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American Cochlear Implant Alliance Task Force Guidelines for Clinical Assessment and Management of Adult Cochlear Implantation for Single-Sided Deafness

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The indications for cochlear implantation have expanded to include individuals with profound sensorineural hearing loss in the impaired ear and normal hearing (NH) in the contralateral ear, known as single-sided deafness (SSD). There are additional considerations for the clinical assessment and management of adult cochlear implant candidates and recipients with SSD as compared to conventional cochlear implant candidates with bilateral moderate to profound sensorineural hearing loss. The present report reviews the current evidence relevant to the assessment and management of adults with SSD. A systematic review was also conducted on published studies that investigated outcomes of cochlear implant use on measures of speech recognition in quiet and noise, sound source localization, tinnitus perception, and quality of life for this patient population. Expert consensus and systematic review of the current literature were combined to provide guidance for the clinical assessment and management of adults with SSD.

Key words: Candidacy, Cochlear implant, Guidelines, Single-sided deafness, Systematic review, Test battery, Unilateral hearing loss.

(Ear & Hearing 2022;43;1605–1619)

PURPOSE

The indications for cochlear implantation in the United States expanded in 2019 to include individuals 5 years of age and older with profound sensorineural hearing loss in the impaired ear and normal hearing (NH) in the contralateral ear, known as single-sided deafness (SSD; U.S. Food and Drug Administration 2019). FDA-approved indications for cochlear implantation currently define SSD as a four-frequency pure-tone average (4PTA:.5, 1, 2, and 4 kHz) of >80 dB HL in the impaired ear and ≤30 dB HL in the contralateral ear (U.S. Food and Drug Administration 2022). There are additional medical and audiologic considerations for the clinical assessment and management of adult cochlear implant (CI) candidates and recipients with SSD as compared to adults with bilateral hearing loss. The present report reviews the current evidence relevant to the assessment and management of adults with SSD and offers recommendations based upon expert consensus from clinicians and scientists in the fields of audiology and neurotology. The initiative to develop this consensus report was through the American Cochlear Implant Alliance whose board recommended field experts to participate in a task force on SSD. This report is further supported by a systematic review of published studies that investigate outcomes of CI use on measures of speech recognition in quiet and noise, sound source localization, tinnitus perception, and quality of life for this patient population. Findings were combined to provide guidance for the preoperative evaluation and post-activation assessment and management of adults with SSD.

BACKGROUND

Adults with SSD experience poorer spatial hearing abilities and diminished speech understanding in the presence of competing noise when compared to listeners with NH bilaterally (Slattery & Middlebrooks 1994; Rothpletz et al. 2012; Firszt et al. 2017; Liu et al. 2018). Historically, the common clinical recommendations for adults with SSD were either to remain in an unaided condition or listen with a hearing technology that reroutes the acoustic signal from the impaired ear to the NH-ear, such as a bone conduction device (BCD) or contralateral routing of the signal (CROS) hearing aid. While rerouting technology provides users with access to the signals on the impaired side, significant improvements on spatial hearing tasks are limited because of reliance on monaural processing by the NH-ear (Hol et al. 2005; Kitterick et al. 2016; Snapp et al. 2017; Agterberg et al. 2019). Alternatively, cochlear implantation of the impaired ear allows for stimulation of both auditory pathways, thereby potentially improving performance on spatial hearing tasks, including sound source localization and speech understanding in spatially separated noise. Investigations of the effectiveness of CI use compared to an unaided condition or with rerouting technologies demonstrated significant improvements on measures of spatial hearing (e.g., sound source localization and speech recognition in spatially separated noise), and subjective benefit with the CI for adult cases of SSD (Van de Heyning et al. 2008; Arndt et al. 2011; Firszt et al. 2012a; Távora-Vieira et al. 2015a; Buss et al. 2018; Galvin et al. 2019; Deep et al. 2021). Part 1 of the following report reviews the current evidence of cochlear implantation for the management of SSD specific to candidacy considerations, audiologic assessment, device programming, and aural rehabilitation. Part 2 reviews the results of a systematic review of the published literature on outcomes of CI use on measures

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<zdoi; 10.1097/AUD.0000000000001260>

of auditory abilities, tinnitus perception, and quality of life for adults with SSD. Findings from both were used to provide guidance for the preoperative evaluation and post-activation assessment and management of adults with SSD.

PART 1: REVIEW OF THE CURRENT EVIDENCE CANDIDACY CONSIDERATIONS

Medical Considerations

Etiology • There are many known causes of SSD which can be either acquired or congenital in nature. The most common etiology of acquired SSD in adulthood is either sudden or progressive idiopathic hearing loss, accounting for more than 50% of cases (Hansen, Gantz, & Dunn 2013; Friedmann et al. 2016; Usami et al. 2017; Snapp & Ausili 2020). Other less common etiologies include chronic otitis media/cholesteatoma, retrocochlear tumors most commonly being vestibular schwannoma, Meniere's disease, and trauma (Usami et al. 2017; Snapp & Ausili 2020).

With regard to the underlying etiology and the status of the contralateral ear, several additional considerations warrant discussion. First, it is recommended that individuals with sudden and/or rapid progression of SSD undergo standard medical workup and monitoring to determine if the hearing spontaneously improves or is recoverable with treatment, such as with oral or intratympanic steroids or hyperbaric oxygen therapy (Chandrasekhar et al. 2019). In most cases, it is recommended that cochlear implantation should not occur earlier than 3 to 6 months after sudden hearing loss to allow ample time for potential recovery of hearing (Angeli et al. 2012). In addition, individuals with SSD may adapt to the monaural condition over time (Kumpik & King 2019). As such, it is recommended that adults with SSD be counseled regarding intervention during the acute period. Careful consideration of an adaptation period post sudden onset of SSD is crucial for the clinical decision-making for optimal long-term outcomes.

The status of the contralateral ear is another important consideration. For etiologies such as Meniere's disease, autoimmune inner ear disease, neurofibromatosis type 2 (NF2), congenital CMV, or bilateral enlarged vestibular aqueduct, the contralateral ear is at relatively high risk for future hearing loss. The possibility of acquiring significant bilateral hearing loss in such cases warrants consideration. Additional consideration should be given to the potential benefits of early implantation of the impaired ear for long-term performance benefits, as this may reduce the risk of poorer performance associated with prolonged duration of deafness (Blamey et al. 1996, 2013; Rubinstein et al. 1999; Leung et al. 2005; Green et al. 2007; Holden et al. 2013) while allowing time for acclimatization with the CI before onset of significant hearing loss in the contralateral ear.

Imaging

Preoperative imaging may include magnetic resonance imaging (MRI) with or without temporal bone computed tomography (CT). In most cases of acquired adult-onset SSD, an MRI alone is sufficient to evaluate for retrocochlear lesions, labyrinthine ossification, and inner ear malformations (Stachler et al. 2012; Choi & Kaylie 2017; Chandrasekhar et al. 2019). The presence of ossification should be explored in patients with a history of meningitis, otosclerosis, labyrinthitis, temporal bone fracture, or prior vestibular schwannoma microsurgery (Booth et al. 2013; Feng et al. 2020). A CT scan may provide additional benefit if the patient had prior temporal bone surgery or there was concern for anatomical facial nerve aberrancy—the latter being uncommon in this population.

