Speech Recognition In Hearing Aids: Used For Assessing CI Candidacy In Tonal Language Population

Yu-Lin Chang  
Department of Otolaryngology

Chia-Jou Liu  
Department of Otolaryngology

Pey-Yu Chen  
Department of Otolaryngology

Hung-Ching Lin (✉ hclin59@mmc.edu.tw)  
Department of Otolaryngology

Research Article

Keywords: speech recognition score, hearing aids, cochlear implantation

Posted Date: December 6th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1058013/v1

License: ☑️ 📧 This work is licensed under a Creative Commons Attribution 4.0 International License.  Read Full License
Abstract

Objective: CI (cochlear implantation) candidacy is somewhat controversial in severe hearing loss among tonal mandarin-speaking patients. To assess the relationship between pure tone audiometry (PTA) and speech recognition score (SRS), with and without hearing aid amplification, among patients who did not meet the NIH criteria of CI candidacy in tonal language mandarin-speaking countries, especially those with severe hearing loss (70 dB HL < 4FPTA(0.5, 1, 2, 4 KHz) ≤ 90 dB HL).

Materials and Methods: A total of 414 patients with sensorineural hearing loss with 774 ears were reviewed retrospectively in a tertiary referral center. The Mandarin Monosyllable Recognition Test (MMRT) was used to evaluate the SRS of these ears.

Results: 31% (10/32) of the 32 ears with severe hearing loss, 70-90 dB HL, still showed poor speech recognition (SRS<30%) after hearing aid amplification, while 71% (46/65) of the 65 ears with profound hearing loss, > 90 dB HL, showed poor speech recognition with hearing aid amplification.

Conclusions: The speech audiometry with Mandarin Monosyllable Recognition Test (MMRT) helped identify those patients whose 4FPTA< 90 dB HL fell outside the CI candidacy criteria of NIH in tonal language mandarin-speaking countries but showed significantly poor (SRS< 30%) speech recognition performance.

Introduction:

Hearing impairment can have a profound impact on the quality of life and has been proven to be associated with other comorbidities such as dementia and depression[1]. According to the World Health Organization (WHO), over 5% of the world's population has disabling hearing loss [WHO 2020.03.01][2]. Hearing aids, one of the treatment options for hearing impairment, have become increasingly sophisticated over the years in the ways they provide amplification that fits the needs of individuals with hearing loss. However, the benefits one can obtain for speech recognition performance via the use of well-fitted hearing aids have their limitations, especially for those with severe to profound hearing loss[3]. Therefore, it is crucial to use appropriate measures to precisely evaluate the effectiveness of hearing aids.

Pure tone audiometry (PTA) is the most commonly used test during an audiological evaluation as it provides information about an individual's hearing acuity. Nonetheless, PTA alone is insufficient to provide information about the speech recognition ability of the person being assessed. It has been shown that PTA cannot provide a complete picture in patients with sensorineural hearing loss (SNHL) in terms of their damaged cochlear epithelium and, thus, restricted ability in speech recognition, even with appropriate hearing aid amplification [4]. Therefore, speech audiometry (speech recognition score, SRS) is administered to patients with SNHL to evaluate the information-carrying capacity of the cochleae and predict hearing aid outcomes. For patients with low post-fitting SRS, poor treatment adherence, and reduced quality of life are expected. An alternative treatment option, such as cochlear implantation (CI), may be better suited for these patients.

CI has been developed for more than 40 years. The criteria for CI candidacy have gradually but significantly expanded over the years due to surgical innovation, continued advancement in amplification technology, and an accumulating number of evidence-based studies[5]. According to Taiwan's National Health Insurance (NHI), adult CI candidates should meet all the following criteria: 1) having post-lingual 0.5K, 1K, 2 K, and 4 KHz > 90 dB HL, 2) obtaining SRS < 30% with a well-fit hearing aid amplification, and 3) no contraindications to CI[6]. These criteria state that only patients with profound hearing loss (4FPTA(0.5, 1, 2, 4 KHz) > 90 dB HL) are eligible for CI.

