First-Person Account of Unilateral Deafness Treated with a Cochlear Implant

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Introduction: The Symposium was hosted by the University of Freiburg and we invited one of our recipients to tell his own story about the impact of sudden Single-Sided Deafness and how he is using a cochlear implant to remediate some of the problems he faces. He highlights many important issues including that motivation is essential.

Background: I had a sudden hearing loss on the left side on the 2nd of October 2008. Before that day my left ear was absolutely normal. I know this exactly because I had had a partial hearing loss on the left side three weeks before, which resolved completely, and the audiogram showed 0–10 dB on both sides over the whole frequency range. All subsequent audiograms showed a complete loss on the left side. When tested with more than 120 dB, I felt the vibration, but absolutely no sound.

As there was also a complete loss of the vestibular function (indeed this was more apparent during the first days), I am quite sure that the etiology was a thrombosis in or in a branch of the common cochlear artery (and the minor attack three weeks before had been a TIA).

A therapy with cortisone was established immediately and I had tympanoscopy with local injection of cortisone 10 days later in a University Hospital. I had so far not read about, but I asked if there would be a chance for, a CI in the future in the case of no spontaneous remission. The answer was a strict 'NO' because the brain is not able to fuse the different impression from the CI and the hearing ear, so I would go barmy in this case. The Baha was not mentioned. Therefore I was advised to live with the situation.

And I tried to do so. I could work as before (surprisingly listening to heart-beat through a stethoscope was no problem at all); communication had no relevant limitations and

was even not exhausting. But why was it that I had changed my lifestyle: no pub, no cinema and no music? Therefore I gave away my almost 25 years old high-end electrostatic STAX headphones to my son. I would never use it again! And I tried to cope with the other problems: it is annoying when you hear a sound (e.g. a dog – I fear dogs!) but have absolutely no idea where the barking comes from. And there was tinnitus, more uncomfortable after having been in noisy surroundings and especially when relaxing. It was never ceasing.

But most impairing was an extremely ugly feeling of a 'half sphere' around my right ear, the whole left side being dead. It was the impression of being in a cage, with no chance to get out for the rest of my life. This was by far the worst implication of the disease.

And so I started on my way to search for a key to my cage. Only the vague hope that there may be a key made the situation for me much more comfortable. And I found a very enthusiastic report on SSD and CI from the Military Hospital in Koblenz (in the magazine *Schnecke* – 'Leben mit CI & Hörgerät').

Treatment: On the 1st of July 2009, I received my CI in the University Hospital in Freiburg. The procedure was without any complications and four days later I was home again.

The First Fitting session was in August, and at the end of the first week I was able to understand a slow and clear-spoken text. Hearing voices on the formerly dead left side was a marvelous feeling, and I had a good learning curve in the following months. In the beginning, it was demanding (as if hearing a foreign language) but now it's quite easy, with the exception of some foreign-language proper names. Up to now, I had listened to about 10 audio books and lots of YouTube videos.

According to what I have heard, I initially had expected a computer voice (Mickey Mouse) but it was not so. The voices are not 'full', I think this is because of missing the harmonics (the maximum frequency of the CI is only about 8000 Hz), but otherwise they sound nearly normal. It's easy to identify a dialect, sometimes even to recognize a well-known voice (e.g. politician or singer).

Music was disappointing in the first months (virtually only noise). I was not able to identify any tunes, not even an earworm or catchy tune, probably because of the multi-sound aspect of a studio recording. But then I made an astonishing discovery: singing birds make a nearly natural sound for my CI (as compared with my healthy ear), probably because they are pure single tones. I spent a bit of time to find comparable simple melodies from YouTube; for example, children's songs or popular tunes (like Green-sleeves) played monaurally on a single instrument (piano, electric and acoustic guitar, saxophone are much better than e.g. violin). And it sounds good! And after a short time, I was able to recognize a known melody or an ascending or descending scale – and even the kind of the instrument. Meanwhile I can enjoy a lot of music with my CI, particularly recordings with a singer and only a few accompanying instruments. Surprisingly male singers sound much better than female singers (it is much easier to differentiate low-pitched tones).

Hearing Experience After 18 Months: A few weeks ago, I got the CD with the best music my CI had ever heard! The recording was created by Richard Reed, a musician who has a CI. It may sound a little unspectacular for normal-hearing listeners but is optimized for the CI-user. And there is a brilliant accompanying booklet (e.g. 'See if you can hear one small tap on a cymbal behind the lyric'. I listened again and again, and finally I heard it indeed).

Perhaps you may question my often selective use of my CI, despite having a normal second ear. It's quite simple: I like experiments. And I'm sure it is useful. Imagine a child with strabismus. You prescribe glasses to correct the optical axis, but this alone is not sufficient. Frequently this child has a good eye and a bad (suppressed) one, and this problem would remain if you do not cover the good eye and force the child to use the suppressed one. I think it's the same with the CI.

