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Evaluation of CROS, BAHA & CI
as Management Strategies for
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Evaluation of CROS, BAHA and CI as Management Strategies for Single Sided Deafness (SSD).

Abbreviation: AN = Acoustic Neuroma; AV = aversiveness to sound; BAHA = Bone Anchored Hearing Aid; BTE = Behind the ear; BGN = background noise; BiCROS = Bilateral Contralateral Routing of Signal; CI = Cochlear Implant; CROS = Contralateral Routing of Signal; dB = Decibels; dB SPL = decibel sound pressure level; DSP = Digital Signal Processing; EC = ease of communication; HHIE = Hearing handicap inventory for the elderly; HINT = Hearing in Noise Test; HL = Hearing Level; IDT = Interaural Time Difference; ILD = Interaural Level Difference; IOI-HA = International Outcome inventory for hearing aids; MD = Meniere's disorder; NHS = National Health Service; NIHR = National Institute for Health Research; NE = Norman ear; PE = Profound ear; RF = Radio frequency; RTS = Reception thresholds for speech; RV = reverberant condition; SNR = Signal to noise ratio; SSD = Single-Sided Deafness; SSNHL = sudden sensorineural hearing loss; SSQ = Speech Spatial and Quality questionnaire; SLT = Sound localization test;

Abstract

Objectives: To assess the effectiveness of contralateral routing of signal (CROS) hearing systems, bone anchored hearing aids (BAHAs) and cochlear implants for the management of single sided deafness.
Study Design: A literature review of research criteria on case studies assessing SSD by means of subjective quality- of-life questionnaires and objective clinical assessment.
Key Words: Single sided deafness, CROS, BAHA, CI.
Method: A search was carried out for clinical research papers on SSD between 2009 and 2015. 46 research papers were found in total. The literature review was narrowed further to considered 13 papers assessing the three management strategies.
Results: Patients with SSD experience significant difficulty with localization of sound and have considerable difficulty with clarity of speech in background noise (BGN). This has a negative effect on their social and secular lives. Self-reported subjective benefit is reported to be significant to the patient even in studies where clinical objective measures show little to no benefit. In view of the wide variety of outcome measures used comparisons between studies is difficult.
Conclusion: All three fitting strategies have been used successfully to provide some degree of benefit to SSD patients. Further clinical research needs to be done to objectively quantify the effectiveness of intervention. Continuity of quality-of-life questionnaires and outcome measures used would make comparative analysis between studies more achievable. Clinicians need to be aware of the current management strategies used for SSD, assess patients on a case by case basis and provide best possible advice regarding suitability then facilitate referral.

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Introduction

Single-sided deafness (SSD) is defined as a severe-to-profound sensorineural hearing loss with hearing thresholds >70dB at 500Hz, 1kHz, 2kHz and 3kHz in one ear and essentially normal hearing thresholds in the contralateral ear. Prevalence is estimated to be 3-6% of the population and affects an estimated 7500 new individuals annually in the United Kingdom (Martin 2010) and 60 000 in the USA (Weaver, 2015).

Congenital SSD occurs at a ratio of 1:3700 in new-borns and between 0.2% - 0.5% in children and teenagers (Giardina, 2014). Of the acquired SSD aetiologies, idiopathic sudden sensorineural hearing loss (SSNHL) is the most common. Other causes include vestibular schwannomas, direct trauma temporal bone fracture, intractable Meniere's disease, unilateral noise damage and ototoxic drug exposure (Ryu et al., 2015; Giardina, 2014; Kitterick, 2014).

Patients with SSD commonly report significant difficulty with localization of sound and lack of clarity of speech in back ground noise (BGN). With self-reported subjective handicap measurements pre-intervention, research suggests patients with SSD rate clarity of conversation in BGN as their most significant difficulty. In terms of degree of difficulty, in one such assessment of 53 post-operative acoustic neuroma (AN) patients, 83% reported a moderate to severe hearing handicap in every-day life (Desmet, 2012). This is consistent with a similar study of 59 postoperative AN patients where 80% reported a significant hearing handicap (Schroder, 2010). Such pre-intervention analysis is invaluable in determining the patient's perception of their handicap as well as setting a bench mark for outcome measures to assess degree of improvement following intervention.

A considerable hearing difficulty can have a debilitating impact on social and secular interaction. The frustration and embarrassment of mishearing can lead to exclusion, withdrawal and subsequent social isolation. According to a report published by the Advisory Group for Single Sided Deafness, 24% of sufferers gave up work as a result of their SSD (Dimmelow, 2003). Similarly, a study of 447 SSD patients reported 39% found work more difficult in view of their hearing loss, 45% were afraid of offending people by mishearing and 25% were forced to stop working because of hearing difficulties (Taylor, 2010).

Age of onset and the length of time SSD has existed prior to treatment may influence the outcome of any intervention. Previous studies suggest reorganisation of auditory and language pathways occur within weeks of onset. If left untreated, the cortical changes occurring with neural plasticity can negatively affect hearing performance and the rehabilitation to corrective amplification (Ryu et al., 2015). Current treatment options are Contralateral Routing of Signal (CROS) hearing aids, Bone Anchored Hearing Aids (BAHA) and Cochlear Implants (CI). Management strategies for SSD need to address the commonly reported difficulties of poor sound localization and address the lack of clarity of speech in noise.

Localization

In order to correctly identify the location of unseen sound sources, we rely heavily on a fully functional binaural auditory pathway to supplement information obtained from visual cues. With SSD, the lost ability to process sound binaurally creates a number of hearing difficulties. Binaural cues of interaural time and intensity that facilitate localization are distorted or absent. Sounds originating from the direction of the impaired ear are attenuated when arriving at the non-impaired ear (Kitterick, 2015). Directional interactions of soundwaves with the pinna, head and torso, provide unique cues that are used for the localization of sounds in the vertical plane.

Horizontal sound localization is based on the processing of binaural acoustic differences, in interaural time differences(ITDs) and interaural level differences (ILDs). Because the binaural sound-localization cues are absent in listeners with SSD, localization of sound is heavily impaired (Agterberg, 2014).

