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Original paper

Evidence-based guidelines for recommending cochlear implantation for postlingually deafened adults

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Abstract

Objective: Adult selection criteria for cochlear implantation have been developed based on analysis of the post-operative performance of a large group of postlingually deafened adults. Original criteria published in 2004 were reviewed and amended to reflect outcomes currently being achieved by implant recipients. *Design*: Retrospective review of 12-month post-operative speech perception performance of adults implanted at the Eye and Ear Hospital, Melbourne, Australia. *Study sample*: A total of 382 postlingually deafened adults, using a Freedom, Nucleus 5, or CI422 Slim Straight cochlear implant were used to create a comparative set of data. *Results*: Revised guidelines suggest that adults with postlingual hearing loss can now be considered cochlear implant candidates if they obtain scores of up to 55% for open-set phonemes in quiet in the ear to be implanted. Functional benefit may vary depending on the recipients' contralateral hearing. *Conclusions*: This study supports the provision of cochlear implants to candidates with significant residual hearing when at least one ear meets the criterion outlined above. Patient-specific counseling is required to ensure the potential to benefit predicted by the current model is acceptable to the individual patient and their family. Counseling regarding functional benefit must take into consideration hearing in the contralateral ear.

Key Words: Cochlear implant; hearing loss; adult; selection criteria

Introduction

Technological advances and the highly successful outcomes being achieved by adults using cochlear implants have resulted in a progressive expansion in audiological criteria for cochlear implantation. Historically, potential recipients presented with bilateral severe-to-profound hearing loss. These candidates were risking minimal residual hearing by proceeding with a cochlear implant (CI), usually in the worse hearing ear. In more recent years it has become increasingly common for candidates to have substantial acoustic hearing in one or both ears. The emergence of this new generation of candidates warranted a review of CI selection criteria to ensure that the widest range of individuals can benefit from the device.

Evidence-based criteria for recommending cochlear implantation have been developed to maximize the number of people able to benefit from cochlear implantation while minimizing the occurrence of unfavorable outcomes. The original criteria developed at the Cochlear Implant Clinic, Royal Victorian Eye and Ear Hospital and published in 2004, suggested that adults with a postlingual hearing loss could be considered candidates if they obtained open-set sentence scores in quiet of up to 70% in the best-aided condition and scores of up to 40% in the ear to be implanted (Dowell et al, 2004). Candidates who fit these criteria could be advised that they had a greater than 75% chance of improving their speech perception with a cochlear implant over their best preoperative condition, and a 95% chance of improvement in their implanted ear alone.

The above criteria were revised in 2010 using a less conservative approach, ensuring that the criteria being applied in the Clinic reflected the current outcomes being achieved by adult recipients. Using the criterion of a 95% chance of improvement in the ear to be implanted meant that a large number of people who had the potential to benefit from a CI were not being advised that benefit was likely. The revised criterion was a 75% chance of improvement in the ear to be implanted. The 2010 review suggested that adults with a postlingual hearing loss could be considered candidates if they obtained a monosyllabic phoneme score, in quiet, of up to 67% in the best-aided condition and a score of up to 46% in the ear to be

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Abbreviations

CI	Cochlear implant
HTL	Hearing threshold level

implanted (Leigh et al, 2010). The equivalent guidelines for sentence perception were a score of 88% in the best-aided condition and of 55% in the ear to be implanted. Candidates who fit these criteria could be advised that they had **a** greater than 50% chance of improving their speech perception with a CI over their best-aided preoperative condition, and a 75% chance of improvement in their implanted ear. This review also represented a shift away from criteria focusing on sentence perception scores. Given the performance that implant recipients have been able to achieve in recent times, sentence perception in quiet had become susceptible to ceiling effects. Linguistic competence is also known to play a greater role in open-set sentence perception, with words being recognized more easily when they are presented in sentences rather than in isolation or in carrier phrases (Boothroyd & Nittrouer, 1988). Sentence testing in hearing-impaired groups also shows higher variability and test-retest fluctuation as the interdependence of key words within sentences means that a score that assesses 50 key words behaves, statistically, as if it contains a smaller number of items. The assessment of 50 unrelated monosyllables, or the 150 phonemes they contain, provides a more reliable measure in a statistical sense, avoids the confounding effect of linguistic abilities, and is less prone to ceiling effects. Therefore monosyllabic word perception was deemed the more appropriate measure on which to base CI speech perception criteria.