A far better experience (and the goal of all the experiments) is the bilateral listening to music, of course. As soon as the First Fitting, bilateral listening gave a spatial impression and was clearly better than listening without the CI. Initially the left side sounded like a bad loudspeaker with much harmonic distortion but I preferred it nevertheless. Meanwhile the distortion has vanished completely, and I really enjoy many types of music, even through an earphone (I bought a superb one two months ago). And it is astonishing, that already a touch of music on the right ear (e.g. an earphone on the table in front of me) is sufficient to achieve a natural sound when listening with the CI.

And that is also true in everyday life. There are often (sometimes they are indeed identical) two different types of sound information arriving at the two ears but the brain is able to fuse them together to make a really comfortable sound. There is an interesting test of this kind of hearing,

where two different words are presented simultaneously to each ear, one word to the CI ear via the implant and a different word to the other ear (via a loudspeaker). If the brain recognizes these two different signals, it's quite easy to understand both words.

The tinnitus is completely suppressed by the CI. Sometimes it is annoying in the morning but the tinnitus vanishes immediately when switching on the CI. This is even so in an absolutely silent atmosphere – that means it's not masking but a true suppression. This is a really fantastic feeling.

With reference particularly to the 'half sphere', the CI 'bursts the cage' and puts me always in the center of the space, regardless whether it is absolutely silent or noisy. Thus the CI is superior in every situation. By the way, this is a much bigger benefit in noisy surroundings, as different noises come from all around, not only from one single point, speech comprehension is better with my CI. All in all, my CI is a really fantastic device, and I will never give it away!

Disclosure Statement

The author states that there is no conflict of interest to be disclosed.

The University of Freiburg Asymmetric Hearing Loss Study

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Background: Patients with single sided deafness (SSD) report difficulties in speech comprehension, conversing in noisy environments when the speaking person is on the deaf side and also difficulties in localizing sounds due to monaural acoustic stimulation. This makes high concentration necessary, leading to rapid fatigue, misunderstandings, frustration and distractibility [Wie et al., 2010]. The rehabilitation methods used, to date, for SSD are conventional hearing aids with cross routing of the sound, (CROS-HA) and bone-anchored bone conduction systems (Baha®). Cochlear implantation (CI) is a new form of treatment for SSD [Vermeire and Van de Heyning, 2009; Arndt et al., 2011].

Fig. 1. Results of HSM-sentence-test in noise in the condition S_{ssd}N_{nh} with CI 6- and 12 months after fitting in comparison to unaided Baha-headband and CROS-HA (each after 3-week test trial) (*p < 0.05; **p < 0.01; ***p < 0.001).

Fig. 2. Results of localization test with CI 6- and 12 months after fitting in comparison to unaided, Baha-headband and CROS-HA (each after 3-week test trial) (**p < 0.01; ***p < 0.001)

Aim: The aim of this study was to compare the rehabilitation options in 66 adult patients with SSD.

Materials and Methods: Speech comprehension was tested in background noise (HSM sentence test, signal and noise @ 65 dB SPL) in the conditions S₀N₀ (speech and noise from front), S_{nh}N_{ssd} (speech from normal-hearing side/noise from deaf side) and S_{ssd}N_{nh} (speech from deaf side/noise from normal-hearing side). Localization was tested using OLSA sentences as stimuli at a mean level of 65 dB SPL with 7 loudspeakers located in a frontal semicircle at subject's head level. We also determined the subjective hearing handicap (HHIE) and subjective rating of the treatment options using the Speech, Spatial and Qualities of Hearing Scale (SSQ) and a Tinnitus Scale.

All but 4 patients reported moderate (n=25) or even severe hearing handicap (n=37). After a 3-week test phase each with Baha-Intenso/BP100 (soft band) and the CROS-HA (Phonak Una M), significantly better speech comprehension was demonstrated in the condition S_{ssd}N_{nh} with the CROS-HA. No significant differences were observed in the other conditions, in sound localization or subjectively via the SSQ scale.

We assigned the 66 patients either to a group with limited therapy options (n=24; failed inclusion criteria for CI-treatment) or a group with all possible therapy options (n=42). In the limited options group, 10 patients selected the Baha, 7 the CROS-HA, 2 wanted neither, 3 had not yet decided and 2 dropped out of the study. For the CI subjects as a whole, 32 patients opted for the CI, 4 for the Baha, 3 for the CROS, 2 had not decided and 1 dropped out. The decision in both groups was independent of the hearing handicap. Thus far, we have operated 28 of the 32 patients who opted for the CI. The inclusion criteria for CI surgery were age >18 years, limited duration of deafness (≤10 years), intact

auditory nerve, patent cochlea, HRCT and MRI without pathological findings and subjective inadequate hearing rehabilitation with CROS-HA and Baha. The mean deafness duration was 32 months and sudden hearing loss was the most frequent cause of deafness.