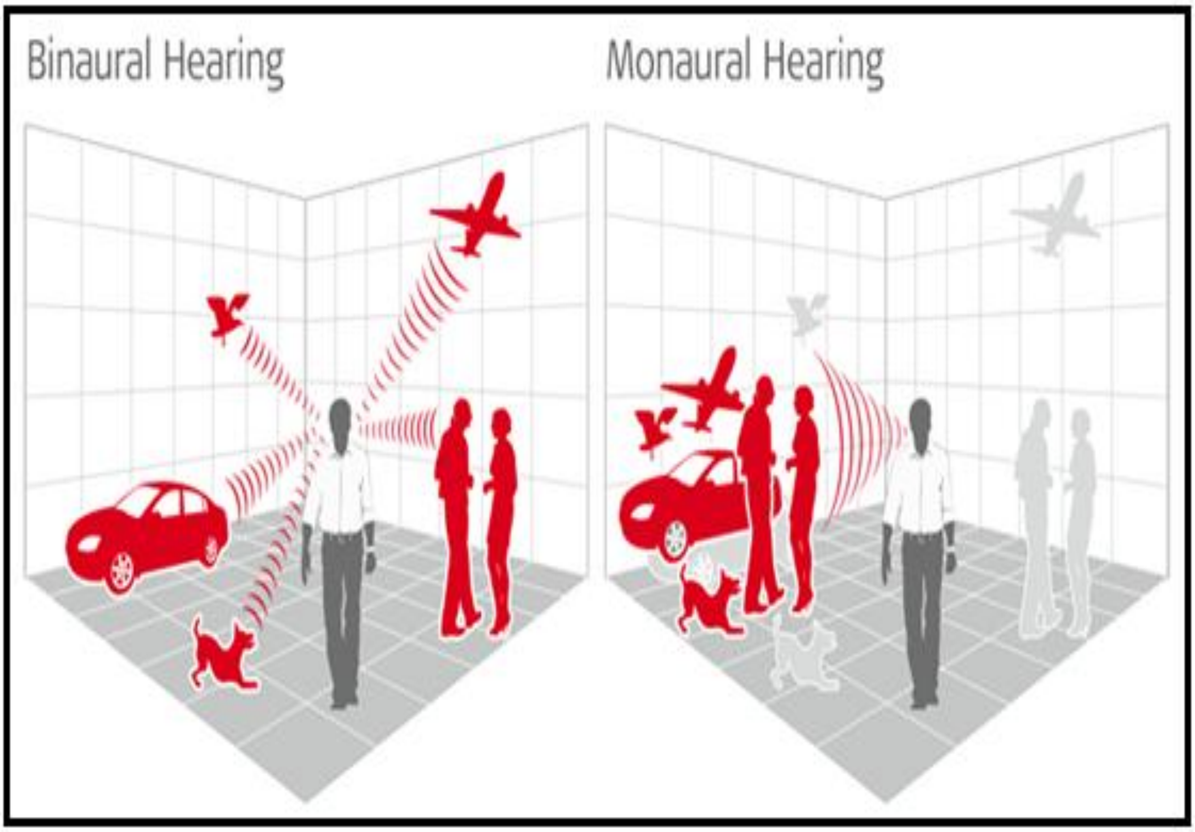

Fig 1. Binaural verses Monaural Hearing and Localisation of Sound (Medel.com)

Speech in Noise

Clarity of speech in noise is a challenge for SSD patients in view of the lost binaural functions of loudness summation, binaural squelch and the head shadow effect.

Binaural Loudness Summation

It is recognized that binaural hearing is beneficial to loudness and that sound presented to both ears is perceived as being louder than the same signal presented to a single ear. This psychophysical effect is termed *binaural loudness summation*. It amounts to approximately +6dB at 50dB HL. SSD will result in the loss of this natural sound perception enhancement (Staab, 2015).

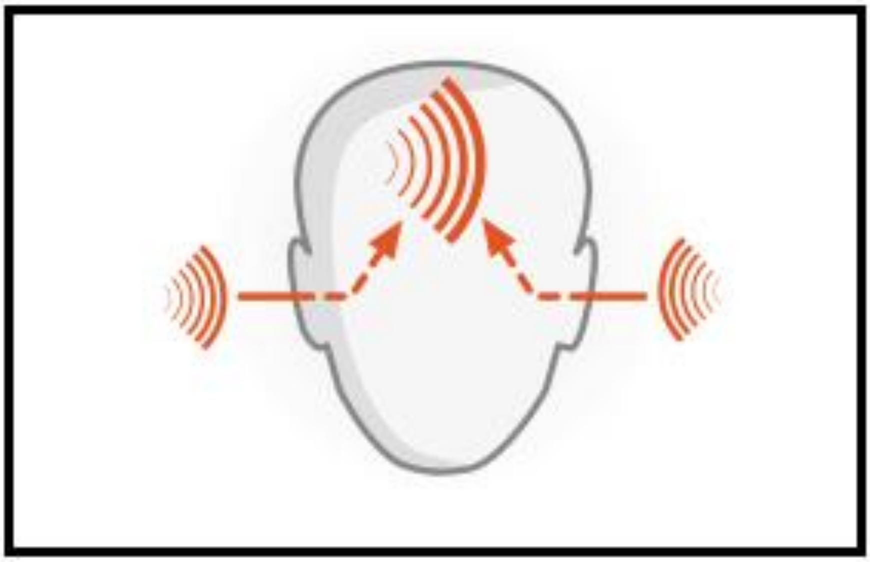

Fig 2. Binaural Loudness Summation (Medel.com)

Binaural Squelch

Binaural squelch is the difference in performance between monaural listening of the ear with the better signal to noise ratio (SNR), and binaural hearing in the condition where the speech and noise are presented on opposite sides. Spatial separation of both ears leads to improved intelligibility and signal identification by taking advantage of differences between the competing signals to the ears. It is the brain stem nuclei’s ability to compare differences in time-of-arrival, amplitude, phase and integrate the different signals being received at each ear. Sounds are integrated separated and prioritized. For this effect to take place, neural integration from both auditory pathways is required.

Intra-aural phase and intensity relationships differ for speech and noise. The central nervous system uses these differences to suppress environmental sounds and improve speech intelligibility. This is because speech and noise are received differently at the two ears enhancing the signal and reducing the noise. With SSD the binaural squelch effect will be redundant.

The practical implication of the difference between monaural and binaural listening is as follows: With monaural hearing, when the listening ear is unfavourably situated, the listener is confronted with much greater masking from background noise. The handicap is reversed when the good ear is toward the primary signal and the bad ear is toward the noise (Staab, 2015).