Potential Medical Contraindications

Cases of advanced cochlear ossification, severe labyrinthine dysplasia, and cochlear nerve aplasia are potential contraindications for cochlear implantation, particularly in adults with SSD; in these conditions, the ear with hearing loss is likely to have a suboptimal CI outcome which increases the likelihood of non-use (e.g., Deep et al. 2021). The therapeutic time window for cochlear implantation is relatively narrow for several conditions with a risk of progressive cochlear ossification. For example, fibrosis and subsequent prohibitive ossification can develop within months of "injury" for cases of otic capsule fractures, meningitis, or vestibular schwannoma microsurgery. If cochlear implantation is being considered in such cases, an additional MRI study with thin-slice heavily T2-weighted imaging may be required to determine cochlear patency, and early surgery may be advantageous.

Cases of Vestibular Schwannoma

To date, there is somewhat limited evidence of the degree of benefit that might be realized for individuals with SSD associated with vestibular schwannoma (Carlson et al. 2012, 2016; Hassepass et al. 2016; Sanna et al. 2016; Rooth et al. 2017; Thompson et al. 2019). Cochlear implantation can be considered after radiosurgery, microsurgery, or in the treatment of individuals with stable tumors during wait-and-scan management. If there is a history of prior microsurgical tumor resection, then the operative note, postoperative imaging, and postoperative audiometric results will need to be reviewed to determine whether the cochlear nerve was preserved and the cochlea has not developed prohibitive ossification (Hoffman et al. 1992; Carlson et al. 2012; Lloyd et al. 2014; Deep et al. 2019). Successful stimulation with a CI requires sufficient cochlear nerve health, and mere anatomical preservation of the cochlear nerve after tumor resection does not guarantee successful auditory pathway stimulation (Wallerius et al. 2022). Simultaneous translabyrinthine excision of vestibular schwannoma and cochlear implantation has also been described, with results ranging from no auditory detection to performance similar to conventional CI recipients (Ahsan et al. 2003; Lloyd et al. 2014; Hassepass et al. 2016; Sanna et al. 2016; Rooth et al. 2017; Choudhury et al. 2019; Thompson et al. 2019; Dahm et al. 2020). While the application of cochlear implantation for individuals with unilateral vestibular schwannoma and SSD requires further study, evidence demonstrates that auditory nerve integrity is a key predictor of outcomes (Carlson et al. 2012, 2016; Hassepass et al. 2016; Thompson et al. 2019) and should be reviewed carefully before consideration of surgery. The utility of promontory stimulation for determining candidacy in this population is controversial, as a positive response does not guarantee good performance with the CI, and a negative response does not necessarily exclude benefit from CI use (Nikolopoulos et al. 2000; Neff et al. 2007). Outcomes of cochlear implantation in individuals with vestibular schwannoma are largely limited to those with contralateral hearing loss or NF2. Currently, there are no large cohort studies describing outcomes of CI use for individuals with vestibular schwannoma with a contralateral NH ear. It is important to note that the need for surveillance imaging of the vestibular schwannoma after cochlear implantation should be given consideration. Ipsilateral MRI artifact is rarely a significant issue when performed with the magnet in place under specific imaging protocols (Walton et al. 2014; Carlson et al. 2015; Sharon et al. 2016; Schwartz et al. 2020; Fussell et al. 2021); therefore, the internal magnet may not need to be removed before imaging.

Duration of SSD

Duration of deafness is a known predictor of CI outcomes in bilaterally deafened individuals, with early intervention being positively associated with improved performance (Blamey et al. 1996, 2013; Rubinstein et al. 1999; Leung et al. 2005; Green et al. 2007; Holden et al. 2013). While less is known about the effects of duration of deafness on CI outcomes in individuals with SSD, consideration is recommended for the potential effect of long durations of SSD on functional outcomes. Whereas some investigations suggest improved hearing performance in adult CI recipients with long durations of SSD (Távora-Vieira et al. 2013, 2015a; Arndt et al. 2017), others observed limited to no benefit, particularly among adult CI recipients with congenital SSD (Arndt et al. 2011; Rahne & Plontke 2016; Cohen & Svirsky 2019). The majority of published cohorts are limited to those with short durations of SSD (e.g., ≤10 years) (Arndt et al. 2011; Firszt et al. 2012a; Zeitler et al. 2015; Friedmann et al. 2016; Buss et al. 2018; Galvin et al. 2019). Investigations of functional outcomes for adult CI recipients after prolonged durations of SSD are limited in number and include small cohorts (n ≤ 7). For instance, Távora-Vieira et al. (2013) reviewed the outcomes of five adult CI recipients with a range of 27 to 40 years duration of SSD. Participants experienced significant improvements on measures of speech recognition in noise and subjective benefit as compared to preoperative performance. A follow-up study of this cohort including CI recipients with shorter durations of SSD reported no significant effect of duration of SSD on measures of speech recognition in noise and subjective benefit (Távora-Vieira et al. 2015a). While promising, the sample of CI recipients with prolonged duration of SSD remained small (n = 7/28) compared to the shorter duration cohort, and participants were required to undergo extensive auditory training post-activation (Távora-Vieira et al. 2015a), which may account in part for the observed outcomes. Similarly, Arndt et al. (2017) reported that the duration of SSD did not influence post-activation outcomes in a subgroup (n = 4) of 41 CI recipients with more than 10 years duration of SSD. In both of these studies (Távora-Vieira et al. 2015a, Arndt et al. 2017), influence of duration of SSD was investigated for speech recognition in noise for the bilateral hearing condition. In a third study, Nassiri et al. (2021a) reported on speech recognition in quiet for the affected ear in seven adult CI recipients with a prolonged duration of SSD (interquartile range: 15 to 28 years) as compared to 28 CI recipients with less than 10 years of SSD and found no statistically significant difference between groups, either categorically or when examining duration of SSD as a continuous feature. In contrast, Rahne and Plontke (2016) observed performance with the CI alone was negatively associated with duration of SSD, which is consistent with longstanding evidence in bilaterally deafened adult CI recipients (Blamey et al. 1996, 2013; Rubinstein et al. 1999; Leung et al. 2005; Green et al. 2007).

The performance benefits reported in adult CI recipients with post-lingual onset SSD may not be experienced in adult cases of congenital SSD due to the development of the auditory pathways in response to prolonged monaural hearing. We encourage the interested reader to review an accompanying manuscript discussing the current evidence of the effectiveness of cochlear implantation in children with congenital SSD (see Park et al. 2022). Adults with congenital SSD have a reduced ability to benefit from binaural cues because of cortical reorganization (Kral et al. 2013; Kral et al. 2015). Studies of sequential cochlear implantation in bilateral congenital deafness suggest reorganization is permanent after significant delays in bilateral CI stimulation during the critical period (Gordon et al. 2013). This suggests the limited ability of the auditory system to make use of bilateral hearing cues after long periods of unilateral hearing, compared to those with adult-onset of SSD who benefit from normal binaural hearing development. A study of CI outcomes for individuals with asymmetric hearing loss (Firszt et al. 2012b) found those with pre/peri-lingual onset of hearing loss had limited improvement in both the bimodal condition and the implanted ear alone, despite considerable hearing in the opposite ear. Further research is required to determine if adults with congenital SSD are able to achieve optimal outcomes with CI use.