Results: The results of 22 patients 6 months after CI-fitting and 11 patients with 12-month CI-experience are presented. After only 6 months, we observed significantly better speech comprehension in the most difficult condition (S_{ssd}N_{nh}) with the CI over the Baha and CROS-HA tested preoperatively and over the untreated situation, with further clear improvement after 12 months (Figure 1). The patients showed significantly better localization capacity with the CI after 6-month CI experience and additional clear improvement after 12 months compared to the other therapy options (Figure 2). These objectively-recorded data were confirmed by the patients' subjective rating in the SSQ-Scale. Here, the patients achieved significantly higher scores in speech understanding and spatial hearing with the CI after 6 and 12 months than unaided or with the Baha and CROS-HA. Speech understanding in the most difficult condition (S_{ssd}N_{nh}) was significantly negatively correlated with the duration of deafness (Figure 3). Twenty-two of 22 patients reported complete suppression or at least reduction of tinnitus 6 months after activation of the CI using the speech processor compared to preoperative tinnitus intensity.

Conclusion: Our results show that CI is superior to alternative rehabilitation options in patients with SSD after careful preoperative audiological diagnostics and patient selection. In both localization and the most difficult hearing condition (S_{ssd}N_{nh}), the patients with CI achieve significantly better results than with the Baha and the CROS-HA or than in the unaided situation. We do not have conclusive data for a sufficient number of patients with sufficiently

Fig. 3. Duration of deafness in correlation to speech understanding in the condition SssdNnh with CI 6- and 12 months after fitting (* $p < 0.05$).

long follow-up to determine the correlation between assured success of treating SSD patients with CI and the duration of deafness. Presumably, shorter duration of deafness enables better binaural processing. The goal of limiting the indication criteria to a particular duration of deafness in our study was to prove that binaural rehabilitation with the CI is possible and successful. We recommend expanding the indication criteria to include patients with longer duration of deafness only after long-term studies (≥ 5 years) have demonstrated proven success. We consider the CI to be an alternative treatment option in SSD patients who have a established intact auditory nerve function, absent obliteration of the cochlea, and a short duration of deafness. The conventional CROS-HA and Baha system remain good therapy options in patients who fail to meet inclusion criteria for CI treatment, and also in patients who refuse invasive interventions at all (e.g. CROS-HA) or who want considerably less invasive interventions than CI (e.g. Baha).

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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The Koblenz Experience in Treating Single-Sided Deafness with Cochlear Implants

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Background: Treatment of patients with single-sided deafness (SSD) aims to restore binaural hearing function. Binaural hearing helps speech understanding in noisy surroundings, allows directional hearing and sound localization, as well as improves balance. It also gives some spatial awareness, meaning the ability to feel the difference of being indoors or outdoors, even with closed eyes. Further, a major effect of binaural hearing is the ability to follow long conversations without hearing fatigue. A cochlear implant differs as a treatment option as it restores the lost function instead of providing some form of coping help through the use of amplification. For patients with SSD coming to the Military Hospital, the initial complaints were reduced speech understanding in loud surroundings, loss of acoustic orientation, reduced sound/noise localization and early fatigue in conversation and often tinnitus was present.

Aim: Evaluate effects of cochlear implantation in patients with single-sided deafness.

Materials and Methods: In 2005, treatment of patients with SSD began in the Koblenz Military Hospital. Since then, more than 25 patients have been treated, including children (age range: 5–76 years). Most patients tried other ways to reduce the hearing handicap (CROS-hearing aids; Baha) but were not satisfied (Table 1). The costs were covered by health care insurance. Evaluations were conducted using a visual analog scale (VAS) questionnaire (scale 1–10), Freiburger Monosyllabic Word test in noise, Oldenburger Sentence Test (OLSA) in noise, dichotic listening (unaided, CI-alone and

Table 1. VAS Questionnaire, scale 1–10, 10= best score. (n= subjects tested per condition)

		VAS
Subjective scores:	CI	8.2 (n=25)
	Baha	3.4 (n=15)
	CROS HA	2.9 (n=14)
	SSD unaided	1.0 (n=25)
Ease of listening:	SSD unaided	4.2 (n=25)
	Baha	4.4 (n=15)
	CI	7.6 (n=25)
Sound localization:	SSD unaided	1.5
	CI	9.6 (n=25)

Additionally 21/25 subjects reported improvements for tinnitus.

Fig. 1. An example of one patient, showing improvement in sound localization when using a cochlear implant in SSD. Presentation angle is plotted versus the response angle, using a set-up of 11 loudspeakers forming a half circle.