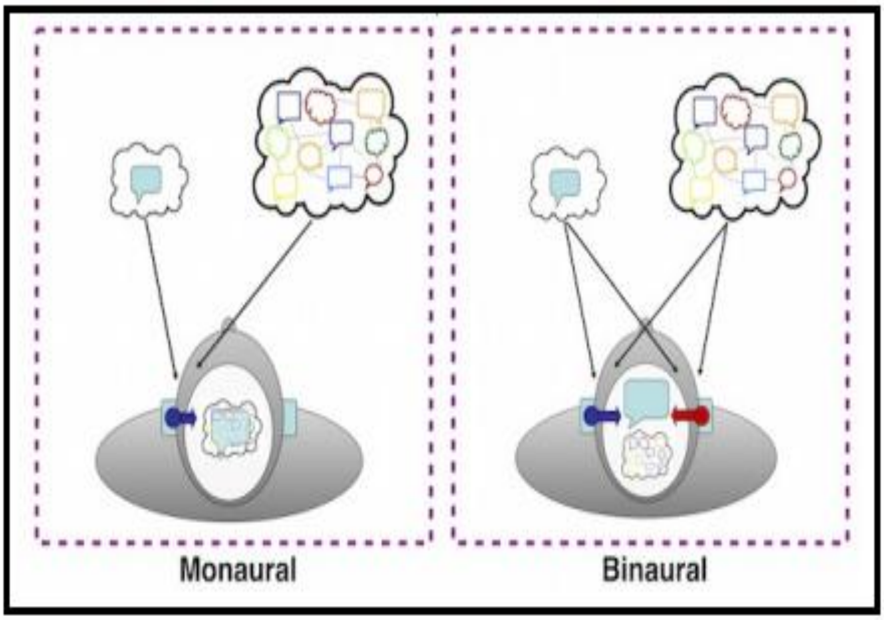

Fig 3. Binaural Loudness Squelch (Staab 2015)

Head Shadow Effect

The head-shadow effect is an acoustic phenomenon whereby speech and competing noise are spatially separated. The SNR at each ear are essentially different due to the filtering of sound by the physical characteristics of the head. The listener can focus on the more favourable SNR to maximise speech intelligibility and sound localization. The head shadow effect does not rely on central auditory processing and produces the most robust effect of binaural listening with improvements of 4-7dB (Balkany, 2013). The average diameter of the head is about 20 centimeters (cms). The wavelength of a 1 kHz tone in air is about 30 cms.

For signals with wavelengths longer than the head diameter, the signal bends around the head and the sound pressure levels at the two ears differ by less than 5dB. At high frequencies, the shadow effect can be as much as 15 dB (Clark, 2000). For pure tones, perceived lateral displacement is proportional to the phase difference of the received sound at the two ears.

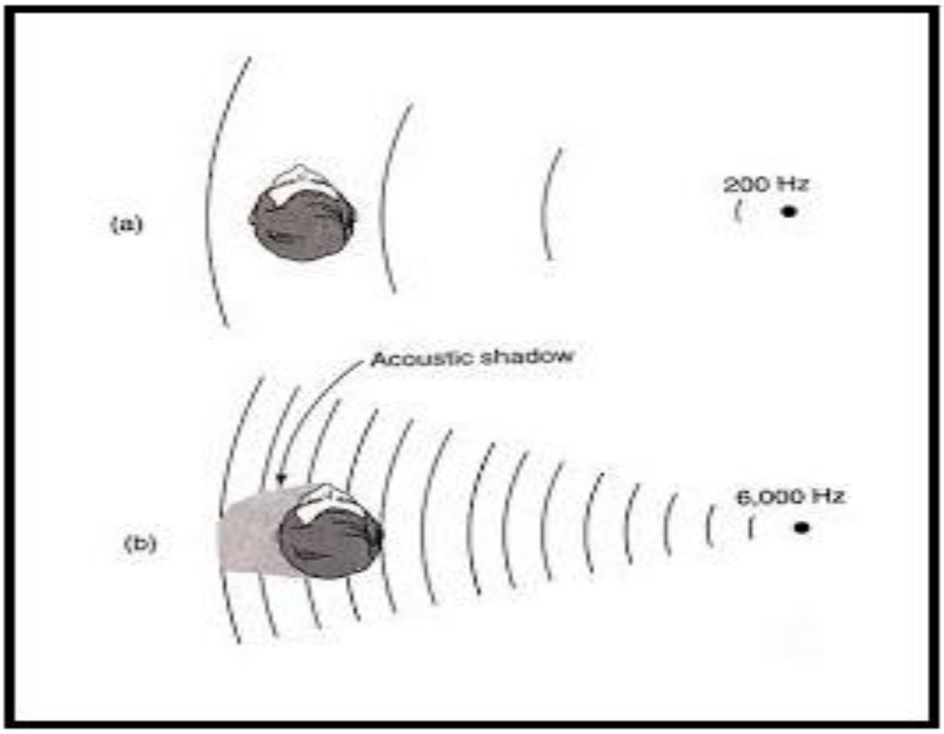

Fig 4. Head Shadow Effect – High vs Low Frequency Wavelength (nasimclinic.com)

However, at approximately 1500Hz, the wavelength of a tone becomes comparable to the diameter of the head, and ITD cues for azimuth become ambiguous. At frequencies above 1500Hz, the head starts to shadow the ear further away from the sound, so that less energy arrives at the shadowed ear than at the non-shadowed ear. The difference in amplitudes at the ears is the ILD and has been shown to be perceptually important to horizontal decoding of frequencies above 1500Hz (Cheng, 1999). With SSD, sounds that originate on the side of the deaf ear are lost to the listener completely.

Low-frequencies with long-wavelengths bend around the head and are often perceived well even though the deaf ear may be turned in the direction of the sound. High-frequencies with short-wavelengths do not bend around to the side of the good ear. Thus many high-frequency sounds are lost to a person with SSD.

Consonant sounds in speech above 1kHz can often be missed and clarity of conversation is compromised (Clason, 2014). Since complex listening environments present combinations of sounds across the frequency range, processing speech sounds and separating speech from unwanted noise is significantly harder with SSD. This attenuation, or head shadow effect, caused by the diffraction of sound waves as they travel around the head, can compromise speech intelligibility in more challenging listening environments (Kitterick, 2015). Patients with SSD have up to 13dB signal-to-noise ratio deficit when compared with normal-hearing individuals in the same listening environment (Taylor, 2010).

