound and total deafness through tests of receptive and
productive vocabulary, language and tests of
communication skill. If speech therapy is not available then
children should not be considered for an implant. The
Melbourne unit and Cochlear Pty Ltd have a list of suitable
places for rehabilitation and are keen to assist with training
more audiologists, teachers of the deaf and speech
pathologists. The language tests are for speech production
articulation (Fischer Logemann), intelligibility (McGarr
sentences), for phonetic skill, for receptive language
(Boehm), for symbolic play (Wesbee), for receptive
language (PPVT), for expressive word vocabulary
(Renfrew), for expressive language (Preschool language
scale), for grammatical analysis (Gael-S), and for
communication behaviour skill (pragmatic skills).

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