In both evolutions of the above criteria there was a focus on the CI providing an improvement over the recipient's best-aided condition for listening in quiet; that is, a CI is only recommended when it is anticipated that the recipient will achieve scores with the CI alone that exceed the level of performance for the better hearing (contralateral) ear. Many people with asymmetric hearing loss have one ear that meets traditional CI criteria but the contralateral ear has better hearing and receives benefit from amplification. Amplification in the poorer ear is often unsuccessful due to the degree of loss; therefore these individuals effectively function with unilateral input. There are a number of limitations to having only unilateral hearing, including a reduced ability to communicate in noise and compromised sound localization (Wie et al, 2010).

The approach of recommending implantation when there is a greater than 50% chance of improving the recipient's best-aided condition has also been challenged by the increase in adult CI recipients seeking bilateral implantation. These recipients often seek a second/bilateral CI because they are pleased with the benefit obtained from the first implant. With bilateral input to the auditory system, the listener may gain greater advantage from the head shadow effect, and may also benefit from binaural squelch, summation, and redundancy (Bronkhorst & Plomp, 1988,1989). Bilateral implantation, therefore, has the potential to improve speech recognition in quiet, in noise, and from a distance (Basura et al, 2009). In addition, bilateral implantation can improve localization of sound in the environment and reduce the overall effort expended during communication (Gaylor et al, 2013; Litovsky et al, 2006; Noble et al, 2008). Subjective evaluation of bilateral and bimodal CI users is overwhelmingly positive regarding real-life benefits, many of which are not captured well by standard clinical evaluations of speech perception (Noble et al, 2009; Summerfield et al, 2006). It is reasonable to anticipate that the range of benefits potentially provided by bilateral implantation may also be obtained by patients with asymmetric and/or unilateral hearing loss when some degree of bilateral hearing is restored if they receive a CI in the worse hearing ear (Vermeire & Van de Heyning, 2009).

Recent studies have demonstrated significant post-operative improvement in speech perception performance for implant recipients who were achieving pre-operative best-aided speech perception scores up to 68% (Amoodi et al, 2012; Firszt et al, 2012; Gifford et al, 2010). These studies demonstrate positive outcomes for candidates with pre-operative acoustic hearing in one or both ears. The most extreme example of this emerging recipient population is that of candidates with single-sided deafness. Traditional measures of post-implantation speech recognition improvement, which involve presenting perception in quiet or in coincident background noise, may not be sensitive enough to capture the benefits of implanting recipients with significant contralateral hearing. Significant speech recognition improvement in spatially-separated speech and noise test configurations has been demonstrated in populations with asymmetric and single-sided deafness (Arndt et al, 2011; Buechner et al, 2010). Additionally, positive findings have been observed on tests of localization ability (Arndt et al, 2011; Dowell et al, 2011; Firszt et al, 2012).

The above research suggests that the focus for setting CI recommendation guidelines should shift to optimizing patients' hearing in their individual ears. This, in turn, will give recipients an opportunity to achieve their best bimodal hearing potential. The criterion described in this article will focus on performance of the individual ear, in most cases the worse hearing ear. The anticipated benefit and/or chance of improvement for that ear can be determined and discussed with the potential recipient. Hearing in the contralateral ear can be considered during expectation counseling, given that the degree of functional improvement will vary depending on the degree of contralateral acoustic hearing.

The aim of the current study is to provide evidence-based speech perception guidelines for the ear to be implanted.

Method

The approach used to assess adult candidates with some useful pre-operative aided speech understanding compares the candidate's pre-operative speech perception scores with the post-operative scores of a large group of adult CI recipients.

Adult patients undergoing implantation at the Royal Victorian Eye and Ear Hospital in Melbourne, Australia, underwent speech perception assessment before and after the procedure. The battery of tests included open-set monosyllabic word testing (consonant-vowel-consonant [CVC] words) scored on the basis of phonemes and words correct, and open-set sentence testing (City University of New York [CUNY] sentences) in quiet and in the presence of background noise (+10 dBSNR). For the purpose of this study, sentence testing in background noise will not be discussed. If time was limited, assessment of open-set monosyllabic words was prioritized over sentence testing. Separate ear and binaural testing was completed when there was useful residual hearing in both ears. Post-operative assessments were performed three and 12 months after implantation. For the purpose of this article only 12-month post-implantation scores are reported.