Age at Cochlear Implantation

For adults with SSD, advanced age is not a contraindication to cochlear implantation. The influence of advanced age on the risks of cochlear implantation and individual performance outcomes are likely similar to that observed in conventional CI recipients. For instance, the incidence of postoperative vertigo rises with increasing age at implantation (Hänsel et al. 2018) and should be considered a risk factor for those over 59 years of age (González-Navarro et al. 2015). For adults with SSD, no additional complications were reported in investigations including subjects 65 years of age or older at implantation (Firszt et al. 2012b, 2018; Távora-Vieira et al. 2015a). As observed in other adult CI recipient populations, there is variability as to whether age at implantation is associated with acclimatization with the CI and the magnitude of the performance benefit. For instance, in a group of CI recipients with SSD with an age at implantation ranging from 38 to 74 years (mean: 54, SD: 12), age at implantation did not have a significant effect on performance for measures of speech recognition in noise or subjective benefit (Távora-Vieira et al. 2015a). Alternatively, age at implantation was significantly associated with performance for a different sample of CI recipients with SSD, with an age range of 23 to 66 years (mean: 50, SD: 11; Buss et al. 2018). Older adults may also demonstrate poorer performance compared to younger adults for specific listening situations, such as listening to a target-directed toward their CI in the presence of background noise (Bernstein et al. 2020). Similar to adults with bilateral moderate to profound hearing loss, consideration for cochlear implantation should prioritize the overall health of the individual as opposed to the chronological age at implantation.

At present, cochlear implantation for SSD is not covered by Medicare, resulting in an insurmountable barrier for beneficiaries (who represent most adults over the age of 65 years in the United States) to access cochlear implantation as a treatment for their hearing loss.

Tinnitus

Cochlear implantation was first investigated in cases of severe to profound SSD as a treatment for incapacitating tinnitus, the same group that is less likely to benefit from conventional masking strategies (Van de Heyning et al. 2008; Vermeire & Van de Heyning 2009; Punte et al. 2011). Recipients reported a reduction in their tinnitus severity with CI use as compared to preoperative perceptions (Van de Heyning et al. 2008). Subsequent investigations have replicated these findings of reduced tinnitus severity after cochlear implantation and/or with CI use in recipients with preoperative tinnitus severity ranging from slight to incapacitating using subjective measures of tinnitus severity (Buechner et al. 2010; Arndt et al. 2011; Arts et al. 2012; Blasco & Redleaf 2014; Gartrell et al. 2014; Dillon et al. 2017a; Holder et al. 2017; Sladen et al. 2017a; Ramos Macías et al. 2018; Galvin et al. 2019; Litovsky et al. 2019; Levy et al. 2020; Poncet-Wallet et al. 2020). With prolonged device use, CI recipients with SSD may experience longer periods of tinnitus relief after the CI is turned off such as when going to sleep—a phenomenon referred to as residual inhibition. When analyzing these outcomes, it is beneficial to obtain subjective measures (see section “Subjective Benefit” later) preoperatively to establish a baseline of tinnitus severity that can be compared to postoperative and post-activation perceptions. Because tinnitus severity may naturally fluctuate over the course of a day or week (Probst et al. 2017), it is often beneficial to obtain more than one measurement, such as at baseline and each follow-up encounter.

Experience with Alternative Hearing Technologies

It is recommended that non-surgical options are discussed with adult cases of SSD, and where possible, that patients are offered a trial with a non-surgical hearing technology before undergoing cochlear implantation (Desmet et al. 2012; Kitterick et al. 2014; Friedmann et al. 2016). CROS hearing aids and BCDs can be trialed in the office and at home to allow individuals with SSD to experience rerouting technologies as a potential non-surgical solution. Rerouting technologies allow for increased sound awareness and head-shadow benefits to improve speech recognition in noise for signals directed to the impaired ear (Snapp et al. 2017; Snapp 2019), though the lack of binaural input limits performance for more complex auditory tasks (Snapp & Ausili 2020). Spatial hearing benefits on speech recognition tasks with rerouting technologies are often only observed for a specific listening condition: when the target signal is delivered to the impaired ear and the masker is presented to the NH-ear (Snapp et al. 2017). In addition, localization is not significantly improved with rerouting technologies (Hol et al. 2005; Kitterick et al. 2016; Snapp et al. 2017; Agterberg et al. 2019). As such, reports of subjective benefit can vary considerably (Andersen et al. 2006; Faber et al. 2013; Finbow et al. 2015; Ryu et al. 2015; Kitterick et al. 2016; Snapp et al. 2017). Investigations comparing outcomes with rerouting technologies to CI in adults with SSD demonstrate that CI use results in significantly improved localization abilities and equal or significantly improved performance on measures of speech recognition in noise and subjective benefit (Arndt et al. 2011, 2017; Buss et al. 2018).

Counseling

The preoperative counseling of conventional CI candidates typically includes a description of the surgical procedure and associated postoperative management, CI devices, and mapping and assessment follow-up recommendations/protocols. It is recommended that the counseling of CI candidates with SSD also include discussion of alternative hearing technologies for SSD, the implications of no treatment, CI device considerations, and realistic expectations. For instance, CI recipients with SSD have demonstrated poorer performance on spatial hearing tasks when device use is less than 8 hours per day (Dillon et al. 2017b). It is recommended that candidates are counseled on the need to listen with the CI consistently to obtain maximum benefit. Post-activation, the data-logging feature provided by the current clinical mapping software may provide a metric for observing daily CI use to facilitate counseling.

Subjective Benefit

The preoperative evaluation and post-activation assessment of adults with SSD may include subjective questionnaires to evaluate the perceived benefits associated with hearing technology. The Speech, Spatial and Qualities of Hearing Scale (SSQ; Gatehouse & Noble 2004) has been used consistently as part of investigations assessing the effectiveness of CI use for adults with SSD (Vermeire & Van de Heyning, 2009; Arndt et al. 2011, 2017; Firszt et al. 2012a; Távora-Vieira et al. 2013, 2015; Mertens et al. 2015; Dillon et al. 2017a; Galvin et al. 2019). The SSQ was developed to assess different aspects of binaural hearing, including speech recognition in multi-talker noise, localization, and segregation of different sounds, which make up the three primary subscales (i.e., Speech Hearing, Spatial Hearing, and Qualities of Hearing). In addition, the responses on the SSQ can be scored using pragmatic subscales, such as multiple speech-stream processing and switching, distance and movement, sound quality and naturalness, and listening effort (Gatehouse & Akeroyd 2006). The SSQ pragmatic subscales have been used in the assessment of subjects listening with unilateral versus bilateral hearing aids (Gatehouse & Akeroyd 2006), unilateral CI versus bimodal or bilateral CIs (Dwyer et al. 2013), and a NH ear alone or with alternative hearing technologies versus a CI and the NH ear (CI+NH) for cases of SSD (Dillon et al. 2017a; Lopez et al. 2021). Administration of the SSQ may allow for the preoperative assessment of perceived limitations because of monaural hearing that motivates an adult with SSD to pursue cochlear implantation, which may not be captured with routine test measures conducted in the sound booth. The success of CI use can be assessed by comparing responses over time post-activation to the preoperative report. Taken together, the SSQ is recommended for adults with SSD before and after cochlear implantation to assess the influence of the hearing loss on the patient’s perceptions on their binaural hearing abilities and the post-activation success of the CI to improve performance.