This study aimed to assess the relationship between PTA and SRS, with and without hearing aid amplification, among tonal mandarin-speaking patients who did not meet the NHI criteria of CI candidacy, especially those with severe hearing loss (70dB HL < 4FPTA ≤ 90dB HL). It is hoped that with the findings of the present study, NHI criteria for CI candidacy in tonal language patients could be further expanded.

Material And Methods:
This study was based on a retrospective analysis of data retrieved from the database of the Mackay Memorial Hospital, a tertiary medical center in Taiwan. The study was approved by the Mackay Memorial Hospital institutional review board (No. 21MMHIS071e Mackay Memorial Hospital IRB board chairman name is Yi-Shing Leu). All study methods were performed in accordance with the Declaration of Helsinki regulations. Because this study was retrospectively done by medical record review, informed consent was not routinely obtained from all our subjects. The requirement to obtain informed consent was waived by Mackay Memorial Hospital institutional review board. The results of the PTA and speech audiometry tests of 427 tonal language patients were reviewed over four years (2016-2020). Finally, data from 414 patients with 774 ears were analyzed. Ears with conductive, mixed, or retrocochlear hearing loss were excluded. Among these 414 patients, only 80 had hearing aids (46 wore hearing aids bilaterally and 34 unilaterally).

Pure tone air conduction thresholds were measured from 250 to 8000 Hz. 4FPTA (0.5, 1, 2, 4 KHz) was calculated to evaluate the severity of the hearing loss. Patients ears were classified into four groups according to their 4FPTA: 1) normal-hearing (4FPTA ≤ 25dBHL), 2) mild-to-moderate hearing loss (25dB HL < 4FPTA ≤ 70dB HL), 3) severe hearing loss (70dB HL < 4FPTA ≤ 90dB HL), and 4) profound hearing loss (4FPTA > 90dB HL)[7, 8]. The Mandarin Monosyllable Recognition Test (MMRT) [9] was used to evaluate the speech word recognition abilities of these tonal language patients. The MMRT stimuli were presented via headphones in a quiet environment for all patients at 65 dB HL, and the maximum achievable word recognition score (unaided PBmax) was recorded in each ear. If a patient scored less than 90% SRS at 65 dB HL, the unaided PBmax of that patient would be retested with a 10dB-steps increase in presentation level or with the loudest possible presentation level for that patient. As for patients fitted with hearing aids, further sound field speech word recognition tests were also performed using the MMRT stimuli with 65 dB HL (ranging from 50-70 dB HL) to obtain the aided PBmax. The contralateral ear was properly occluded with earplugs in cases of the unilateral fitting, and speech-shaped noise masking was applied when appropriate.

Logistic regression analysis was used to analyze PBmax in relation to 4FPTA. A box plot was presented to show the PBmax obtained as a function of 4FPTA. Data from patients in the severe hearing loss group were further analyzed. An aided PBmax of less than 30% was considered a poor speech word recognition performance after hearing aids[10]. Statistical analyses were performed using SPSS V25.

**Results:**

Demographic information of the patients in this study is shown in Table 1. Among the 774 ears, there were 151 ears with normal hearing, 419 with mild to moderate hearing loss, 83 with severe hearing loss, and 121 with profound hearing loss. The 4FPTA hearing threshold average was 15.7 ± 5.8, 50.5 ± 11.9, 80.5 ± 6.3, and 105.7 ± 9.0 dB HL in each group respectively. The age of the patients ranged from 5 to 94-years-old and the overall mean age was 58.6±23.2 years. Female patients were slightly predominant.

| The patients’ demographic data |
|-----------------------------|----------|---------|---------|
| Group size(ears) | Gender(M/F) | Age(years) | 4FPTA(dB HL) |
| Normal hearing    | 151 | 40/111   | 48.5±15.3 | 15.7±5.8 |
| Mild to moderate HL | 419 | 187/232 | 68.5±17.4 | 50.5±11.9 |
| Sever HL          | 83  | 46/37    | 59.4±24.5 | 80.5±6.3 |
| Profound HL       | 121 | 57/64    | 36.4±27.3 | 105.7±9.0 |
| Total             | 774 | 330/444  | 58.6±23.2 | 55.6±29.7 |