CI + normal hearing ear) and sound localization (speech or white noise stimuli – randomly presented at 60dB, 70dB or 80dB via 11 speakers at 18° intervals in a frontal semi-circle). Further, we assessed acoustic orientation and equilibrium with the use of a questionnaire and posturography (i.e. Equitest).

Results: The reported subjective benefit of CI in SSD is far superior to that from CROS treatment techniques. The user rate increased to 100% in 25 patients having follow-up from 8 months to 5.5 years. Successful restoration of sound localization was demonstrated (Figure 1). This is of importance to some patients, especially when their jobs require exact sound localization such as for aircraft engineers, military commanders, etc.

Speech understanding in noisy surroundings was difficult to demonstrate with available speech test materials because it is not easy to isolate the normal-hearing ear. Small but not significant benefit was shown for the Freiburger Monosyllabic Word test in noise (group mean score of ~ 50% at SNR= 0dB); however, patients subjectively

reported benefits in noise. Currently, no test is available to assess hearing fatigue in long conversations as speech materials usually only test listening for 5–10 minutes at a time. However, the effect of the CI is obvious in patients' anecdotal reports, e.g. 3 patients were able to convert from part-time to full-time employment following treatment.

Acoustic orientation also improved as demonstrated with results for the postural equilibrium test (Equitest). With binaural hearing restored, the balance test results improved in most patients (Figure 2). This is seen in the ability to better align around the center of gravity throughout the balance test conditions (sway) where patients who are unable to maintain their center of gravity begin to decompensate. The increase in balance control amongst the patient varied between ca. 10–30%.

Conclusion: Binaural hearing is of great importance for our social life as it is the main information pathway in our daily life. Precise sound localization with its warning function eases our concentration, i.e. in road traffic situations or for specific professional requirements. The detected gain in

Fig. 2. An example of one patient, showing improvement in balance control measured by dynamic posturography (Equitest™). When using the implant, swaying from the centre of gravity is reduced (COG alignment) and balance-control in various test conditions improves (circles).

balance control decreases risks of injury, especially for the elderly. These aspects demonstrate the major role of binaural hearing in our life, hence the influence upon quality of life.

Cochlear implants can potentially restore binaural hearing function up to 90% of that for normal hearing and therefore this treatment option sets a benchmark. The experience in treating SSD with a cochlear implant shows that specific aspects associated with binaural hearing ability can be restored. From our experience, we estimate this can be achieved when at least 80% of normal hearing is present/restored in each ear. The treatment needed to achieve this result is determined by the outcome for each ear individually, irrespective of the device or combination of devices used.

Restoration of the loss of function must therefore be the prime medical recommendation, as it is superior to any form of hearing aid. From an ethical point of view, it is unacceptable to withhold a powerful treatment option based on costs. Binaural hearing should be regarded as a basic human right that is not subject to cost efficiency calculations.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

Cochlear Implantation as a Treatment Option for Single-Sided Deafness: Speech Perception Benefit

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Background: Treatment for unilateral severe-profound hearing loss has included BiCROS fitting or Baha®. While these options offer a solution, they do not provide the benefits of binaural hearing since the sound is directed from the poorer ear to the better ear.

Aim: The purpose of this investigation was to determine if cochlear implantation in the poorer ear can provide improved auditory benefits and useful binaural hearing.

Materials and Methods: This study represents a retrospective chart review approved under IRB # 11281. Three adults ranging in age from 31–62 years of age, who presented with sudden idiopathic unilateral severe-profound hearing losses and a near-normal contralateral ear with excellent speech discrimination, were subjects for this study. Under headphones, the mean pure tone average (PTA) in the affected ear was 93dBHL with a mean speech discrimination score of 0%. The mean PTA in the contralateral ear was 20dBHL with a mean speech discrimination score of 98%. Although all reported some tinnitus in the affected ear, their major complaint was the effects of the hearing loss. S1 and S2 were implanted with the Cochlear™ Nucleus® Freedom™ device; S3 received the Cochlear™ Nucleus® 5 device. (Cochlear Ltd, Macquarie University, Australia) All had previously tried the Baha (softband trial) with no success and refused it as a treatment option. All had complete insertions of the electrode array with no peri-operative or postoperative complications.

The Consonant-Nucleus-Consonant (CNC) test was used to evaluate monosyllabic word recognition presented at 60dB SPL and scored as percent correct and was administered to each ear individually and binaurally in the sound field. The BKB-SIN test [Etymotic Research 2005, Elk Grove Village, IL] is designed to assess sentence recognition in noise and consists of the Bamford-Kowal-Bench sentences (36 lists) presented in 4-talker babble noise. The sentences are presented at 65dB SPL and the level of the noise is varied in 3 dB steps at fixed signal-to-noise ratios (SNR) beginning at +21 dB SNR (easy) descending to -6 dB SNR (hard) in order to obtain a speech reception threshold where the subjects can repeat key words 50% of the time (SNR-50); therefore, a lower dB score is indicative of better performance. The test was performed in the sound field in each ear individually and in the sound field in three conditions: speech front/noise front, speech front/noise right, speech front/noise left.