Other questionnaires to consider in the preoperative and post-activation assessment of adults with SSD include measures of quality of life and tinnitus severity. Measures of quality of life may include the Health Utilities Index (Furlong et al. 2001) and the Cochlear Implant Quality of Life (CIQOL) CIQOL-35 Profile and CIQOL-10 Global (McRackan et al. 2019). Subjective measures of tinnitus severity may include the Tinnitus Handicap Inventory (Newman et a. 1996), the Tinnitus Functional Index (Henry et al. 2016), and tinnitus loudness/annoyance Visual Analog Scale.

AUDIOLOGIC ASSESSMENT

The audiologic assessment for adults with SSD before and after cochlear implantation includes traditional measures, such as the behavioral assessment of unaided hearing detection thresholds, and additional considerations, including the need to isolate the input to the affected ear and the addition of assessing spatial hearing abilities. It is recommended that behavioral measurement of the unaided hearing detection thresholds in the NH ear is completed at routine follow-up intervals to monitor hearing stability—particularly for cases of SSD with unknown etiology. For the implanted ear, behavioral measurement of unaided hearing detection thresholds may be recommended considering preoperative findings, such as cases with moderate or better low-frequency hearing thresholds (Dillon et al. 2020).

Affected Ear Alone

One consideration when assessing the impaired ear for cases of SSD is the need to isolate the input from the contralateral, NH ear. This allows for the assessment of performance with a traditional hearing aid in the impaired ear preoperatively and for the evaluation of the effectiveness of the CI at improving sound detection and speech recognition in the implanted ear post-activation. Test methods used to isolate the input to the affected ear during the measurement of aided sound field thresholds and speech recognition include: (1) use of direct audio input technology, (2) plugging the contralateral ear and placing a circumaural phone over the pinna, and (3) presenting masking to the contralateral ear via an insert phone and placing a circumaural phone over the pinna (Firszt et al. 2012b; Hansen et al. 2013; Friedmann et al. 2016; Sladen et al. 2017b; Buss et al. 2018; Litovsky et al. 2019). Buss et al. (2018) compared speech recognition in quiet with the CI-alone with stimuli either presented via direct audio input or in the sound field with masking presented to the contralateral ear and reported no significant difference in performance between test methods.

Most investigations assessing the effectiveness of CI use in adult cases of SSD have used the consonant-nucleus-consonant words test (Peterson & Lehiste 1962) to measure speech recognition in the impaired ear alone (Firszt et al. 2012a; Hansen et al. 2013; Friedmann et al. 2016; Buss et al. 2018; Galvin et al. 2019). Other investigations have also included the use of the AzBio sentences (Spahr et al. 2012) presented in quiet (Hansen et al. 2013; Zeitler et al. 2015). There is a discrepancy in the literature as to whether the pattern of performance growth and magnitude of the benefit for speech recognition with the CI-alone is similar to that observed in CI recipients with bilateral moderate to profound sensorineural hearing loss. For instance, some have observed acclimatization with the CI-alone for adults with SSD at an earlier interval than conventional CI recipients (Nassiri et al. 2022), while others have observed similar acclimatization patterns between CI recipients with SSD and conventional CI recipients (Buss et al. 2018). Also, some have observed slightly poorer speech recognition for CI recipients with SSD as compared to conventional CI recipients (Finke et al. 2017a; Sladen et al. 2017a, 2017b), while others have observed similar mean speech recognition performance (Buss et al. 2018; Deep et al. 2021). Further research is warranted to elucidate the variables that contribute to acclimatization and the magnitude of the benefit for adult CI recipients with SSD when listening with the CI alone.

Spatial Hearing

Spatial hearing encompasses the use of monaural spectral cues and binaural cues, including interaural timing and level differences. The ability to extract these cues allows listeners to successfully identify auditory events in space and spatially separate target sounds from competing signals. Individuals with SSD do not have access to binaural hearing cues and, for those with high-frequency hearing loss in the better hearing ear, may have limited access to monaural spectral cues (Agterberg et al. 2014). It is recommended that the test battery for adults with SSD also include the assessment of spatial hearing because poor spatial hearing is a primary reason for pursuing cochlear implantation (Deep et al. 2021) and performance with the CI-alone is not consistently associated with performance in the bilateral condition (Buss et al. 2018; Bernstein et al. 2020). Spatial hearing measures can be used in the clinical space to assess for perceptual and difference thresholds of these cues to inform on binaural hearing abilities. In terms of outcomes measures, this can largely be categorized into tasks of sound source localization and speech recognition in noise.

Preoperatively, the assessment of spatial hearing should be completed with the individual's everyday listening condition (e.g., with or without a hearing aid for the poor ear) and/or with a non-surgical hearing technology (e.g., CROS hearing aid or BCD). Post-activation should be completed in the CI+NH listening condition. The assessment may also be completed in the unaided condition (NH-ear alone) to assess the benefits of listening with the CI.

Speech Recognition in Noise

Hearing in noise is facilitated through the bilateral advantages of the acoustic head-shadow, binaural summation, and binaural squelch. The acoustic head-shadow is a predominately physical phenomenon; the head and torso form a barrier between the competing noise/masker and the signal of interest to produce an optimal signal to noise ratio (SNR) at the ear closest to the target. Binaural summation is the improvement in speech recognition when the speech and masker are co-located because of the redundancy of the acoustic information at the two ears. When the speech and masker are spatially separated, listeners experience binaural squelch through the use of binaural difference cues when the ear with the poorer SNR is added. The benefits of binaural summation and squelch vary based on the signal and masker characteristics (Bronkhorst & Plomp 1989).

The effects of the acoustic head-shadow, binaural summation, and binaural squelch can be measured clinically using different spatial configurations for the target speech and masker (Fig. 1) by comparing performance in the unilateral to bilateral listening conditions. This can be achieved using the common two-speaker setup in the sound booth where one speaker is positioned at 0° azimuth and the other is positioned

