Critical Review: Comparison of contralateral routing of signal (CROS) hearing aids with bone-anchored implantable hearing devices (BAHAs) in adults with single-sided deafness

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The purpose of this critical review is to compare the subjective and objective rehabilitative benefit of contralateral routing of signal (CROS) hearing aids with bone-anchored implantable hearing devices (BAHAs) in adults with single-sided deafness. Study designs include: single group with repeated measures (5), meta-analysis (1), and systematic review (1). Overall, the current literature provides suggestive evidence to support greater subjective and objective benefit of BAHAs over CROS hearing aids, though there is a need for future research to address methodological shortcomings and device limitations. Clinicians are therefore advised to proceed with caution when forming intervention recommendations for BAHAs in adults with single-sided deafness.

Introduction

In individuals with acquired single-sided deafness (SSD), a myriad of unique and specific listening challenges and hearing disabilities are faced (Bishop & Eby, 2009). The most commonly reported difficulties for monaural listeners revolve around hearing sounds presented to the impaired side, sound localization, and speech intelligibility in background noise (Wazen, Spitzer, Ghossaini, Fayad, Niparko, Cox, Brackmann, and Soli, 2003). These difficulties suggest two forms of impairment: loss of hearing sensitivity makes it difficult to hear lateralized sounds, and the lack of binaural processing poses challenges in segregating signals of interest from background (masking) noise (Lin, Bowditch, Anderson, May, Cox, and Niparko, 2006).

The traditional approach to SSD rehabilitation has been with the fitting of contralateral routing of signal (CROS) hearing aid systems. CROS systems transfer sound from a microphone on the deafened ear to an open fit hearing aid on the opposite, normal-hearing ear. The system may be connected either with cables or wireless technology (Dillon, 2001).

Newer approaches have been developed utilizing bone-anchored implantable hearing devices (BAHAs) in an effort to improve localization ability and speech perception in noise while reducing the detrimental head shadow effect experienced in unilateral hearing loss (Hol, Kunst, Snik, & Cremers, 2010). Instead of using traditional air conduction of sound they employ direct mechanical coupling of the vibration transducer to a titanium implant anchored in the temporal bone, thus bypassing the outer and middle ear to stimulate both the normal and impaired cochleae (Hol, Bosman, Snik, Mylanus, and Cremers, 2004).

Due to the fairly recent application of BAHAs as a rehabilitation option in adults with SSD, limited research exists regarding its efficacy in relation to improved speech perception and localization outcomes. Therefore, a critical review of the literature will provide clinicians with an improved understanding of the BAHA technology, its appropriate applications and rehabilitative benefit, and its effect(s) on speech perception in noise and localization ability when compared to the more traditional CROS approach to SSD rehabilitation.

Objectives

The primary objective of this literature review is to critically evaluate the current literature comparing localization ability, speech perception in noise, rehabilitative benefit, and patient satisfaction of CROS and BAHA devices in adults with SSD. A secondary objective is to determine an evidence-based approach in the selection of the most appropriate type of technology to benefit afflicted adults.

Methods

Search Strategy

Computerized databases including CINAHL, SCOPUS, MedLine, PubMed, and Google Scholar were searched using the following search strategy: [(CROS) OR (contralateral routing) OR (contralateral routing of signal) OR (hearing aid, contralateral)] AND [(BAHA) OR (bone-anchored) OR (hearing aid, bone)] AND [(SSD) OR (single-sided) OR (unilateral) OR (deafness)]. The search was limited to the English language and human subjects. Reference lists in the selected papers were also searched for any additional relevant articles.

Selection Criteria

Studies included in this critical review were required to investigate comparisons between the localization ability, speech perception in noise, perceived benefit, and

patient satisfaction of CROS and BAHA devices in adults with SSD. No limits were set on the type of subjective or objective measurements or on the demographics of the research participants (age, gender, race, or socioeconomic status).

Data Collection

A review of the literature yielded seven articles consistent with the selection criteria: single group with repeated measures (5), meta-analysis (1), and systematic review (1). All of these studies provide a grade III level of evidence (Dollaghan, 2007).