In order to ensure that the poor ear was completely isolated, the good ear was plugged and covered using E.A.R. foam earplugs [3M Co., St. Paul, Minnesota] and TASCO sound shield over-the-head earmuff. For validation purposes to ensure that the plug-and-muff method was in fact completely separating the two ears, the subjects were also tested using a direct connect system (DCAT).

The DCAT software developed by Cochlear Americas [Cochlear Americas, Centennial, CO] was designed to deliver signals directly to the Nucleus Freedom sound processor. The signals are processed via a Head Related Transfer

Function (HRTF) so that it's equivalent to sound field presentation and the software provides calibration to ensure that the signals are delivered at the desired presentation levels. Warble tone thresholds, the CNC word test and the BKB-SIN sentence test were administered using direct connect for comparison with the plug and earmuff sound-field results in the same session.

Results: The binomial model of Thornton and Raffin was used to calculate the significance of the difference in CNC test scores ($p=0.05$). For the BKB-SIN, the difference in scores between conditions and or testing sessions has to be greater than 3.1 dB to be significant at the 95% confidence interval. Preoperative data for the CNC word and BKB-SIN tests were available in all conditions for all 3 subjects and 2-year postoperative data are available for S1, 1-year data for S2 and 2-month data for S3. Test scores revealed a significant improvement in CNC and BKB-SIN test scores from the preoperative to the most recent postoperative evaluation in the implanted ear with the contralateral ear muffed and plugged.

No significant differences were found comparing preoperative to post-implant results on CNC words for the non-implanted ear or binaurally for all subjects in all conditions. For the BKB-SIN test, no significant differences were found for S2 and S3 binaurally in all conditions. S1, however, at 2 years post-implantation did show a significant improvement in the binaural condition when the noise was presented to the CI ear.

A comparison of the plug-and-muff and direct connect techniques was conducted. No significant differences in scores were found for CNC words or BKB-SIN sentences in the implanted ear between the two methods.

Conclusion: The data reveal significant improvement in speech perception performance in quiet and noise in patients with single-sided deafness following implantation. Further study is necessary to determine the variables that affect performance, including length of hearing loss and device usage, etiology of hearing loss and age at implantation. Additionally, this group of patients provides a unique opportunity for the study of technology and programming parameters that might enhance cochlear implant outcomes.

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Table 1. Acoustic and implant details for patients suffering from debilitating unilateral tinnitus

Pat no.	PTA dBHL (pre-op)		CI side	Contralateral side	CI device
	Right ear	Left ear			
1	86,67	51,67	Right	Hearing Aid	CI24REH
2	83,33	70	Right	Hearing Aid	CI24RE (CA)
3	93,33	83,33	Right	Hearing Aid	CI24RE (CA)
4	43,33	86,67	Left	Hearing Aid	CI24REH
5	98,33	61,67	Right	Hearing Aid	CI24RE (CA)
6	16,67	85	Left		CI24REH
7	13,33	105	Left		CI512
8	25	80	Left		CI24REH
9	38	82	Left		CI24REH
10	Total deafness	25	Right		CI24RE (CA)

CI24REH= Hybrid L24 Cochlear Implant; CI24RE(CA)= Freedom™ Cochlear Implant; CI512= CI512 Cochlear implant

Cochlear Implantation in Patients with Sudden Unilateral Sensorineural Hearing Loss and Associated Tinnitus

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Background: Debilitating tinnitus can appear in more than 80% of patients after sudden profound hearing loss. Tinnitus handicap is influenced by the degree of hearing loss and associated problems including psychological distress. Recent reports have demonstrated suppression of tinnitus as a side-effect after cochlear implantation and as a consequence incapacitating or highly disturbing tinnitus is emerging as a potential new indication for cochlear implantation [Masgoret et al., 2010; Vermeire and van de Heyning, 2009].

Aim: The aim of this study was to identify whether severe tinnitus in patients with sudden sensorineural hearing loss (SNHL) can be successfully treated with a cochlear implant.

Materials and Methods: The clinical investigation was designed as a prospective repeated measures study. Ethical approval was obtained from the appropriate hospital and Health Department boards. Selection criteria for the ear to be implanted included: etiology of hearing loss secondary to idiopathic sudden hearing loss; handicapping tinnitus as demonstrated by a score on the Tinnitus Handicap Inventory (THI) >58% ; duration of handicapping tinnitus <3 years; SNHL <15 years; disyllabic speech test score in quiet at

65 dB-SPL in the best-aided condition without lip reading <50%. For the non-implanted ear, the inclusion criteria were normal-to-moderate hearing levels and a disyllabic speech score in quiet at 65 dB-SPL in the best-aided condition without lip reading >50%.