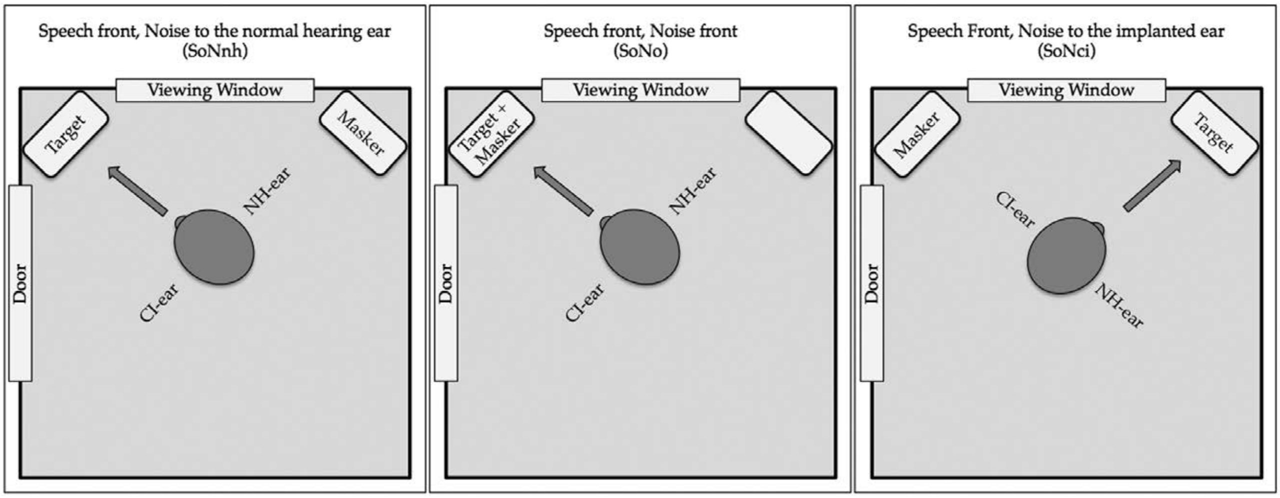

Fig. 1. Depiction of a two-speaker setup that allows for the assessment of speech recognition for three listening conditions: (1) target and masker co-located (SoNo; middle panel), which is the traditional test configuration for the assessment of CI candidates and recipients, (2) target from the front speaker and masker presented 90° toward the affected ear (SoNci; right panel), and (3) target from the front speaker and masker presented 90° toward the NH ear (SoNnh; left panel).

45 to 90° toward either the NH or affected ear. The patient is seated approximately 1 meter away from both speakers. As shown in Figure 1, this two-speaker setup allows for the assessment of three listening conditions: (1) target and masker co-located (SoNo; middle panel), which is the traditional test configuration for the assessment of CI candidates and recipients, (2) target from the front speaker and masker presented 90° toward the affected ear (SoNci; right panel), and (3) target from the front speaker and masker presented 90° toward the NH ear (SoNnh; left panel). The patient's chair is oriented to face a specific speaker to present the masker for the SoNci and SoNnh conditions. Comparing performance in a unilateral versus bilateral listening condition allows for the assessment of binaural summation in the SoNo configuration, head-shadow in the SoNnh configuration, and binaural squelch in the SoNci configuration. Others endorse the assessment of performance with speakers positioned on both sides of the head, with the target presented toward the impaired ear and the masker presented toward the NH ear (see Van de Heyning et al. 2016). While this target-to-masker configuration allows for the assessment of the maximum head shadow benefit experienced by the individual (Bernstein et al. 2017), the clinical utility is low considering the majority of conversations occur with the speaker facing the listener. Performance in the SoNnh configuration (head-shadow effect) has been shown to be significantly improved over unaided conditions or with alternative hearing technologies (Gartrell et al. 2014; Arndt et al. 2017; Buss et al. 2018; Távora-Vieira et al. 2019; Deep et al. 2021). While some studies report significant improvements with CI use on measures of binaural summation (Buss et al. 2018) or binaural squelch (Grossman et al. 2016), these effects are typically not observed (Williges et al. 2019).

Sentence recognition materials used in investigations of the effectiveness of CI use in adult cases of SSD include the AzBio sentences in a 10-talker masker at a fixed SNR (e.g. 0 dB; Buss et al. 2018) and adaptive noise measures such as BKB-SIN that provide the SNR at which a listener understands 50% correct (Firszt et al. 2012a; Friedmann et al. 2016).

Sound Source Localization

One of the main reasons adults with SSD reportedly pursue cochlear implantation is difficulty with sound source localization (Deep et al. 2021). There is consistent evidence that adults with SSD experience a significant improvement in sound source localization with CI use (Arndt et al. 2011, 2017; Firszt et al. 2012a; Hansen et al. 2013; Dorman et al. 2015; Zeitler et al. 2015; Grossmann et al. 2016; Dillon et al. 2017b; Döge et al. 2017; Buss et al. 2018; Dirks et al. 2019; Galvin et al. 2019; Litovsky et al. 2019; Távora-Vieira et al. 2019). The assessment of sound source localization currently requires a multi-speaker arc surrounding the listener. Notably, the loudspeaker configurations and methodological approaches vary across laboratories and clinics. For example, test configurations have used arcs of 7 (Arndt et al. 2011), 9 (Grossman et al. 2016; Mertens et al. 2017), 11 (Buss et al. 2018), 12 (Galvin et al. 2019), or 15 (Firszt et al. 2012a,b) loudspeakers spaced evenly across the horizontal plane. These test configurations may not be feasible in the majority of CI centers considering sound booth sizes that cannot accommodate a speaker arc. A potential alternative is to use direct audio input measures to assess sound source localization, which needs further investigation. Also, stimuli have included broadband noise (Dillon et al. 2017b), high-pass/low-pass filtered stimuli (Dorman et al. 2015; Mertens et al. 2016; Dirks et al. 2019), words (Firszt et al. 2012a,b), and sentences (Arndt et al. 2011). It is important to note that the results may be influenced by the methodological approach, such as whether leveling roving of the stimulus is used to limit the sole use of level cues (Middlebrooks & Green 1991; Wightman & Kistler 1997; Arras et al. 2022). Taken together, investigation is needed for clinically feasible test configurations that can assess sound source localization within the typical clinical setup and an optimal test battery.

DEVICE PROGRAMMING

The mapping procedures for CI recipients with SSD have the same goal of providing electric speech information at a level of audibility to maximize speech recognition in the implanted ear and the consideration of balancing the loudness with the contralateral ear. Unfortunately, the majority of the literature on CI recipients with SSD does not include descriptions of the mapping procedures, which may influence performance with the CI. The measurement of electric threshold and maximum comfortable loudness (MCL) levels for all active channels are recommended, as for conventional CI recipients (Shapiro & Bradham 2012; Vaerenberg et al. 2014). For the behavioral measurement of electric threshold levels, it has been recommended to plug the NH ear with an insert plug to limit the influence of environmental noise (Buss et al. 2018). For the behavioral measurement of MCL levels, the NH ear may remain plugged during procedures to rank loudness for individual channels and to balance loudness across channels (see Dillon et al. 2019). The assignment of MCL levels may also be conducted with an objective measure, such as Electrical Stapedial Reflex Threshold (Shapiro & Bradham 2012). After assigning the MCL levels, the insert plug may be removed in order for the patient to assess the loudness in the contralateral ear. For bimodal and bilateral CI recipients, loudness balancing between the ears is thought to support better spatial hearing with devices; however, this is not consistently demonstrated in the literature, likely due to other variables such as differences in the status of the periphery and electrode array placement (Poon et al. 2009; Goupell et al. 2013; Kan et al. 2013; Fitzgerald et al. 2015; Todd et al. 2017). For CI recipients with SSD, it is currently unclear whether loudness balancing with the NH ear supports better spatial hearing abilities. Clinical experience has observed that some patients with SSD may dislike the sound quality of the CI initially when compared to their NH ear and request a reduction in the overall intensity. Future work is needed to assess the influence of mapping procedures on performance when listening with the CI+NH.