Results

Single group with repeated measures #1: Niparko, Cox, and Lustig (2003) compared the effects of a semi-implantable bone conductor with conventional CROS amplification in order to assess rehabilitative benefit in adults with unilateral deafness. This study looked at ten patients with a pure tone average (PTA) >90 dB HL for the affected ear and normal hearing (PTA <25 dB HL) in the opposite ear. Subjects had experienced SSD after: acoustic neuroma excision, sudden idiopathic sensorineural hearing loss (SNHL), and sudden SNHL associated with chronic suppurative otitis media (OM). Average age of the subjects was 45.4 years, with an average SSD experience of 5.2 years. Subjects were assessed one month after fitting the CROS system, at which time BAHA implantation occurred; subjects were then re-assessed one month following BAHA activation.

Subjective measures of rehabilitative benefit included in this study were the Abbreviated Profile of Hearing Aid Benefit (APHAB) and the Glasgow Hearing Aid Benefit Profile (GHABP). APHAB scores demonstrated a highly variable range of reported experience. Mean data revealed little subjective benefit associated with CROS amplification. BAHA scores reached clinical significance for benefit in 3 of the 4 principal listening categories: reverberant conditions, background noise, and ease of communication. A non-clinically significant impact was noted for aversion to loud noise. GHABP data also revealed a variable range of reported experience, with mean scores suggesting greater subjective benefit with BAHA over CROS amplification. The researchers noted that the subject preference for BAHAs over CROS aids may be due to several factors, including unilateral use and no occlusion of the better ear by another device or mold.

Objective measures of benefit used in this study included the Source Azimuth Identification in Noise Test (SAINT) and the Hearing in Noise Test (HINT). SAINT scores employed student t-test statistics for comparisons; data revealed no significant directional hearing in any of the three test conditions (unaided, CROS, or BAHA) and poor sound localization. HINT scores were also calculated using a student t-test: BAHA amplification showed an advantage over CROS in speech performance for all five test conditions, with significance in three of the five (quiet, noise front, composite noise score).

The article concludes that while sound localization is not achieved there is strong subjective and objective benefit in the use of BAHAs over CROS amplification in subjects with SSD. However, several limitations regarding the research exist. No technical details regarding the CROS or BAHA fitting were provided; results are thus not replicable and the fitting protocol and techniques not available for scrutiny. Additionally, all patients included in the study had to have had an unsuccessful CROS trial, though the number of patients with a successful CROS trial was not stated. An additional bias exists in the lack of a randomized crossover design, with the BAHA always being applied last after a rejected CROS trial. Furthermore, a confound exists in the participant selection: all subjects had to have previously rejected the CROS aid, and SSD experience ranged widely from 0.5 to 27 years. Lastly, with only 10 subjects the study was underpowered given the limited number of participants. As such, the conclusions drawn by the authors is suggestive rather than compelling, with some appraisal points open to debate but with overall valid and important evidence lending support to the rehabilitative advantage of BAHA over CROS use in adults with SSD.

S*ingle group with repeated measures #2:* In their article Wazen, Spitzer, Ghossaini, Fayad, Niparko, Cox, Brackmann, and Soli (2003) explored the effectiveness of BAHAs in transcranial routing of signals through implantation of the deaf ear. They expanded their subject pool from the 10 in the Niparko et al. (2003) study to 18, with a mean age of 50.61 years. Inclusion criteria were a PTA >90 dB HL and speech discrimination scores <15% in the poorer ear and a PTA <20 dB HL in the good ear. SSD etiologies included: acoustic neuroma excision, failed stapedectomy, chronic OM complications, and sudden SNHL. Prior to implantation patients had to demonstrate a positive response to a BAHA head band test and the ability to clean and maintain the implant site. Subjects were assessed 4-8 weeks after a CROS trial and again 4-8 weeks after BAHA activation following implantation.

HINT performance revealed improvement in speech intelligibility for both the CROS and BAHA aids when compared to the unaided condition, though no reference was made in the article as to how the results were computed. Also, the authors indicate that the number of

subjects varied for this test, though no reason was provided for this discrepancy.

APHAB scores indicated that participants perceived the BAHA as the most beneficial and effective when compared to unaided scores, though again no data for the unaided scores was provided in the article. Scores on the Single Sided Deafness Questionnaire (SSDQ) also indicated greater patient satisfaction and improved quality of life with the BAHA as compared to the CROS system, though participants reported that the device was not helpful in sound localization. Again there is an issue with the reporting of results: the authors state an n=17, though no explanation for the lack of inclusion of data for the final subject is given.