HL, hearing loss; 4FPTA (average of 0.5,1,2,4 KHz)
Figure 1A presents the unaided PBmax values of the 774 ears as a function of their corresponding unaided 4FPTA. The 4FPTA displayed on the x-axis was divided into 12 regular intervals, which started at 5 dB HL and had a unit of 10 dB in each interval. Figure 1B presents the same set of data as in figure 1A for an easier view of the mean unaided PBmax. For each 4FPTA interval, the mean unaided PBmax scores were 98.5 ± 3.1% in the 10 dB HL group (70 ears), 97.7 ± 3.7% in the 20 dB HL group (78 ears), 96.0 ± 4.5% in the 30 dB HL group (55 ears), 91.8 ± 8.1% in the 40 dB HL group (93 ears), 82.9 ± 13.8% in the 50 dB HL group (115 ears), 66.4 ± 21.3% in the 60 dB HL group (107 ears), 60.5 ± 21.6% in the 70 dB HL group (76 ears), 43.5 ± 29.0% in the 80 dB HL group (29 ears), 29.2% ± 24.2% in the 90 dB HL group (38 ears), 14.5% ± 18.2% in 100 dB HL group (40 ears), and 0% in 110-120 dB HL group (48 ears) respectively. Altogether, most patients with normal hearing and mild to moderate hearing loss (for those with 25 dB HL < 4FPTA ≤ 50 dB HL) could achieve a PBmax greater than 80%; however, PBmax deteriorated accordingly as the value of 4FPTA increased. Figure 1B shows that the interval of 4FPTA ranging from 81 to 90 dB HL had the greatest standard deviation.

Figure 2 presents the relationship between the aided PBmax and unaided 4FPTA of 114 ears that had been fitted with hearing aids. The 4FPTA displayed on the x-axis was also divided into regular intervals with a unit of 10 dB in each interval. However, the scale starts from 41 to 50 dB and ends at 111 to 120 dB HL, as shown in Figure 2. Based on the NHI criteria for CI candidacy, only patients with aided PBmax less than 30% were considered to demonstrate poor speech recognition performance. Therefore, the percentage of patients who scored less than 30% in each 4FPTA interval was calculated as poor speech recognition performance with hearing aid amplification. None of the 3 patients with 4FPTA of 50 ± 5 dB had aided SRS < 30%; 1 in 11 patients (9.1%) with 4FPTA of 60 ± 5 dB had aided SRS < 30%; 2 in 9 patients (22.2%) with 4FPTA of 70 ± 5 dB had aided SRS < 30%; 5 in 12 patients (41.7%) with 4FPTA of 80 ± 5 dB had aided SRS < 30%; 10 in 23 patients (43.5%) with 4FPTA of 90 ± 5 dB had aided SRS < 30%; 16 in 29 patients (55.2%) with 4FPTA of 100 ± 5 dB had aided SRS < 30%; 18 in 21 patients (85.7%) with 4FPTA of 110 ± 5 dB had aided SRS < 30%; all 6 patients (100%) with 4FPTA of 120 ± 5 dB had aided SRS < 30%. In summary, 31% (10/32) of the 32 ears with severe hearing loss 70-90 dB HL still showed poor speech recognition after hearing aid amplification, while 71% (46/65) of the 65 ears with profound hearing loss > 90 dB HL showed poor speech recognition with hearing aid amplification.