An emerging area of investigation is the influence of frequency-to-place mismatch on the performance of CI recipients with SSD. Frequency-to-place mismatch is the discrepancy between the electric filter frequencies and the cochlear frequency region stimulated by an electrode contact. The magnitude of frequency-to-place mismatches is influenced by the design of the electrode array (e.g., lateral wall versus perimodiolar), length of the electrode array, cochlear morphology, surgical procedure, and electric filter assignments. Poorer performance has been associated with larger magnitudes of frequency-to-place mismatch in participants with NH when listening to CI simulations and CI users with moderate to profound hearing loss in the contralateral ear (Dorman et al. 1997; Shannon et al. 1998; Fu & Shannon 1999; Başkent & Shannon, 2003, 2004, 2005; Canfarotta et al. 2020; Li & Fu 2010). Poorer spatial hearing performance is associated with interaural mismatches in spectral information, which has been observed in bilateral CI recipients and participants listening to CI simulations (Goupell et al. 2013; Kan et al. 2013; Xu et al. 2020). The influence of interaural mismatch on spatial hearing performance for cases of SSD has been investigated using CI simulations with varying magnitudes of frequency-to-place mismatch, with results demonstrating better speech recognition in spatially-separated noise when mismatch is reduced (Zhou et al. 2017). For CI recipients with SSD, mismatch may be reduced by implantation of a long electrode array that approximates the cochlear place frequency with the default filter frequencies and/or mapping the filter frequencies for individual electrode contacts to match the cochlear place frequencies. Providing electric filter frequencies that approximate the cochlear place frequency may support early acclimatization with the CI (Dillon et al. 2019) and binaural fusion (Wess et al. 2020). However, whether improving cochlear place frequency matching results in benefits for functional outcomes is presently unknown.

Investigation is needed to determine the optimal mapping procedures for CI recipients with SSD, including the influence of electric threshold levels, MCL levels, and filter frequencies. In addition, investigations are needed on the influence of device characteristics, such as the influence of omnidirectional versus directional microphone settings on spatial hearing performance (Kurz et al. 2021). Future work is also needed on the temporal differences in information presented by the CI relative to the NH ear (Zirn et al. 2015).

AURAL REHABILITATION

Auditory training has been shown to improve the performance of conventional CI recipients and participants with bilateral NH when listening to CI simulations (Rosen et al. 1999; Fu & Galvin 2003; Boothroyd 2007; Oba et al. 2011; Zhang et al. 2012; Moberly et al. 2018). Investigations of the effectiveness of CI use in adult cases of SSD have noted the inclusion of auditory training as part of the post-activation management (Nawaz et al. 2014; Távora-Vieira et al. 2015a; Arndt et al. 2017; Buss et al. 2018; Távora-Vieira & Marino 2019). Auditory training is recommended within the initial months of CI use, with some including auditory training within the initial weeks of CI use (Arndt et al. 2017; Buss et al. 2018) and others recommending a minimum of 20 to 30 minutes per day within the initial months of CI use (Távora-Vieira & Marino 2019). For instance, a group reviewed by Távora-Vieira et al. (2015a) completed auditory training weekly within the first two months post-activation and then once a month to the 6-month interval. Auditory training has been described as isolating the input to the CI via a direct audio input cable or wireless technology (Távora-Vieira et al. 2015a; Van De Heyning et al. 2016; Dillon et al. 2017b; Evans & Dillon 2019; Távora-Vieira & Marino 2019). Bilateral auditory training procedures have also been described (Nawaz et al. 2014; Yu et al. 2018) with the aim of improving spatial hearing performance. Auditory training can be conducted with an aural rehabilitation clinician either in-person or via telehealth. In addition, adult CI users with SSD may also benefit from online resources, such as materials used for learning a second language, documentaries that include subtitles, and audio books (Távora-Vieira & Marino 2019). Adults with SSD who receive a CI may also benefit from localization training; improved localization after training has been shown for some individuals with SSD without a CI (Firszt et al. 2015). Investigations are needed to determine optimal auditory training procedures and recommended timelines for CI users with SSD.

PART 2: SYSTEMATIC REVIEW ON OUTCOMES OF COCHLEAR IMPLANT USE FOR ADULTS WITH SINGLE-SIDED DEAFNESS

The majority of investigations on outcomes of CI use for adults with SSD include small sample sizes that limit the generalizability of the data and recommendations. To support the guidelines in the present report, a systematic review was conducted on published studies on outcomes of CI use on measures of speech recognition in quiet and noise, sound source localization, tinnitus perception, and quality of life for adults with SSD.

Methods

A literature search was conducted for investigations of CI use in adults with SSD that were published between January 2008 and September 2021. The following 6 health science databases were queried: PubMed, MEDLINE, Embase, Cochrane Central Register of Controlled Trials, Web of Science, and Scopus. Studies were screened by two independent reviewers based on title and abstracts.

Articles were eligible for inclusion if they assessed the effectiveness of CI use for adults (≥18 years) with SSD as compared to either preoperative abilities or post-activation abilities in an unaided condition (NH-ear alone) on measures of speech recognition in quiet for the impaired ear (CI-ear), speech recognition in noise in the CI+NH condition, sound source localization, perceptions of tinnitus severity, and quality of life. The search criteria included cases of moderate to profound sensorineural hearing loss in the ear-to-be implanted and normal to near-NH (pure tone average of .5, 1, and 2 kHz ≤ 30 dB HL) in the contralateral ear. Articles for inclusion were limited to those published in a peer-reviewed journal in English. Potential articles were excluded if they were small (i.e., ≤ 10 participants) case series.

Each article was assessed for the level of evidence and categorized based on the reported outcome data. The level of evidence was scored according to the AAO-HNSF modified criteria (Wasserman et al. 2006). The articles were categorized as investigations of auditory abilities (i.e., speech recognition in quiet for the impaired ear alone, and speech recognition in noise and sound source localization with the CI+NH condition), tinnitus perception, and quality of life. Four ordinal categories of the probability of the observed effect of CI use as compared to preoperative abilities or an unaided condition post-activation on the outcome of interest were defined: Level 1—*high probability* (>75 to 100%), Level 2—*moderately high probability* (>50 to 75%), Level 3—*moderately low probability* (>25 to 50%), and Level 4—*low probability* (0 to 25%). Probability was calculated from the total number of cases for studies reporting significant improvement by the total number of participants evaluated on each measure.