The speech perception performance of 382 postlingually deafened adults using a Freedom, Nucleus 5, or CI422 Slim Straight

Table 1. Demographic information for the 382 subjects. Mean, median, standard deviation (SD) and range for demographic factors of age at implantation, duration of severe-to-profound hearing loss for the implanted and contralateral ear, pre-operative pure-tone average (PTA) (average of HTLs at 250, 500, 1000, 2000, & 4000 Hz) for the implanted and contralateral ears.

Demographic factor	*Mean*	*Median*	*SD*	*Range*
Age at implantation (years)	66.6	67.8	14.7	19.2–93.4
Duration of severe-to-profound deafness: implanted ear (years)	18.0	15.0	14.9	0.2–70.0
Duration of severe-to-profound deafness: contralateral ear (years)	15.9	10.0	13.7	0.0–65.0
PTA implanted ear (dBHL)	100.9	99.3	15.6	57–125
PTA contralateral ear (dBHL)	86.9	86.5	18.5	7–125

Table 2. Etiology (listed from most to least prevalent), pre-implantation hearing-aid (HA) use, and gender for the 382 subjects.

	N	*Percentage (%)*
Pre-implantation device use		
HA use: implanted ear	224	57
HA use – contralateral ear	327	86
Etiology		
Unknown	197	51.6
Otosclerosis	43	11.3
Genetic – non-syndromic	32	8.4
Middle-ear disease	26	6.8
Ménière's disease	17	4.5
Head injury	15	3.9
Noise induced	14	3.7
Meningitis	9	2.4
Ototoxicity	7	1.8
Disease/virus: childhood	6	1.6
Disease/virus: adulthood	5	1.3
Acoustic neuroma	5	1.3
Large vestibular aqueduct	3	0.8
Genetic: syndromic	2	0.5
Acoustic trauma	1	0.3
Gender		
Female	200	52
Male	182	48

CI was used to create a comparative set of data. Non-English-speaking recipients and those who did not use the implant device owing to medical or surgical complications were excluded. Five recipients implanted with Hybrid-L electrode arrays were also excluded from the analysis due to the shorter build of the devices in comparison with the other full-length arrays. Table 1 and 2 provide demographic details for the 382 recipients included in this study.

Results

Figure 1 shows the 12-month post-operative **open-set monosyllabic word scores, reported as phonemes and words correct, and** open-set sentence scores in quiet for the postlingually deafened adults using the CI alone. Only a subset of 281 of the total 382 recipients completed open-set sentence testing, due to time limitations. There was a wide range of performance on all three measures of perception. Performance for monosyllabic words, scored for phonemes correct ranged from 0% to 98%, and word score ranged from 0% to 94%. The range of scores for open-set sentences was from 0% to 100%.

The distribution of speech perception scores yields the mean, median, and first quartile scores. Table 3 further outlines the mean, median, and first quartile scores for the speech perception tests. The first quartile is the highest score achieved by the lowest 25% of recipients in ranked order. For open-set sentence scores in quiet, 50% of the recipients scored greater than 89%. This raises the issue of a ceiling effect on this test measure and suggested that phoneme scores for monosyllabic words may be a more valid measure to guide speech perception recommendation guidelines. The first quartile for open-set monosyllabic words scored for phonemes correct was 55%. Therefore 75% of recipients scored above 55% phonemes correct using the CI alone after 12-months experience with their CI. The first quartile can be used to estimate the likelihood of a successful post-operative outcome for individuals seeking implantation. If the candidate's pre-operative scores are below the first quartile, there is a greater than 75% likelihood that post-operative performance will be better than pre-operative performance in the ear to be implanted. This assumes that the individual characteristics of the candidate are similar to the criteria used for the comparative data set.

Based on these outcomes, speech perception selection guidelines for adults with postlingually acquired hearing loss have been revised. It is suggested that adults with postlingual hearing loss can be considered candidates for a CI if:

The score for open-set words scored for phonemes correct in the ear to be implanted is less than 55%
The score for open-set words scored for words correct in the ear to be implanted is less than 26%
The score for open-set sentences in quiet in the ear to be implanted is less than 61%

It is important to have optimized hearing devices for adults considering cochlear implantation before assessing speech perception. Patients may require a significant hearing-aid trial period if they have not previously used hearing aids, have not used up-to date technology, or their hearing aids are a poor match to target gain.