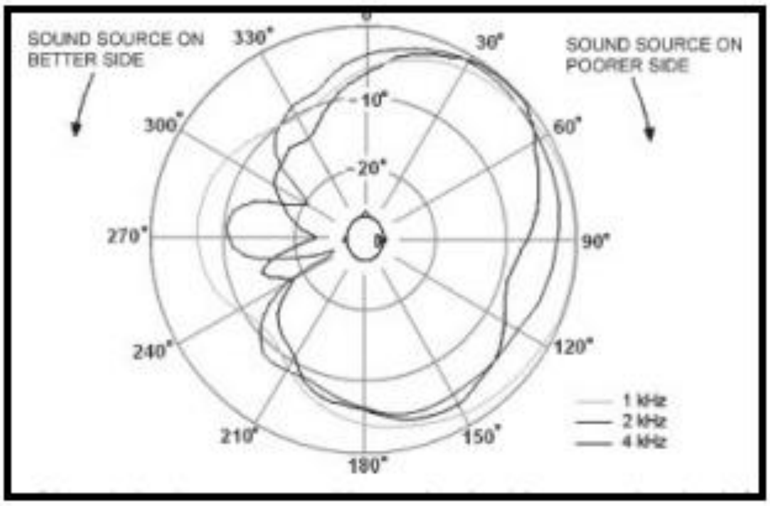

Fig 5. Polar plot Head shadow effect 1000, 2000, 4000Hz (Taylor 2010)

The aim of the literature review was to assess CROS systems, BAHAs and CIs as management strategies for SSD and to determine the clinical effectiveness of intervention. Does the evidence presented in the literature provide a basis for statistical comparison of one intervention against another? Can the effectiveness of these management strategies be verified by clinical assessment? Could the date be correlated and compared as suggested in Figure 7?

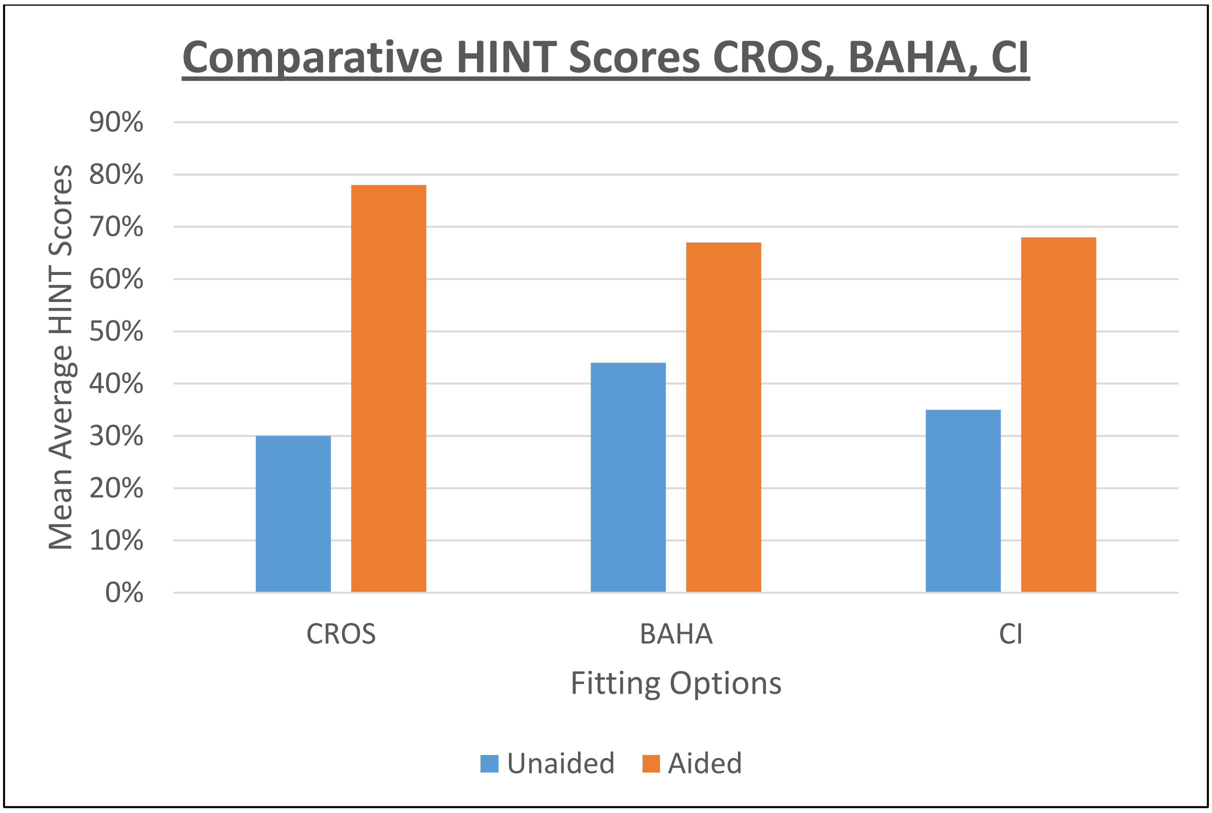

Fig 6. Hypothetical graph of comparative benefits of CROS, BAHA, & CIs

Search Strategy

A search was carried out on clinical evaluations related to SSD between 2009 and 2016. The key search criteria included SSD; CROS systems; BAHAs; CIs; management strategies and outcome measures. A total of forty-six articles were identified. Studies were excluded if there was unclear recording of data or missing data. Further exclusions were made for case studies where the study sample was too small. The final number of articles used for review was thirteen.

Overview of CROS BAHA & CI Fitting Strategies for SSD

In view of the significant sensorineural degradation in the affected ear, conventional hearing aids are ineffective in treating SSD. With an understanding of the challenges presented with SSD, we can consider hearing aid intervention and make comparisons of their effectiveness. Three management strategies are considered here-CROS systems, BAHA and CI.

Contralateral Routing of Signal (CROS)

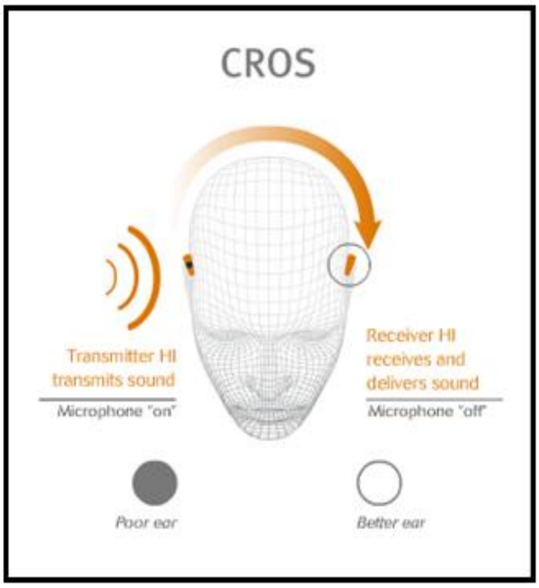

Fig 7. CROS system (audiohealth.com)

A modern CROS system comprises of hearing aids situated near both the impaired and the normal ear. The two aids are linked wirelessly and communicate with each other.

Reference directional microphones are worn in the impaired ear and they transmit collated sounds to the aid worn in the better ear.

Out of the three treatment options, CROS systems are the cheapest and the only non-surgical option and therefore realistically used as the first management strategy for SSD (Rhu et al., 2015).