**Discussion:**

The purpose of the present study was to examine the relationship between pure tone thresholds and speech recognition performance in tonal mandarin-speaking patients. The results of the logistic regression analysis showed that 4FPTA is highly correlated with unaided PB\(_{\text{max}}\) in patients with normal hearing and profound hearing loss in cases where patients with 4FPTA in the range of normal hearing consistently scored higher values of unaided PB\(_{\text{max}}\) and patients with 4FPTA in the range of profound hearing loss scored the poorest value of unaided PB\(_{\text{max}}\). However, the variability of speech recognition performance has increased greatly in patients with moderate and severe hearing loss, with the greatest variability occurring when the 4FPTA falls within the range of 60 to 80 dB HL. This trend in tonal mandarin-speaking patients is consistent with those reported by Hoppe et al. and Maeda et al.[11, 12]. As a result, 4FPTA cannot accurately reflect an individual's speech recognition ability. In other words, 4FPTA is a poor predictor of unaided PB\(_{\text{max}}\), which is highly associated with different extents of cochlear hair cell damage[4, 10], especially for those with 70-90 dB HL severe hearing loss. Therefore, one needs to be aware that it is possible to underestimate the severity of hearing disability among patients with severe hearing loss based solely on the information provided by PTA alone.

Although unaided PB\(_{\text{max}}\) is a poor predictor of aided word recognition performance[13], in practice, unaided PB\(_{\text{max}}\) is still regarded as an index of cochlear function and is used to predict the outcome benefit of hearing aid amplification. Another study[10] also suggested that unaided PB\(_{\text{max}}\) should be regarded as an individual's potential upper limit of word recognition performance with hearing aid amplification. Therefore, the relationship between the 4FPTA and unaided and aided PB\(_{\text{max}}\) was examined in our study to determine how 4FPTA correlated with speech recognition performance with hearing aids. As shown in Figure 1B, patients who underwent 4FPTA fell within the range of severe hearing loss (70-90 dB HL). They showed the greatest variability in their unaided PB\(_{\text{max}}\). Therefore, the aided PB\(_{\text{max}}\) of the severe hearing loss patients was the main
interest for this study to see how much benefit they could obtain in terms of speech recognition performance with hearing aid amplification, and whether their 4FPTA was in any way correlated with the aided $PB_{max}$. Figure 2 results showed that about 30% of the patients with 70-90 dB HL severe hearing loss did not sufficiently benefit from hearing aids amplification and scored an aided $PB_{max} < 30\%$. Our 30% data in tonal language mandarin-speaking patients is relatively similar but slightly lower than other language studies' findings, which were mostly greater than 50%[10, 14]. This difference is speculated to be caused by the different speech materials used, different test environments, and different ways of conducting speech audiometry.

Evaluating post-lingual CI candidacy has become increasingly challenging in clinical practice because of the changing and expanding CI indications[15]. Different countries and studies have adopted different sets of CI candidacy criteria. In America, CI indications included adults with bilateral moderate to profound sensorineural hearing loss and $PB_{max} \leq 50\%$ in the intended implant ear and < 60% in the contralateral ear[16]. In the UK, the CI indications suggested by National Institute for Health and Care Excellence included bilateral severe to profound hearing loss (> 80 dB HL at low or more frequencies from 500 to 2000 Hz) and an aided phonemic $PB_{max}$ less than 50%[17]. Although different CI candidacy criteria were adopted, the worldwide consensus is to loosen up the candidacy criteria so that individuals, especially those with severe hearing loss, who have not gained sufficient benefit from hearing aids, could be considered as candidates and start the CI evaluation. Our study in tonal mandarin-speaking patients reaffirms the importance of speech recognition testing in the CI evaluation process. The speech recognition audiometry using Mandarin Monosyllable Recognition Test (MMRT) could help identify those whose 4FPTA< 90 dB HL fell outside the CI candidacy criteria of NHI but showed significantly poorer speech recognition performance. In conclusion, our study suggest that the NHI in tonal language mandarin-speaking countries could start expanding the CI candidacy criteria to include patients who have 4FPTA< 90 dB HL but could not benefit from hearing aid amplification with poor SRS <30%.