Ten adult patients (4 males and 6 females) met the study selection criteria and had a mean age of 42.7 years (range, 34–60 yrs) at enrolment in the study and at implant, mean duration of deafness of 3.8 years (range: 1–5 yrs). Table 1 lists the type of implant and preoperative bilateral pure-tone averages. The audiometric results for those implanted with the Cochlear™ Nucleus® Hybrid™ L24 Cochlear Implant (CI24REH, n=5) included thresholds ranging from mild-to-moderate hearing loss in the low frequencies (up to 500 Hz) and severe-to-profound hearing loss in the mid and/or high frequencies above 1500 Hz). The remaining five patients met standard CI implant criteria with moderate-to-profound hearing loss in the lower frequencies (<1000 Hz) and severe-to-profound hearing loss in the higher frequencies. The mean duration of tinnitus was 1.5 years (range: 1–3 years). Five cases used bimodal stimulation and 5 cases did not use a conventional hearing aid (HA) as they have normal hearing in the contralateral ear.

The degree of tinnitus was evaluated using the subjective scales indicating the severity of tinnitus: a 10-point Visual Analog Scale (VAS) and the Anxiety and Depression Scale. Self-report questionnaires included the Tinnitus Handicap Inventory (THI) and the Subjective Discomfort Scale (SDS). Speech recognition was evaluated with disyllabic words in quiet at 65 dB SPL. When presenting speech in noise (SNR=+10/+15), both monaural and bimodal conditions were evaluated. In patients with normal hearing in the contralateral side, the normal-hearing ear was plugged and covered with a headphone and the CI was tested monaurally. Follow-up evaluations occurred between 3 to 18 months.

Major consideration was given to programming the speech processor and an innovative mapping method was developed [Masgoret et al., 2010]. Electrodes approximating the pitch of the tinnitus were stimulated to identify which one reportedly was most similar in perception compared to the tinnitus. When the electrode was identified, the four neighboring electrodes were given the same T-levels. For C-levels, the stimuli were increased to match the perceived intensity of the tinnitus. This C-level was then applied to the neighboring four electrodes. Using these adjustments, several maps were created. After 10 days, the fitting was optimized and one map kept as the Reference Map and tinnitus, audiometric and speech perceptions evaluations commenced using the Reference Map.

Results: The mean preoperative score on the Tinnitus Handicap Inventory (THI) was 72.1% (range 58–89), after 1-month experience (post switch on) the score was 27.4% (range: 0–51%) and after 3 months the result was 14.3% (range: 0–45%). The VAS score improved from a preoperative result of 7.9 (range: 6–10) to 2.7 (range: 0–5) at 3 months postoperatively. The perception of how much disturbance was perceived in percent of hours/day dropped from 100% to 11.7% (range: 0–30%) after 1 month. According to the Tinnitus Subjective Questionnaire, preoperative responses averaged grade 4 (range: 2–5) and at 3 months postoperatively grade 1.7 (range: 1–3) when the CI was switched on. When the CI was switched off during the night, tinnitus returned to grade 2.3 (range: 1–4) as shown in Figure 1. All patients reported using their cochlear implant all waking hours. In summary, all subjective tinnitus reports, scales and questionnaires demonstrated improvement post-implant after 1 and 3 months.

Preliminary observation of speech perception results using disyllabic words in quiet after 12 months in 2 patients with the relatively shorter Hybrid L24 Cochlear Implant as compared to 2 patients with the standard implants with a Contour Advance™ electrode array showed moderately higher performance for the standard array CI-users in the CI-alone condition. However, all patients showed a binaural summation effect, with a larger effect shown for those with a Hybrid L24 Implant in the binaural listening condition (Hybrid L24 + HA).

Conclusion: In our series of unilaterally deafened patients, we demonstrated cochlear implantation in the affected ear can suppress or significantly decrease tinnitus. This is also evident in the presence of preserved residual hearing that enables the use of electroacoustic stimulation in the implanted ear. It is essential to specifically tailor programming of the speech processor to achieve this outcome quickly post-implant. Additionally, use of the CI improves speech comprehension and enables access to binaural listening advantages (by default not available through monau-

Fig. 1. Tinnitus Subjective Questionnaire. Results showing differences between tinnitus recovery grades preoperatively and at 3 months postoperatively in two conditions, with the CI switched on and switched off.

ral listening) when used in combination with a HA or normal-hearing in the contralateral ear.