Bone Anchored Hearing Aid (BAHA)

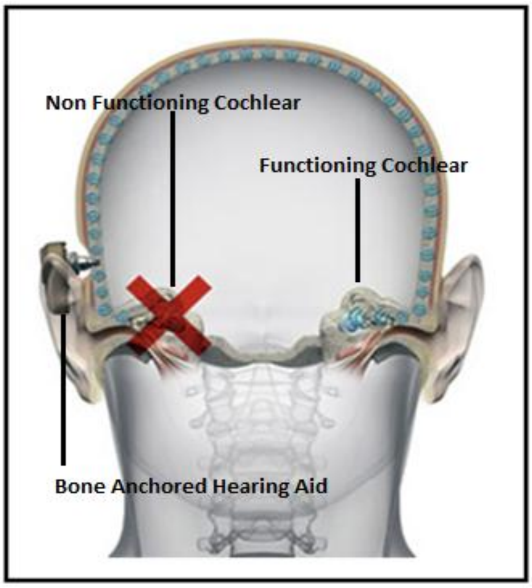

Fig 8. BAHA;Signal Routing (surgery.arizona.edu)

A BAHA is an osseointegrated implanted device surgically attached to the mastoid bone with a titanium screw. The unit consists of a microphone, amplifier and receiver that transmits sound collated from the side of the non-functioning cochlear to the functioning cochlear via bone conduction.

The titanium screw is surgically attached to the skull and is a permanent fixture. The BAHA itself can be attached and removed. An alternative fitting option is a subcutaneous plate and magnetic BAHA.

With this fitting option there is a loss of approximately 10dB in view of the transcutaneous sound delivery. The BAHA has been an effective means of sound delivery to the unaffected ear and it has been increasingly used as a management strategy for SSD patients.

Cochlear Implant (CI)

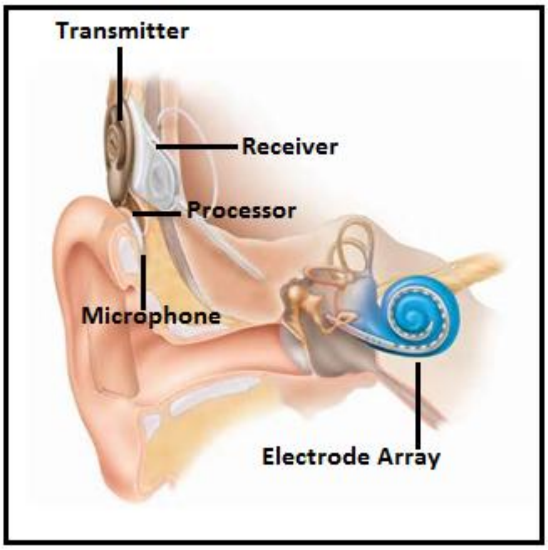

Fig 9. Cochlear Implant – (Drpaulose.com)

A cochlear implant is a small surgically implanted electronic device that provides stimulation directly to the auditory nerve. The implant consists of an external portion resembling a conventional behind the ear (BTE) hearing aid that sits behind the ear and a second portion that is surgically placed under the skin.

The collated sound picked up by the external microphone is processed and transduced into electrical impulses by the implant and delivered directly into the cochlear via the electrode array (NIDCD, 2014).

Clinical Evaluation of CROS systems

Since their first appearance in the 1960s CROS systems have been used to treat SSD (Harford, 1965). Bilateral Contralateral Routing of Signal (BiCROS) are used for a severe to profound sensorineural hearing loss in one ear and a loss in the contralateral ear that can be corrected by conventional amplification. The sound is collated from the poorer ear and directed to the better ear along with corrective amplification according to the loss in the better ear. Manufacturers have developed wireless, discrete, light-weight aesthetically pleasing fitting options that can provide effective routing of collated sound from the poor ear to the normal ear.

All Current CROS systems use Radio Frequency (RF) transmission that have limitations in range. If the distance between the two hearing aids is greater than six-and-a-half inches, the sound quality is negatively affected. For every half inch additional distance, there can be as much as a 4dB decrease in gain. CROS devices are also prone to electromagnetic interference and can generate an audible humming or buzzing sound when in proximity to certain electrical devices. Variance in acceptance rates for CROS fittings is reported to be between 50% and 77.5%. Successful fittings have been linked to high levels of motivation by the user (Valente, 2006; Taylor 2010).

A clinical evaluation assessed the effectiveness of CROS systems fitted to twenty-one SSD patients (8 <40 years and 13>40 years). Three subjective satisfaction questionnaires were used: the Hearing Handicap Inventory for the Elderly (HHIE) (Weinstein, 1986); the International Outcome Inventory for Hearing Aids (IOI-HA) (Cox, 2003) and the Speech Spatial and Quality (SSQ) questionnaire (Gatehouse, 2004).
The objective measures used were the Sound Localization Test (SLT) and the Hearing In Noise Test (HINT) (Nilsson, 1994). The patients were assessed pre-fitting, and again at two and four weeks post-fitting. All patients reported improvements with emotional, situational and total scores with HHIE, SSQ and IOI-HA.

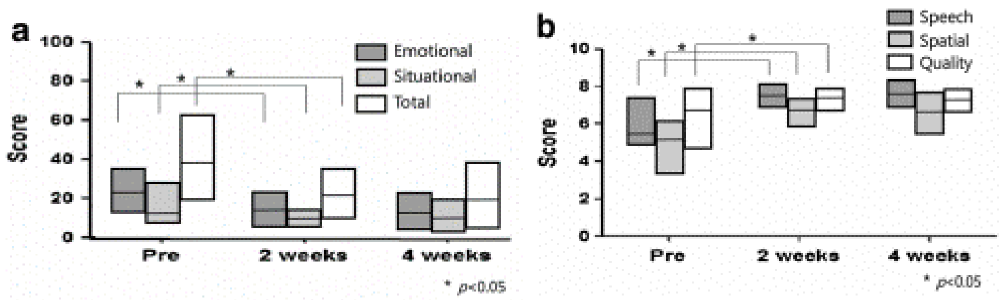

Fig 10. Results (a) HHIE (b) SSQ (Ryu 2015).

For the HINT assessment, each patient was tested in a free-field environment with eight speakers placed from 0 degrees to 360-degree azimuth. Stimulation sound was generated at 0, 90 and 270 degrees' azimuth during the HINT test - six speakers separated by 45 degrees (with the exception of 0 and 180 degrees) during the SLT.