Discussion

Analysis of recent outcomes suggested that adults with a postlingual hearing loss can now be considered candidates for cochlear implantation if they obtain open-set phoneme scores in quiet of up to 55% and/or word scores of up to 26% in the ear to be implanted in pre-operative assessments. The revised criteria recommends placing greater emphasis on the use of open-set monosyllabic words, scored for phoneme and words correct, for recommendation guidelines, given that the usefulness of open set sentence testing in quiet has been compromised by ceiling effects. The level of hearing and speech perception performance in the contralateral ear should be taken into consideration during pre-operative expectation counselling, as the amount of contralateral

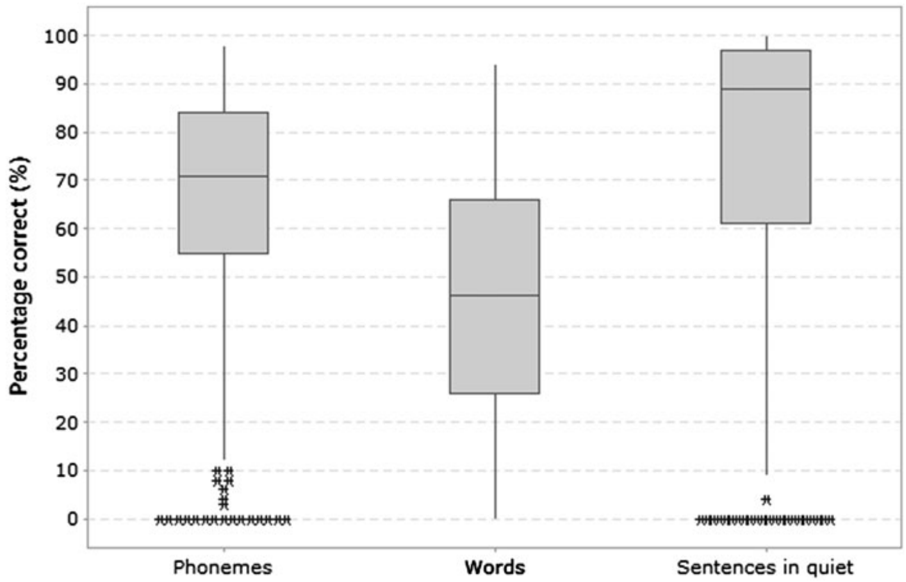

Figure 1. Open-set monosyllabic words ($n = 382$), scored for phonemes and words correct, and open-set sentences scores in quiet ($n = 281$) for postlingually hearing-impaired adults. Results obtained in the CI alone condition. Figure shows median, interquartile range, and range for each metric. Asterisks represent outliers (defined as observations that are greater than 1.5 times the interquartile range).

Table 3. Mean, median, and 1st quartile scores for open-set monosyllabic words and open-set sentences in quiet for postlingually hearing-impaired adults with 12 months experience using a Freedom, Nucleus 5, or CI422 Slim Straight CI. Results obtained in the CI alone condition.

Speech perception measure	*N*	*Mean*	*1st quartile*	*Median*
Monosyllabic (CVC) words: phonemes score	382	65%	55%	71%
Monosyllabic (CVC) words: word score	382	45%	26%	46%
Open-set (CUNY) sentences: in quiet	281	75%	61%	89%

hearing may influence the recipients post-implantation functional improvement. For example, if the recipient is achieving 90% speech perception performance with the contralateral ear, that individual may not notice a significant benefit from the CI when listening in quiet post-implantation, it may be when listening to spatially-separated speech and noise that this recipient gains the greatest benefit from their CI.

This article has focused on audiological guidelines for recommending implantation. Medical and otological issues must also be taken into consideration. There must be evidence that an auditory nerve is present and accessible to a CI electrode. The surgical procedure should only be undertaken when there is minimal risk to the patient, and there should be evidence that the patient has sufficient cognitive ability to respond to external stimuli. Many factors, in addition to level of hearing, have been identified as having a significant impact on outcomes for adults with CIs. These include duration of deafness, use of pre-operative residual hearing for speech recognition, and age at implantation (Dowell et al, 2004). In addition, medical considerations such as anatomy of the inner ear and auditory nerve have the potential to impact on the outcome (Eisenman et al, 2001; Wasson & Briggs, 2016; Yamazaki et al, 2015). These factors must not be overlooked when counseling potential recipients on their expected outcome.