Disclosure Statement

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Preliminary Experience in Children using a Hybrid™ Cochlear Implant System and a Contralateral Hearing Aid

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Background: The standard indication criteria for unilateral or bilateral cochlear implantation (CI), in children

are severe-profound hearing loss across the speech frequencies. This currently excludes treatment with a CI for children who wear a hearing aid in one ear but show low-frequency hearing (normal-moderate threshold levels between 125 Hz and 500 Hz) in the contralateral ear and consequently are deprived from the opportunity to gain binaural advantages. It is important not to overlook these children.

Further, we are encountering educated parents more frequently who are aware of the potential for future new technologies and on the other hand know the impact of depriving stimulation for auditory plasticity. They have very high expectations with respect to how useful residual hearing is for speech understanding and educational possibilities and have extended experience with conventional hearing aids. They are presented with the conflict of wanting to take advantage of the auditory plasticity but also wanting to keep the door open for new technologies and thus, can be critical of a second implant.

Our implant approach towards the treatment of hearing loss, whether bilateral or unilateral, combines use of the most atraumatic surgical option to increase the likelihood of preserving residual hearing for future technologies while providing access to binaural auditory cues and the potential to take advantage of auditory plasticity. In bilaterally deaf children who meet current CI criteria, we offer the option to receive both a Cochlear™ Nucleus® Hybrid™ L24 Implant that includes a relatively shorter, straight electrode array and a CI with a Contour Advanced™ electrode array (modiolar-hugging) in one simultaneous procedure. Currently under research, for children who present with asymmetrical hearing loss (AHL), where only one ear meets CI selection criteria and has minimal low-frequency hearing, we offer the Hybrid L24 Cochlear Implant which includes an acoustic stimulation component provided to the implanted ear which may be used in combination with a hearing aid (HA) in the contralateral ear.

Aim: We present our preliminary research data on a subset of children treated at our clinic that demonstrated asymmetrical hearing loss with measureable low-frequency hearing levels to 500 Hz and a severe-profound hearing loss for the mid-high frequencies and received the Hybrid Cochlear Implant System.

Materials and Methods: Unilateral implantation took place in 13 children presenting with AHL who had usable aided hearing in the non-implant ear. The mean age at implantation was 9.5 years (2.0–17.8); however, three children were still undergoing program fine-tuning and thus are not included in these data and four were too young to participate in the evaluation procedures. Seven children use the acoustic component of their Hybrid CI System and one has

preserved normal hearing in the low frequencies and does not use the acoustic component. All children wear both their contralateral hearing aid and implant during all waking hours. Of the children who were old enough to be tested with the Freiburger Monosyllabic Word Test in quiet (6/6) and the Hochmair-Schulz-Moser sentence test (HSM) in noise (5/6), the average age at implant was 11.8 years and onset was 1.7 years (note: onset unknown for KW). For the majority of children (5/6) etiology was unknown (see Table 1).

Results: Postoperative audiometric results show preservation of low-frequency function. An average downward threshold shift from preoperative to first fitting intervals, of 10 dB, 4 dB and 6 dB was noted for unaided thresholds at 125 Hz, 250 Hz and 500 Hz, respectively. Subsequently, at 6 months post-implant, an additional average shift of 8 dB, 14 dB and 20 dB, respectively was observed.

The Freiburger Monosyllabic Word test showed that 5/6 children improved over time at 12 and 24 months postoperative test intervals when compared to their preoperative performance with the HA alone (see Table 1). Furthermore for the HSM sentence test in white noise (S_0N_0 , SNR = +10 dB), which could be tested in five children, 3/5 showed improvement.

All of these children use bilateral stimulation (contralateral HA + Hybrid L24 CI) and are consistent all-day users in all school situations.

Conclusion: These data are preliminary. For the 13 children with audiometric results, we can assume that the pathological physiology in young-aged patients permits implant of a Hybrid L24 CI and use of electroacoustic stimulation. There is no evidence to suggest that the progression of the hearing loss is different to that observed within the adult implant population. For our unilaterally implanted children, one may hypothesize that they stand to gain potentially even more benefit through the use of electroacoustic stimulation in the implant ear coupled with acoustic input in the contralateral ear. It is essential however, to conduct longer-term studies to determine the characteristics of unilateral hearing loss specifically in potential implant candidates in the child population versus the adult population. In our unilaterally implanted child sample, speech testing data revealed improvement after one year, with preserved low-frequency thresholds within the normal-mild hearing level range. All children are consistent all day users of both devices (Hybrid + HA). We are convinced that it is important to implant children as early as possible to provide the potential for the development of binaural hearing while, at the same time, keeping the door open for future technologies by using a surgical approach and specifically designed electrodes that offers the possibility for the most atraumatic surgery.