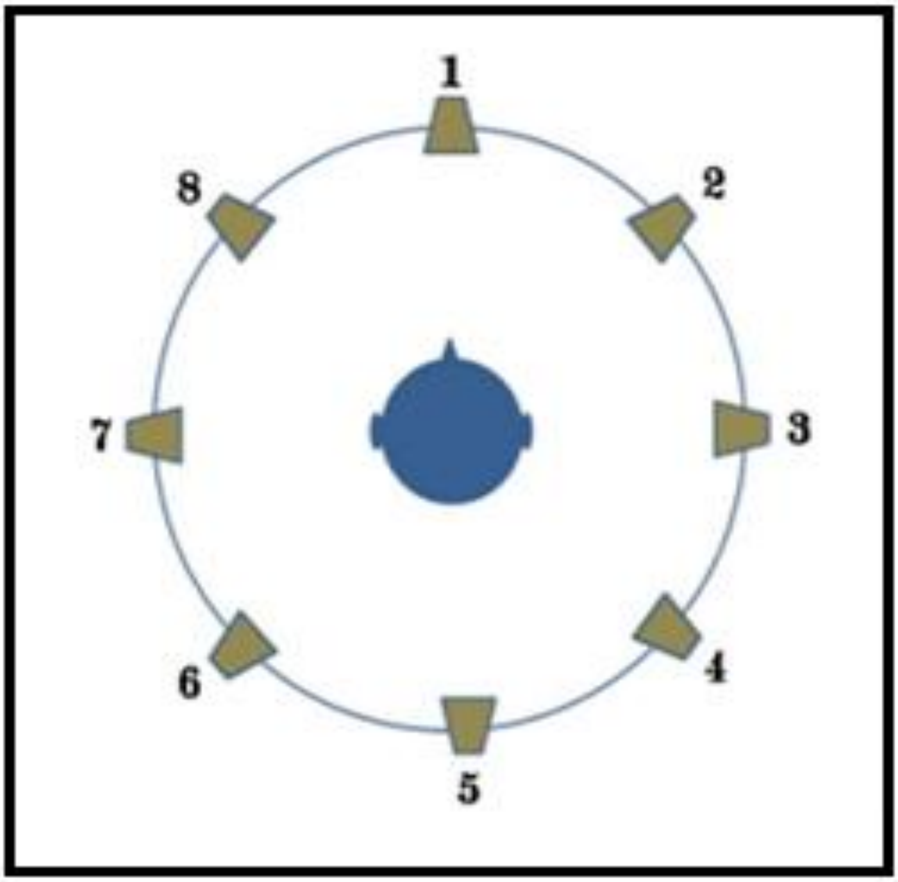

Fig 11. Speaker placement for HINT and SLT (Ryu 2015)

The results of the HINT reflected significant improvement with reception thresholds for speech (RTS) in quiet. No significant benefit was recorded when noise was presented from the front. However, the signal to noise ratio (SNR) significantly improved when nose was presented from the normal ear (contralateral noise). There were improvements in both groups with SLT results after two and four weeks. The younger group showed significant improvement with localization hit rate and error degree (Ryu et al., 2015).

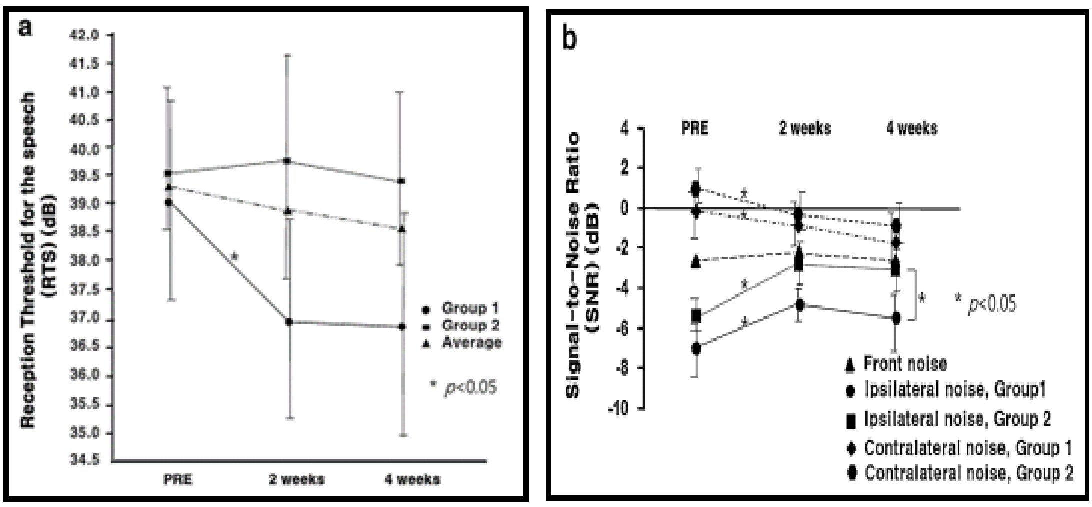

Fig 12. (a) HINT results for quiet test environment (b) HINT results for noisy condition – noise from front, ipsilateral and contralateral side (Ryu 2015)

A similar study of twenty-one patients using CROS systems used the APHAB questionnaire for the subjective assessment and HINT for the objective measure. According to the APHAB, the perceived benefit in the aided condition was rated between 32.4% and 40.7% by the patients, yet the HINT revealed no significant difference between the aided and unaided condition. The study concluded that directional microphones and an independent volume control may further improve patient satisfaction and improve clarity of conversation in BGN.

There is a high degree of variance regarding effectiveness of CROS fittings. In view of the fact that CROS systems remain the only non-surgical management option for SSD, it should be considered as a first treatment protocol. Patients that show little to no benefit from CROS aids can be referred to implant centres for further assessment for BAHAs or CIs. A patient that cannot benefit from conventional hearing aids may be considered for implantation and a hearing aid trial is currently a pre-requisite for consideration.

Clinical Evaluation of BAHAs

BAHAs have been used to treat SSD since the mid-1990s. Several clinical evaluations have been conducted and reports on effectiveness vary. A case study assessed 58 SSD patients with BAHAs. The Glasgow Benefit Inventory (GBI) (Gatehouse, 1999) and SSQ subjective assessments was used and the results suggested a slight improvement with clarity of speech in quiet and small groups. However, little to no benefit in BGN. (Martin 2010).

Conversely, 36 SSD patients were assessed in another study that reported improved performance for speech in noise but no improvement with localization of sound. Patients were assessed with GBI, Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox, 1995) and the Entific Medical System Questionnaire (EMSQ) (Dutt, 2002). These subjective measures and the test battery included a simplified speech in noise test.

The manner of the free field testing assessed both the issues of localization and speech in noise. Patients were placed in a free field environment in the middle of an array of speakers. For the speech in noise assessment, a 65dB SPL white noise was presented at 0-degree azimuth and speech presented at 90-degrees to the poorer ear at intensities between 60 and 75dB.For the localization test, short bursts of white noise stimuli were presented in a random pattern through the speaker array (similar to the array layout in Figure 10). Hit scores reported for correct and incorrect identification of the sound source.