As such, the study conducted by Wazen et al. is suggestive of BAHA benefit over the traditional CROS hearing aid, though results must be interpreted cautiously due to methodological issues and reporting discrepancies. No technical fitting details for either the CROS or BAHA were provided, and three of the patients included in this study had previously been reported in a previous study conducted by Niparko et al. in 2003. Additionally, the lack of a randomized crossover design, the small number of participants, and the short acclimatization periods (4 weeks) given for each test condition must be taken into account when interpreting results and formulating conclusions on the rehabilitative benefit of BAHAs versus CROS aids in adults with SSD.

Single group with repeated measures #3: Hol, Bosman, Snik, Mylanus, and Cremers (2004) evaluated the benefit of a BAHA in 20 patients with SSD. Twenty-one participants were recruited for the study with various SSD etiologies ranging from: acoustic neuroma excision, cerebellopontine angle tumour excision, inflammatory pseudotumour, congenital unilateral deafness, failed stapedectomy surgery, and unilateral Morbus Menières. One participant was excluded during the measurements due to reduced mental abilities. Measurements were completed one month following CROS fitting and BAHA activation respectively to allow for habituation. Inclusion criteria also stated the requirement of an air-bone gap <10 dB for the better ear, though exceptions to this were then made for 4 subjects. Additionally subjects used 2 different types of BAHA processors during the study: the BAHA Compact and the BAHA Classic.

Student's t-tests were applied to the speech perception and localization tests and to compare the mean APHAB scores. Sound localization and lateralization scores were found to be at chance level for all test conditions (unaided, CROS, and BAHA). Speech Perception in Noise Test Revised (SPIN-R) results indicated better speech perception in noise with the BAHA when noise was presented in front with the speech signal on the poorer side, as seen with improvements in the signal-to-noise ratio (SNR). APHAB scores demonstrated a significant improvement for both the CROS and BAHA aids in the background noise and reverberation domains, though significant improvement in the ease of communication domain was only noted for the BAHA.

Hol et al. concluded that while there was no improvement in localization ability, BAHAs were more beneficial than the traditional CROS system in lifting head shadow effects and improving speech perception in noise. However, results must again be interpreted with caution given the methodological and design shortcomings inherent in this study. In addition to a lack of randomized crossover design, small number of participants, and lack of CROS and BAHA fitting details several other confounds also exist. Two of the participants included in this study had extensive long-term experience with CROS amplification, two different BAHA processors were used, and in some instances exceptions in the inclusion criteria were made. As such the accumulated evidence in this study is suggestive of BAHA benefit over CROS aids in the rehabilitation of adults with SSD, though results must be interpreted cautiously.

Single group with repeated measures #4: Hol, Bosman, Snik, Mylanus, and Cremers (2005) evaluated the benefit of a BAHA CROS device in 29 patients with unilateral inner ear deafness in a prospective clinical follow-up study to the one performed in 2004 (described above). An additional 9 subjects were added to the original participant pool (n=21), though inclusion and exclusion criteria remained unchanged. Baseline and post-intervention outcome data were obtained on Dutch versions of the APHAB, GHABP, and the SSDQ. Data were also obtained from the International Outcome Inventory for Hearing Aids (IOI-HA). Mean follow-up duration was 1.3 years; in the case of missing data domains were calculated with a reduced number of overall participants (at most a reduction from n=30 to n=23). Student's t-tests were applied to assess the data and to compare the means of the various domains on the APHAB and GHABP.

Results for sound localization, speech perception in noise, and APHAB/GHABP outcome measures were essentially unchanged from the previous study. After a mean follow-up of 1 year there was a statistically non-significant deterioration in BAHA results when compared to those obtained after 6 weeks of BAHA use. Scores on the IOI-HA indicate better hearing aid fitting outcome with the BAHA; however it should be noted

that IOI-HA norms are based on bilateral adult in-the-ear hearing aid fittings, and as such outcome comparisons are suspect. SSDQ results also indicate increased satisfaction, benefit, aesthetics, and ease of use with the BAHA over the CROS aid, with the majority of participants reporting an increased quality of life and benefit when listening to music and television and when in large groups. All subjects were found to still use the BAHA daily, though reports of usage times varied considerably.