References:

1. Deal, J. A. et al. Incident Hearing Loss and Comorbidity: A Longitudinal Administrative Claims Study. *JAMA Otolaryngol Head Neck Surg*, **145**, 36–43 (2019).
2. WHO. Deafness and hearing loss. 1 March 2020; Available at https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss
3. Lupo, J. E., Biever, A. & Kelsall, D. C. Comprehensive hearing aid assessment in adults with bilateral severe-profound sensorineural hearing loss who present for Cochlear implant evaluation. *Am J Otolaryngol*, **41**, 102300 (2020).
4. Halpin, C. & Rauch, S. D. Clinical implications of a damaged cochlea: Pure tone thresholds vs information-carrying capacity. Otolaryngology—. *Otolaryngol Head Neck Surg*, **140**, 473–6 (2009).
5. Szyfter, W., Karlik, M., Sekula, A., Harris, S. & Gawęcki, W. Current indications for cochlear implantation in adults and children. *Otolaryngol Pol*, **73**, 1–5 (2019).
6. Administration Ministry of Health and Welfare, code 84038B. Available at https://www.nhi.gov.tw/Resource/webdata/31716_1_%E4%BA%BA%E5%B7%A5%E9%9B%BB%E5%AD%90%E8%80%B3-HTA%E5%A0%B1%E5%91%8A.pdf
7. Clark, J. G. Uses and abuses of hearing loss classification. *Asha*, **23**, 493–500 (1981).
8. Baiduc, R. R., Poling, G. L., Hong, O. & Dhar, S. Clinical measures of auditory function: the cochlea and beyond. *Dis Mon*, **59**, 147 (2013).
9. Tsai, K. S., Tseng, L. H., Wu, C. J. & Young, S. T. Development of a Mandarin Monosyllable Recognition Test.. *Ear Hear*, **30**, 90–9 (2009).
10. Hoppe, U., Hast, A. & Hocke, T. Audiometry-based screening procedure for cochlear implant candidacy. *Otol Neurotol*, **36**, 1001–5 (2015).
11. Hoppe, U., Hocke, T., Müller, A. & Hast, A. Speech Perception and Information-Carrying Capacity for Hearing Aid Users of Different Ages. *Audiol Neurootol*, 21 (Suppl 1), 16–20 (2016).

12. Maeda, Y. *et al.* Relationship between pure-tone audiogram findings and speech perception among older Japanese persons. *Acta Otolaryngol*, 138, 140–4 (2018).

13. McRackan, T. R., Ahlstrom, J. B., Clinkscales, W. B., Meyer, T. A. & Dubno, J. R. Clinical implications of word recognition differences in aided conditions. *Otol Neurotol*, 37, 1475–81 (2016).

14. Dörfler, C., Hocke, T., Hast, A. & Hoppe, U. Speech recognition with hearing aids for 10 standard audiograms. *HNO 2020:1–7*

15. McRackan, T. R. *et al.* Earphone and aided word recognition differences in cochlear implant candidates. *Otol Neurotol*, 39, e543–9 (2018).

16. Deep, N. L., Dowling, E. M., Jethanamest, D. & Carlson, M. L. Cochlear implantation: an overview. *J Neurol Surg B Skull Base*, 80, 169–77 (2019).

17. NICE guidance. Cochlear implants for children and adults with severe to profound deafness Mach, 2019; Available at https://www.nice.org.uk/guidance/ta566/chapter/1-Recommendations

**Figures**

**Figure 1**

A. The unaided maximum speech score (PBmax) as a function of the unaided 4FPTA (N=774). Individual ear distribution. In X-axis: 4FPTA: 4FPTA (average of 0.5,1,2,4 KHz). In Y-axis: PBmax (maximum speech score (PBmax))  
B. The unaided maximum speech score (PBmax) as a function of the unaided 4FPTA (N=774). Each box plot showing the mean, median, first/third quartiles, minimum/maximum, and the outliers. In X-axis: 4FPTA: 4FPTA (average of 0.5,1,2,4 KHz). In Y-axis: PBmax (maximum speech score (PBmax))
Figure 2

A. The correlation between aided SRS and unaided 4FPTA (N=114). Individual ear distribution. In X-axis: 4FPTA : 4FPTA (average of 0.5,1,2,4 KHz). In Y-axis: SRS (speech recognition score, SRS) B. The correlation between aided SRS and unaided 4FPTA (N=114). Each box plot showing the mean, median, first/third quartiles, minimum/maximum, and the outliers. In X-axis: 4FPTA : 4FPTA (average of 0.5,1,2,4 KHz). In Y-axis: SRS (speech recognition score, SRS)