The clinical evidence suggested an eleven percent improvement when comparing aided and unaided thresholds for speech in noise testing. However, no improvement in the sound localization test was indicated. The review concluded that BAHAs were a successful management strategy for SSD offering improvements for clarity of speech in noise. Self-reported questionnaires completed pre-fitting and post-fitting, suggested the subjective benefits of BAHA to be significant (Nicolus, 2012).

An earlier study of twenty-one SSD patients used APHAB and GHABP as the subjective assessment and the HINT to objectively assess speech discrimination. The APHAB assessment of perceived improvements in ease of communication (EC), reverberant conditions (RV) background noise (BN) and aversiveness to sound (AV) reflected mean average improvements of 16.2%, 18.2%, 26.4% and 9.5% respectively. The GHABP results also suggested significant improvement in the aided condition and the HINT results showed an improvement of 5.5dB SPL with the signal to noise ratio (SNR) in the aided condition (Yeun, 2009).

A thorough review of twenty-one BAHA patients was carried out assessing speech discrimination objectively with CNC, HINT and NU-6 (North-western University Test No.6) (Wilson, 1976) and subjectively with GBI. There were significant improvements in all domains. The results recorded the mean average improvement in the aided condition to be: CNC 43.2%, HINT 44.5%, NU-6 31.5%. The subjective benefits recorded with GBI were high with 91% of the patients happy to recommend the BAHA fitting for SSD (Wazen, 2010).

It is noteworthy to mention that all BAHAs fitted prior to 2013 are analogue. Digital BAHAs have been fitted since 2013 and the Digital Signal Processing (DSP) can offer additional features promising to offer greater benefits for directionality with directional microphones and improved localization. To my knowledge, there are no current published studies that have clinically assessed the effectiveness of the new technology platforms or new features and benefits of DSP, directional microphones or assistive devices.

There are also additional accessories offering direct streaming of television and telephone and remote microphones to help to address the signal to noise ratio in back ground noise. Remote controls offer further regulation of volume and directionality of microphones for specific listening environments. Clinical evaluation is yet to address the functional benefits and quantify the improvements of localization and clarity of digital BAHAs and assistive devices. Thus, further studies are needed to address this. When comparing the vast improvements achieved in modern technology with conventional digital hearing aids, it would be realistic to expect improved performance with digital BAHAs.

One question we may consider is: Why is it that self-reported quality-of-life questionnaires indicate that patients experience greater benefit than the clinical evidence obtained? A review of current clinical assessments will be considered in the *'Clinical Evaluation: Challenges with Validation and Comparison*' section of this review.

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Clinical Evaluation of CROS verses BAHAs

Very few studies have evaluated clinical effectiveness of CROS systems verses BAHAs. One study assessed ten patients with the two devices by means of an eight-week trial of each device. The patients were asked to complete three subjective benefit questionnaires APHAB, SSQ and SSD. They were further evaluated objectively with a sound localization test and a speech in noise test. The sound localization test was performed with a 9-speaker array at 30 degree intervals. The speech in noise test consisted of spectrally shaped noise presented in front of the patient. 'Short everyday sentences' were presented to the profound ear (PE) and the normal ear (NE).

The lateralization test showed no improvement with either the CROS or BAHA system. For the speech in noise test, the CROS system showed slight improvement when speech was presented to the NE. However, no improvement was recognized when presented to the PE. The study does not specify which sentences were used for the speech in noise test. The results from the subjective self-reported questionnaires shows the highest satisfaction scores to be with the BAHA. The pilot study has limited benefit and is restricted by the small study sample. In its discussion section, the author acknowledges this and suggests that a more robust study sample would prove to be more beneficial therefore offering more conclusive evidence.

During the 8-week trial the patients would have had sufficient time to use each device in their normal day to day areas of difficulty. From the response on the questionnaires, it suggests the patients found overall more consistent performance with the BAHA. The trial of using a BAHA on a headband results in a loss of 10 dB of gain in view of the sound delivery (transcutaneous verses percutaneous).

The clinical assessment design may benefit from using the HINT or at least provide clarification on the sentence structure used for the basis of their assessments. There is a need for further clinical evaluation to validate and quantify the differences in performance of CROS systems and BAHAs (Hol, 2010).

Clinical Evaluation of Cis

CIs are a relatively new treatment for SSD. The first UK study on the effectiveness of CIs as a management strategy for SSD is currently being carried out by the Nottingham Hearing Biomedical Research Unit of the National Institute for Health Research (NIHR) by Pádraig Kitterick. The results are yet to be published. The study is registered with ISRCTN Registry (International Standard Registered Clinical/soCial sTudy Number) and the registration states that the proposed number of patients to be used is ten (ISRCTN, 2015). Given the variables expected with individual performances related to rehabilitation to CIs, a larger study sample would provide a more robust platform for analysis (Kitterick, 2014).

A similar controlled trial in the recruitment faze in the Netherlands will evaluate one hundred-and-twenty SSD patients after cochlear implantation. It aims to assess CROS systems, BAHAs and CIs as a management strategy for SSD. The study will use several self-reported quality-of-life questionnaires: SSQ, APHAB, GBI. Objective assessments will assess speech in noise and localization. A larger study sample of this nature is likely to provide more conclusive data for analysis purposes (Peters, 2015).

One published study assessed twenty-six CI patients with SSD using CNC and AzBio (Spahr, 2012) sentences with pre-operative and post-operative evaluation over a twelve-month period. The study included ten patients with Meniere's disorder (MD) that had been implanted following a labyrinthectomy. The labyrinthectomy is the destruction of the vestibular system to prevent transmission of sensory information to the brain to eradicate chronic vertigo (VDA, 2015).

The CI has been used to successfully treat the resultant sensorineural hearing loss, tinnitus and vertigo. The electrical stimulation with the CI helps to restore auditory perception to the affected ear. Pre-operative assessments were CNC, Azbio sentences and a sound localization test. The sound localization test was performed using an eight speaker array on a 180-degree arc. There was a high degree of variation amongst the test subjects. Despite this, the mean average CNC word scores reflected an overall improvement of 28% and 40% improvement with AzBio sentence recognition. Most, but not all improved with sound localization.

All of the Meniere's labyrinthectomy patients reported complete resolution of their vertigo and most patients experienced relief from tinnitus while the CI was turned on (Hansen, 2013).
There seems to be a high degree of variance in performance with CI candidates and studies that use smaller numbers of test subjects report higher variance. One such study assessed 9 CI candidates by means of sound localization testing and speech testing using AzBio sentences.