Hol et al. therefore concluded that patients were still satisfied with the BAHA at a 1 year follow-up, as demonstrated by the stability of scores and measures of subjective benefit. Similar to their previous study in 2004, methodological and study design flaws exist: in addition to a lack of crossover design, blinding, device fitting details and a small number of participants, a confound exists in that reasons for the lack of responses to the follow-up assessments ranged from poor health to non-BAHA use and compliance, though no specifics were given as to how many participants were non-compliant or their reasons for BAHA dissatisfaction. As such, while the level of evidence is suggestive of long-term BAHA satisfaction and benefit in adults with SSD results must be interpreted cautiously when formulating rehabilitation interventions.

Meta-Analysis: Baguley, Bird, Humphriss, and Prevost (2006) evaluated the peer-reviewed published evidence for the application of contralateral BAHAs in acquired unilateral sensorineural hearing loss in adults. A MedLine search (1960-2005) was performed using the terms "unilateral" and "hearing loss": 238 abstracts and four prospective controlled trials were identified. Observational and non-peer reviewed studies were also identified and included in the review. The four studies included in the meta-analysis were chosen to maximize participant numbers and to minimize subject overlap. Mean and SD values between the unaided, CROS, and BAHA periods were extracted from the papers; as SDs were not available for one study, the pooled SDs of the other three were used as a proxy. Using the DerSimonian and Laird method to perform random-effects meta-analysis pooled mean values and a 95% confidence interval (CI) were obtained. Heterogeneity between the three studies was also assessed using the chi-squared test.

A pooled mean difference for the four APHAB domains was calculated. Results indicate a BAHA advantage compared to both CROS and unaided conditions; a similar advantage was also found for speech discrimination in noise. Also consistent across the four studies was the finding of no significant difference in auditory localization ability across the three conditions. Results of this analysis must be interpreted with caution, as there were several study design flaws outlined by Baguley et al. (2006) for the four studies. For all conditions there was a bias in patient selection, in addition to ordering issues with the BAHA condition always being tested last. Also, no clear CROS aid fitting protocol was outlined. While Baguley et al. do address several of the methodological shortfalls in the studies included in their meta-analysis, their study also has some inherent limitations: a lack of blinding occurred, in addition to a large amount of subject overlap in all of the studies. Also, none of the studies selected for inclusion in the analysis contained measures of hearing handicap, limiting the generalizability of their results to the wider population of SSD adults who are not bothered by their hearing loss. As such, while there is suggestive evidence of BAHA benefit in adults with SSD the lack of robust evidence limits the generalizability of these results in formulating SSD treatment interventions.

Systematic Review: Bishop and Eby (2009) performed a contemporary literature review on the current status of audiologic rehabilitation for profound unilateral SNHL in adults. A review of the meta-analysis performed by Baguley at al. (2006) and the four inclusion studies was performed. In addition to the limitations listed by Baguley et al., further study design flaws were also identified: the CROS and BAHAs were only trialed for 4-8 weeks in each of the studies, none used a measure of hearing handicap during subject selection, all of the studies were statistically underpowered, and no use of randomized control trials was employed with respect to the order of conditions (unaided, CROS, and BAHA).

The review concludes that although no randomized control trials were employed the collective findings of the studies offer compelling evidence that BAHAs are generally preferred by patients and may offer some enhancement in speech perception in noise over CROS hearing aids. Caution must be taken when interpreting their recommendations, as the methodological and study design flaws of the inclusion studies denote a suggestive rather than compelling level of evidence for BAHA benefit over CROS (Dollaghan, 2007).

Single group with repeated measures #5: In response to the methodological criticisms of previous research outlined by Baguley et al. in their 2006 meta-analysis (mentioned above) Hol, Kunst, Snik, and Cremers (2010) addressed certain study shortcomings in an attempt to quantify the subjective and objective benefit of CROS aids and BAHAs in adults with unilateral SNHL. Ten adult patients were recruited with various SSD etiologies including: congenital unilateral SNHL, acoustic neuroma excision, trauma, meningitis, and

sudden idiopathic SNHL. Average deafness duration was 23 years. A headband BAHA was used, allowing the researchers to randomly order the devices being trialed (CROS, BAHA, and CIC – not to be discussed in this paper), thus addressing one of the main methodological criticisms with previous research. Participants were allowed an eight week acclimatization period per device prior to outcome measurement on sound localization, speech perception in noise, and hearing aid benefit using the SAINT, HINT, and APHAB; additional measures including the SSDQ and the Speech, Spatial, and Qualities questionnaire (SSQ) were also used.