A number of studies have identified duration of deafness and use of residual hearing (open-set speech perception using a hearing aid) as consistent predictors of implantation outcomes (Dowell, 2016; Dowell et al, 2004; Green et al, 2007; van Dijk et al, 1999). Duration of deafness has been shown to have a negative effect on CI outcome. However the definition of duration of deafness, as it relates to the ear implanted, has varied among studies. A recent study by Boisvert *et al* (2012) found equivalent performance on speech perception testing in the everyday listening condition for adults with long-term monaural sound deprivation (severe hearing loss or worse, without the use of a hearing aid for greater than or equal to 15 years) irrespective of whether they had received the implant in the sound deprived ear or the aided ear. This finding supports the provision of a CI in the worse hearing ear, even when there has been long-term sound deprivation.

It must be noted that patients with greater pre-operative hearing are presenting regularly to CI centers, providing clinicians with additional challenges in making recommendations. Patients with significant residual hearing in the ear to be implanted and patients with unilateral hearing loss are emerging patient groups that warrant attention in a discussion of CI candidacy. A recent study examined individuals with significant pre-operative hearing in the ear to be implanted whose hearing was not preserved following the implant procedure (Moran et al, 2014). The results from this study demonstrated that the group with significant residual hearing obtained equivalent improvement with a CI compared with a matched group with pre-operative profound loss.

These results suggest that clinicians should base recommendations for those with significant residual hearing on their pre-operative speech perception, as per the guidelines outlined in the present article. In the case where hearing is preserved, it may be possible for the individual to gain the additional known benefits of electro-acoustic stimulation, such as improved speech perception in noise and enhanced music perception (Gfeller et al, 2006; Turner et al, 2008).

For patients with unilateral hearing loss, benefit is more difficult to predict. A recent meta-analysis and systematic review of adults implanted following sudden unilateral sensorineural hearing loss indicated improvements in tinnitus (decreased loudness) and speech discrimination; however a large amount of variability in outcomes was noted (Blasco & Redleaf, 2014). Tavora-Vieira *et al* (2013) examined adults with unilateral hearing loss of greater than 25 years duration in the ear to be implanted, and found significant improvements in speech perception and subjective measures of hearing quality post-implantation. In contrast, Firszt *et al* (2012) reported that patients with prelingual onset of hearing loss and duration of deafness between 23 and 25.5 years showed no benefit from implantation for sound localization and speech perception in noise. These results highlight the fact that individuals with unilateral hearing loss must be assessed on a case-by-case basis, and that duration of deafness should not be considered a barrier to success with a CI if hearing loss is postlingually acquired.

In the present article, a 75% chance of improvement in the ear to be implanted has been used to guide clinical recommendations. It should be highlighted that, in many cases, the residual hearing in the implanted ear may be unusable post-implant, and that there is still a small risk of a surgical failure or inexplicably poor results. Therefore, before adopting criteria as outlined in this article, clinicians should discuss with the recipient whether this likelihood of benefit, in combination with any risk involved in their individual case, is acceptable to them.

Traditional measures of post-implantation speech recognition improvement may not be sensitive enough to capture the benefits of implanting recipients with significant contralateral hearing. In order to capture the benefits obtained by the emerging candidate populations with asymmetrical hearing loss and/or single-sided deafness, clinics will need to adopt more sophisticated test batteries. This may include speech recognition in spatially-separated speech and noise and measures of localization ability. Questionnaires, such as the speech, spatial and qualities of hearing scale (SSQ), may also provide useful information (Gatehouse & Noble, 2004).

Conclusion

Cochlear implantation can be confidently recommended for postlingually deafened adults who obtain open-set phoneme scores in quiet of up to 55% and/or word scores of up to 26% in the ear to be implanted. Individually tailored pre-operative counseling is required for all patients to ensure their expectations for outcome are realistic and achievable. Present day benefits of implantation extend beyond improved speech perception in quiet. With significant contralateral hearing, recipients can expect improvements in speech perception in the presence of noise and localization.

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