The results from the study were so varied that no statistical analysis could be made. The sound localization results were generally very poor and speech discrimination scores so varied that statistical analysis revealed no concrete evidence of benefit. There was no quality-of-life subjective assessment carried out. The study concluded that further research needs to be done to verify clinical data and to address the variance in individual performance (Zeitler, 2015).

Discussion: Clinical Evaluation- Challenges with Validation and Comparison

In clinical evaluation of management strategies, self-reported questionnaires and outcome measures are essential in establishing an index or starting point with which to compare the effectiveness of intervention. There is however excessive diversity in clinical evaluation. This makes comparison of one clinical trial against the other difficult or impossible. Over the last fifty years there have been no less than one- hundred-and-thirty-nine self-reported hearing-specific questionnaires. Of these, one-hundred-and-eleven were primary questionnaires and twenty-eight were variations of the original.

In total, there were three-thousand-six-hundred-and-eighteen questions across all the primary questionnaires. The median number of items per questionnaire was twenty; the maximum was one-hundred-and-fifty-eight (Akeroyd, 2015). The clinical studies all identify the fundamental issues with SSD as being difficulties with localization of sound and lack of clarity of speech in background noise. Butt are the clinical tests currently being used adequately to quantify the handicap or effectiveness of intervention?

Sound Localization Test

The sound localization tests vary in arrangement; number of speakers used; intensity levels; test procedure; tone presentation; recording of sample rate and subject matter. It would appear that the end result is a clinical assessment that does not relate to 'real world' listening or correlate with other clinical assessments in view of diversity.

If a benchmark could be set for an agreed speaker array; sound presentation and recording of data, more accurate comparisons between studies could be possible. It would also be more accurate in quantifying the handicap and success of intervention.

Speech in Noise Testing

The speech in noise assessments again have variation in presentation; test procedure; masking levels; masking noise; word lists; sentences and speaker array. Variations of the HINT test have been used in some of the clinical evaluations. The variations make direct comparison against another study impossible. The unique handicap of speech in noise experienced by SSD patients, may call for the development of clinical speech in noise testing specifically for SSD.

It would seem sensible to use *speech* babble or *cocktail party* masking noise and test patients with sentence presentations, varying the intensity of the background noise, consequently assessing speech signal presented to the PE and NE. This will provide a signal to noise ratio index unique to each patient that could prove useful for device programming purposes.
More importantly, it will also achieve an index with which to use as a comparison against other test subjects in the study as well as provide data for comparison against other clinical studies.

Quality of Life Questionnaires

Some outcome measures such as APHAB, GBI and GHABP relate to hearing loss in a general sense. Comparatively the SSQ questionnaire may be more relevant to SSD clinical evaluation in view of its analysis of speech, spatial and quality assessment. While the clinical assessment reflects little or no improvement in the aided condition following intervention, the quality of life self-reported questionnaires reflect more positive results in everyday life.

In the UK, CROS systems BAHAs and CIs are the management strategies used for treating SSD. It would be beneficial for centres to reach an agreement in protocols for clinical evaluation and use quality-of-life questionnaires and outcome measures that were consistent. This would facilitate the use of collective data in assessing the effectiveness of intervention. There are currently nine versions of the SSQ test that have been developed by the MRC Institute of Hearing Research. According to the institute, SSQ (B) may be the best version to use for SSD evaluation since it was designed for measures of benefit (Jensen, 2009).

Conclusion

CROS systems are the only current non-surgical management strategy for SSD. Patients report positive results with using CROS systems, however results vary considerably. Patients that do not benefit from CROS can be referred to implant centres for evaluation for BAHAs and CIs.

Although significant variance in effectiveness is recorded in clinical evaluation, patient satisfaction is generally high when rating intervention in ‘real world’ scenarios. Advancements in technology with the introduction of digital BAHA and assistive devices, increased patient satisfaction and increased benefit should be realised. Further research is needed to clinically verify and quantify these improvements.

CIs have successfully been fitted to treat SSD. It is the only fitting strategy to offer restoration of speech perception. There is likely to be a growing demand for cochlear implantation for the treatment of SSD. Further clinical evaluations are likely to be conducted in the future. It would be useful to have continuity of self-reported quality of-life-questionnaires and outcome measures to facilitate comparisons and correlations between studies.

Table 1: Literature Review- Comparative Benefits of Contralateral Routing of Signal (CROS) Systems, Bone Anchored Hearing Aids (BAHA) and Cochlear Implants for the management of Single-Sided Deafness.

Management Strategy	Author	Year	No of Test Subjects	Subjective Measurement	Objective Measurement	Conclusion
BAHA	Yuen	2009	21	APHAB and GHBP	HINT	APHAB improvements of 16.2%, 18.2%, 26.4% and 9.5%. Improvement with HINT 5.5dB SPL SNR.
BAHA	Wazen	2010	21	GBI	CNC, HINT, NU-6	Subjective increase in satisfaction GBI. Speech tests: NU-6 31.5%, CNC 43.2%, HINT 44.5%
BAHA & CROS	Hol	2010	10	SSQ, SSDQ, and APHAB	SLT, SRT	Poor Sound localization. Subjective benefit reported. Low acceptance of intervention 30%.
BAHA	Martin	2010	58	GBI and SSQ	BKB (in noise)	Slight improvement with BKB in noise Subjective benefit of 78% with GBI
BAHA	Schroder	2010	21	VAS	-	Subjective increase in satisfaction, however low uptake of BAHA 20%.
BAHA	Pai	2012	25	SSQ	-	Overall subjective improvement in satisfaction however considerable variation between patients.
CI	Firszt	2012	3	SSQ	CNC, HINT	High subjective satisfaction, Increased speech perception and speech in noise performance.
BAHA	Nicolus	2012	20	EMSQ, GBI and APHAB	-	No improvement with sound localization. Subjective high level of satisfaction 73% APHAB, GBI.
BAHA	Granthem	2012	7	-	SLT	No significant benefit aided/unaided for localization. No quality of life questionnaire used.
CI	Hensen	2013	26	-	CNC, AzBio sentences	28% improvement in CNC speech scores post fitting. 40% improvement on AzBio sentence scores.
CROS	Oeding	2013	21	APHAB,	HINT	No significant improvement with HINT aided/unaided. APHAB showed significant benefit from aided condition.
CI	Zietler	2015	9	-	AzBio	Poor Sound localization, no conclusive evidence of improvement with speech regognition.
CROS	Ryu	2015	21	HHIE, IOI-HA and SSQ	SLT and HINT	Subjective increase in satisfaction. Improvements with sound localization and improvements in BGN.

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