TABLE 1. Articles on cochlear implant use for measures of auditory abilities, including speech recognition in quiet for the impaired ear (CI-ear), speech recognition in noise with the CI plus the contralateral normal hearing (NH) ear (CI+NH), and sound source localization

			Speech Recognition in Quiet	Speech Recognition in Noise								
				CI+NH								
Article	Level of Evidence	Number of Participants	CI-ear	SoNo	SoNci	SoNnh	SciNo	SnhNo	SnhNci	SciNnh	Localization
Vermeire and Van de Heyning (2009)	2	11	DNT	–	–	DNT	+	DNT	DNT	DNT	DNT
Hansen et al. (2013)	2	29	+	DNT	DNT	DNT	DNT	DNT	DNT	DNT	+
Mertens et al. (2015)	2	12	DNT	–	–	DNT	+	DNT	DNT	DNT	DNT
Távora-Vieira et al. (2015a)	2	28	DNT	+	DNT	+	DNT	DNT	DNT	+	DNT
Távora-Vieira et al. (2015b)	3	16	DNT	+	DNT	+	DNT	DNT	DNT	+	DNT
Friedmann et al. (2016)	3	10	+	–	+	+	DNT	DNT	DNT	DNT	–
Grossmann et al. (2016)	3	11	0	–	DNT	DNT	–	–	DNT	DNT	+
Rahne and Plontke (2016)	3	17	+	+	DNT	DNT	DNT	DNT	DNT	+	+
Sladen et al. (2017a)	3	17	+	–	DNT	DNT	DNT	DNT	DNT	DNT	DNT
Arndt et al. (2017)	2	27	DNT	+	DNT	DNT	DNT	DNT	–	+	+
Dillon et al. (2017b)	2	20	DNT	DNT	DNT	DNT	DNT	DNT	DNT	DNT	+
Döge et al. (2017)	4	11	DNT	DNT	DNT	DNT	DNT	DNT	DNT	DNT	+
Buss et al. (2018)	2	20	+	+	–	+	DNT	DNT	DNT	DNT	+
Dorbeau et al. (2018)	2	10	DNT	+	DNT	DNT	DNT	DNT	DNT	+	+
Prejban et al. (2018)	2	10	DNT	DNT	DNT	DNT	DNT	DNT	DNT	+	+
Galvin et al. (2019)	2	10	DNT	+	–	+	DNT	DNT	DNT	DNT	+
Kurz et al. (2019)	3	55	+	DNT	DNT	DNT	DNT	DNT	DNT	DNT	DNT
Lorens et al. (2019)	2	25	+	+	+	DNT	DNT	DNT	DNT	+	DNT
Peter et al. (2019)	2	10	DNT	–	–	+	+	–	–	–	+
Sullivan et al. (2020)	4	60	+	–	–	+	DNT	DNT	DNT	DNT	DNT
Távora-Vieira et al. (2019)	2	33	DNT	+	DNT	+	DNT	DNT	DNT	DNT	+
Wedekind et al. (2020)	3	29	DNT	+	DNT	+	DNT	DNT	DNT	+	+
Häußler et al. (2020)	2	21	+	–	DNT	DNT	DNT	DNT	–	+	DNT
Poncet-Wallet et al. (2020)	2	26	DNT	–	–	DNT	+	DNT	DNT	DNT	DNT
Deep et al. (2021)	4	53	+	–	–	+	DNT	DNT	DNT	DNT	DNT
Kurz et al. (2021)	2	29	DNT	–	+	DNT	DNT	DNT	DNT	+	+
Lorens et al. (2021)	2	11	DNT	+	+	DNT	DNT	DNT	DNT	+	DNT
Müller and Lang-Roth (2021)	2	11	DNT	–	–	DNT	DNT	DNT	DNT	+	DNT
Speck et al. (2021)	3	24	DNT	–	DNT	DNT	DNT	DNT	–	+	+
Total evaluated			307	521	299	280	70	21	82	268	300
Total improved			307	226	86	280	59	0	0	256	290
% Improved			100%	43%	29%	100%	84%	0%	0%	96%	97%

Articles are ordered by publication year. For speech recognition in noise, performance was assessed with the target speech presented from the front (So), toward the CI-ear (Sci), or toward the NH-ear (Snh) and the masking noise either from the front (No), toward the CI-ear (Nci), or toward the NH-ear (Nnh). Results were reported as a significant improvement (+), no significant change (–), or not evaluated (DNT).

Results

The initial search yielded 1147 articles for review; 1114 articles remained after the removal of duplicates. Of those, 42 articles reported outcomes of CI use on measures of auditory abilities (n = 29), tinnitus perception (n = 17), and quality of life (n = 21) for adults with SSD. One study was categorized as Level 1, 27 as Level 2, 11 as Level 3, and 3 as Level 4.

Table 1 lists the 29 reviewed articles on CI used for measures of auditory abilities, including speech recognition in quiet for the CI-ear, speech recognition in noise in the CI+NH condition, and sound source localization. A high probability of improvement (>75 to 100%) was observed for speech recognition in quiet for the CI-ear, indicating a significant improvement in speech recognition in the impaired ear with CI use. For speech recognition in noise in the CI+NH condition, there was a high probability of improvement (>75 to 100%) for the SoNnh, SciNo, and SciNnh configurations. The benefit observed in these conditions is likely due to the head-shadow effect. There was a moderately low probability of improvement (>25 to 50%) for the SoNo and SoNci configurations, reflective of the variable performance benefits observed for measures of binaural summation and squelch. There was a low probability of improvement (0 to 25%) for the SnhNo and SnhNci configurations, indicating a lack of improvement on measures of binaural squelch. For sound source localization, there was a high probability of improvement (>75 to 100%) when listening in the CI+NH condition.

Table 2 lists the 17 reviewed articles on CI use in adults with SSD for measures of tinnitus perception. For subjective measures of tinnitus severity, there was a high probability of a significant reduction (>75 to 100%) in tinnitus severity when listening with the CI.

Table 3 lists the 21 reviewed articles on CI use in adults with SSD for measures of quality of life. For subjective measures of quality of life, there was a high probability of an improvement (>75 to 100%) in perceived quality of life with CI use.

TABLE 2. Articles on cochlear implant use for measures of tinnitus perceptions

Article	Level of Evidence	Number of Participants	Tinnitus Perception
Van de Heyning et al. (2008)	2	12	+
Punte et al. (2011)	2	26	+
Arts et al. (2015)	1	10	+
Távora-Vieira et al. (2015a)	2	28	+
Távora-Vieira et al. (2015b)	3	16	+
Holder et al. (2017)	3	12	+
Mertens et al. (2016)	2	12	+
Ahmed & Khater (2017)	2	13	+
Dorbeau et al. (2018)	2	10	+
Ramos Macias et al. (2018)	2	13	+
Galvin et al. (2019)	2	10	+
Peter et al. (2019)	2	10	+
Sullivan et al. (2020)	4	60	+
Häußler et al. (2020)	2	21	+
Poncet-Wallet et al. (2020)	2	26	+
Deep et al. (2021)	4	53	+
Speck et al. (2021)	3	24	+
Total evaluated			356
Total improved			356
% Improved			100%

Articles are ordered by publication year. Results were reported as a significant improvement (+), no significant change (–), or not evaluated (DNT).

Summary and Considerations

The present report included a review of the current evidence relevant to the assessment and management of adults with SSD (Part 1) and a systematic review of the effectiveness of CI use for adults with SSD on measures of auditory abilities, tinnitus perception, and quality of life (Part 2). Cochlear implantation is observed to be an effective treatment option for adults with SSD. Findings from Parts 1 and 2 were used to provide guidance for the preoperative evaluation and post-activation assessment and management of adults with SSD.