Sound localization performance was found to be at chance level for all test conditions (unaided, CROS, and BAHA). In contrast with previous research, for speech perception in noise findings indicate that the CROS system is most beneficial in situations where noise was presented to the front and the speech signal to the poorer ear when compared to the unaided and BAHA conditions. No explanation for this finding was offered.

Also contrary to previous research findings, scores on the APHAB revealed the greatest amount of improvement in the ease of communication domain with the BAHA, though overall the conventional CROS system had the best scores on the 4 domains of the APHAB. Mean scores on the SSQ indicate the most benefit in spatial hearing, speech perception and quality of sounds in the unaided condition, with less benefit from the BAHA and CROS. Results of the SSDQ indicate that the majority of the participants (n=6) found the BAHA more beneficial for hearing but that the CROS system had slightly better sound quality. However, no mention of significance was made. Following completion of the trial 3 participants opted for the BAHA and 1 for the CROS system; the other 6 declined either device, though no explanations for why participants opted for one device over the other were given.

Hol et al. therefore concluded that most patients experienced some degree of benefit from either the BAHA or CROS aids, and that preference was independent of the trial order. While many of the results are contradictory to those obtained in earlier studies, they would still recommend that all SSD patients be offered at minimum a BAHA trial as a rehabilitative option. However, there exist confounds in this study with respect to participant selection and acclimatization levels: both congenital and acquired SSD participants were included, with SSD experience ranging from 1-56 years. As such clinicians should use caution when formulating rehabilitation recommendations in adults with SSD given the lack of robust, compelling evidence of BAHA benefit over CROS aids.

Discussion

Traditionally unilateral inner ear deafness was not considered to have a large impact on auditory function in daily life and as such did not deem audiological intervention. However, in the mid-1990`s mounting evidence began to emerge indicating a significant audiological handicap experienced by some adults with SSD. Studies found that upwards of 73% of afflicted adults experienced significant audiological handicap as a result of their SSD, as indicated by results of the Hearing Handicap Inventory (HHI) (Newman, Jacobson, Hug, and Sandridge, 1997; Chiossoine-Kerdel, Baguley, Stoddart, and Moffat, 2000).

The conventional use of CROS aids as a rehabilitation approach in adults with SSD has been met with poor user satisfaction and success rates, leading researchers to investigate alternative methods of intervention (Hol et al., 2004). While historically the BAHA has been most widely prescribed for individuals with permanent conductive hearing loss, it has more recently been evaluated as an effective means of audiological rehabilitation in adults with SSD.

Although methodological and reporting flaws existed in many of the studies included in this critical review, the general consensus indicates that: 1) patients do not experience improved localization ability in either the BAHA or CROS conditions; 2) speech perception in noise has a greater improvement with BAHAs when compared to the CROS and unaided conditions; and 3) subjective measures of rehabilitative benefit indicate greater satisfaction, use, and ease of communication under various listening conditions with BAHAs when compared to the CROS and unaided conditions (Baguley et al., 2006).

Conclusions and Clinical Implications

Overall the conclusions drawn in these studies provide suggestive evidence of subjective and objective rehabilitation benefit with BAHAs over CROS aids in adults with SSD. While the BAHA cannot restore binaural hearing or sound localization abilities, findings suggest that it is beneficial in reducing head shadow effect and has been met with greater patient satisfaction and acceptance when compared to CROS aids.

However, further research to address methodological shortfalls and device limitations is needed in order to provide compelling evidence for the improved rehabilitation benefit of BAHAs over CROS aids in

adults with SSD. To date research comparing the two devices generally shares the same fundamental shortcomings, as such making it difficult to view either as a valid standard of care (Bishop and Eby, 2009). There is also a need for further investigation to distinguish between the characteristics of those adults with SSD who opt for a BAHA or CROS trial and those who do not. Lastly, additional research on the possible implementation of directional microphones to improve sound localization, as well as improved surgical precision of the implant site for transcranial stimulation of the contralateral cochlea is also recommended.

Thus, while some studies recommend that all patients with SSD be offered at minimum a BAHA trial (Hol et al., 2010) many other factors must also be taken into account when promoting the use of BAHAs, including age, socioeconomic status, ability to maintain the implant site, surgical candidacy, motivation, and expectations. In the absence of compelling clinical evidence of BAHA benefit over CROS, clinicians are therefore advised to proceed with caution at this time when forming recommendations for rehabilitation intervention with BAHAs in adults with SSD.

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