The systematic review of published studies found CI use has a high probability (>75 to 100%) of improving speech recognition in the CI-ear, sound source localization, tinnitus perception, and quality of life for adults with SSD. The probability of significant improvement in speech recognition in noise was dependent on the target-to-masker configuration—which varied across studies. Investigations are needed as to the optimal target-to-masker configurations and test materials to assess speech recognition in noise clinically.

The recently approved indications for cochlear implantation also included cases of asymmetric hearing loss, which includes individuals with mild to moderately-severe hearing loss (4PTA 31 to 55 dB HL) in the contralateral ear (U.S. Food and Drug Administration, 2019). The majority of the preoperative assessment and post-activation management recommendations are similar for cases of SSD and asymmetric hearing loss. There are additional factors for cases of asymmetric hearing loss that warrant further consideration, including optimal

TABLE 3. Articles on cochlear implant use for measures of quality of life

Article	Level of Evidence	Number of Participants	Quality of Life
Vermeire et al. (2009)	2	11	+
Arts et al. (2015)	1	10	–
Mertens et al. (2015)	2	12	+
Távora-Vieira et al. (2015a)	2	28	+
Távora-Vieira et al. (2015b)	3	16	+
Arndt et al. (2017)	2	27	+
Finke et al. (2017a)	3	48	+
Finke et al. (2017b)	3	19	+
Dillon et al. (2017b)	2	20	+
Louza et al. (2017)	2	10	+
Dorbeau et al. (2018)	2	10	+
Prejban et al. (2018)	2	10	+
Ramos Macias et al. (2018)	2	13	+
Galvin et al. (2019)	2	10	+
Muigg et al. (2020)	2	20	+
Peter et al. (2019)	2	10	+
Távora-Vieira et al. (2019)	2	33	+
Häußler et al. (2020)	2	21	+
Kurz et al. (2021)	2	29	+
Lopez et al. (2021)	2	20	+
Speck et al. (2021)	3	24	+
		Total evaluated	401
		Total improved	391
		% Improved	98%

Articles are ordered by publication year. Results were reported as a significant improvement (+) or no significant change (–).

programming methods for the contralateral hearing aid, when to encourage the use of the contralateral hearing aid (e.g., at CI activation versus after a few months of CI use), loudness balancing between the CI and hearing aid technologies, and the influence of different modes of technology on spatial hearing. The present recommendations are also specific to adults with SSD. The reader is directed to Park et al. (2022) for a comprehensive review of the current evidence and recommended guidelines for the preoperative evaluation and post-activation assessment and management of children with SSD.

GUIDELINES FOR THE ASSESSMENT AND MANAGEMENT OF ADULTS WITH SINGLE-SIDED DEAFNESS

Based on the current evidence and the results of the systematic review, the following guidelines are recommended for the preoperative evaluation and post-activation assessment and management of adults with SSD:

(1) It is recommended that individuals with sudden and/or rapid progression of SSD undergo standard medical workup and monitoring to determine if the hearing spontaneously improves or is recoverable with treatment, and that cochlear implantation should not occur earlier than 3 to 6 months after the sudden hearing loss to allow ample time for potential recovery of hearing. The potential exception to this is cases exhibiting evidence of progressive ossification (e.g., meningitis, after vestibular schwannoma resection, otic capsule fracture) where early implantation may be advantageous.

(2) Consideration of the potential for significant bilateral hearing loss is warranted, as well as the benefits of early implantation of the impaired hearing ear for long-term performance benefit.

(3) Preoperative imaging may include MRI with or without temporal CT. In most cases of acquired adult-onset SSD, an MRI alone is sufficient to evaluate for retrocochlear lesions, labyrinthine ossification, and inner ear malformations.

(4) Cases of advanced cochlear ossification, severe labyrinthine dysplasia, and cochlear nerve aplasia are potential contraindications for cochlear implantation, particularly in the setting of SSD where there is a heightened risk of device non-use.

(5) Some consideration is recommended for the potential effect of long durations of SSD on functional outcomes; however, prolonged duration of deafness in an adult with post-lingual onset is not a contraindication to cochlear implantation. Additional consideration is recommended for an adult with congenital SSD onset. Prolonged duration of deafness combined with congenital SSD onset may result in limited CI outcomes.

(6) Advanced age is not a contraindication for cochlear implantation. Consideration for cochlear implantation should prioritize the overall health of the individual as opposed to the chronological age at implantation.

(7) Reduced tinnitus severity is frequently reported after cochlear implantation and/or with CI use. It is recommended to obtain subjective measures preoperatively to establish a baseline of tinnitus severity that can be compared to postoperative and post-activation perceptions.

(8) It is recommended that non-surgical options are discussed with adult cases of SSD, and where possible, that patients are offered a trial with a non-surgical hearing technology before undergoing cochlear implantation.

(9) Preoperative counseling for cochlear implantation typically includes a description of the surgical procedure and associated postoperative management, CI devices, and mapping and assessment follow-up recommendations/protocols. It is recommended that the counseling of CI candidates with SSD also include a discussion of alternative hearing technologies for SSD, the implications of no treatment, CI device considerations, and realistic expectations.

(10) The preoperative and post-activation test battery should include subjective questionnaires to assess the perceived benefit of CI use, quality of life, and/or tinnitus severity.

(11) For CI recipients with preoperative moderate or better acoustic low-frequency hearing detection thresholds in the affected ear, hearing preservation should be monitored postoperatively by assessment of unaided hearing detection thresholds.

(12) One consideration when assessing the impaired ear for cases of SSD is the need to isolate the input from the contralateral, normal-hearing ear. Test methods used to isolate the input to the affected ear during the measurement of aided sound field thresholds and speech recognition include: (1) use of direct audio input technology, (2) plugging the contralateral ear and placing a circumaural phone over the pinna, and (3) presenting masking to the contralateral ear via an insert phone and placing a circumaural phone over the pinna.

(13) It is recommended that the test battery for adults with SSD also include the assessment of spatial hearing, such as speech recognition in spatially-separated noise.

(14) For the behavioral measurement of electric threshold levels, it is recommended to plug the normal-hearing ear with an insert plug to limit the influence of environmental noise. For the behavioral measurement of MCL levels, the normal-hearing ear may remain plugged during procedures to rank loudness for individual channels and to balance loudness across channels.

(15) Wear time of the CI is associated with outcomes for adults with SSD. A minimum of 8 hours of device use per day is recommended.

(16) Auditory training is recommended within the initial months of CI use.

CONCLUSIONS

Cochlear implantation is an effective treatment option for adults with SSD. The present report provided guidance for the preoperative evaluation and post-activation assessment and management of adults with SSD based on the current evidence. There is a need for further research investigating the patient and device variables that may influence the performance of adult CI users with SSD, and optimal aural rehabilitation procedures unique to this patient population (e.g., training of the implanted ear alone, training in the binaural condition).

ACKNOWLEDGMENTS

This article was written by an American Cochlear Implant Alliance Task Force, which included authors Margaret T. Dillon, Armine Kocharyan, Ghazal S. Daher, Matthew L. Carlson, William H. Shapiro, Hillary A. Snapp, and Jill B. Firszt.

M.T.D. is supported by a research grant provided by MED-EL Corporation to her university.

This work was performed without commercial sponsorship or support.

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Received December 17, 2021; accepted June 1, 2022; published online ahead of print August 22, 2022.

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