Table 1. Six children evaluated with speech materials who demonstrated preserved low-frequency hearing after implantation with the Hybrid L24 Electrode array

Subject	Age at implant	Etiology	Age at Onset yrs. mos	Contralateral HA use: experience	Hybrid CI system including acoustic component
CA	10	Oxygen deficiency	0	yes	yes
JW	13	unknown	2.9	yes	yes
SV	6	unknown	2.5	yes	yes
CR	9	unknown	3	yes	yes
BW	18	unknown	0	yes	yes
KW	15	unknown	unknown	yes	yes
	Mean		Mean		
	11.83		1.68		

Table 2. Speech Tests for six unilaterally implanted children

	Freiburger Monosyllabic Word Test						HSM Sentence Test in Noise (S_0N_0)				
Ipsilateral Implant Ear	CA	JW	SV	CR	BW	KW	CA	JW	SV	CR	BW
<i>Preop HA</i>	60	30	40	5	50	15					
Hybrid L24 – no AC (initial fit)	0	0	30	na	0	0	0	0	16	0	0
Hybrid L24 + AC (3 mo)	0	0	65	65	na	55	0	0	16	0	0
Hybrid L24 + AC (6 mo)	65	0	na	81	na	45	46	0	33	na	0
Hybrid L24 + AC (12 mo)	na	0	75	65	65		na	0	22	48	0
Hybrid L24 + AC (24 mo)	100				65		40				0

na = not available

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

Treatment of Asymmetric Hearing Loss with Cochlear Implants and Hearing Aids

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Background: Bimodal stimulation is defined as electrical stimulation to the implanted ear with acoustic stimulation to the opposite ear using traditional acoustic amplification. Morera et al. in 2005 studied the performance of patients with classic cochlear implant (CI) indications who had a bimodal fitting and showed that patients performed better in the binaural condition when compared with either the unilateral hearing aid (HA) or cochlear implant condition alone.

Today, cochlear implant candidates are more likely to have better contralateral residual hearing than in the past. This population is growing rapidly due to the fact that the

technology used in cochlear implants is improving fast, allowing for expanded cochlear implantation candidacy that includes less severe hearing losses [Cullen et al., 2004].

Aim: The objective in our presentation is to demonstrate that CI candidates with functional residual hearing can obtain clinically relevant speech perception benefits after cochlear implantation in quiet and noise environments.

Materials and Methods: We conducted a retrospective review of our adult database (>18 years of age) for subjects with asymmetric hearing loss described as following: CI-implanted ear having severe to profound postlingual sensorineural hearing loss; duration of a severe loss component ≤ 15 years; contralateral non-implanted ear having moderate to severe hearing loss, and an open set score >50% for disyllabic words in quiet at 65dB.

Twenty-one patients met the criteria, 10 male and 11 female, with age at implant ranging from 24 to 73 years of age (mean 52.43; SD 13.2) and a mean preoperative disyllabic word discrimination score for the CI ear of 27.76% (SD 32.9) and 82.6% (SD 14.5) for the HA ear.

We performed pure tone audiometry and speech audiometry using disyllabic words in quiet and CID sentences with white noise in all patients. Sound field thresholds were measured with HA, CI and CI+HA in order to control the fitting of both devices. Speech tests in quiet and in noise were administered in a calibrated sound-field room with

Fig. 1. Mean correct score for disyllabic words at 65 dB in quiet, for each group studied. Vertical bars denote 0,95 confidence interval. Groups are described as following: CI presurgery (n=21); HA presurgery (n=21); CI 1 year follow-up (n=17); Bimodal 1 year follow-up (n=11); HA 1 year follow-up (n=15); CI 2 years follow-up (n=16); Bimodal 2 years follow-up (n=11); HA 2 years follow-up (n=13). Word scores obtained via bimodal stimulation are statistically significantly better when compared to scores for the HA alone condition at 1 year follow-up and versus HA alone and CI alone scores at 2 years follow up.

subjects seated at a distance of 1 meter and at 0° azimuth to the loudspeaker. All tests were performed pre- and postoperatively at 2–3 years follow-up.

All patients were mapped at surgery, optimizing the map parameters after first activation. The hearing aid optimization was done by adapting the prescription to achieve the best sound quality and balancing the loudness of the HA with the CI so that both devices sounded equally loud [Ching et al., 2004].

Results: Audiometrically, we found statistically significant improvement in aided thresholds via bimodal stimulation ($p < 0.05$) at all frequencies for the two-year follow-up when compared with the preoperative aided levels for the CI-ear and HA ear, and versus the two-year postoperative follow up for HA-alone. No statistically significant difference was observed between PTAs for aided thresholds at 2 years follow-up, however a consistent 2 to 3 dB advantage was noted at all frequencies in the bimodal condition versus the CI alone condition suggesting a binaural summation effect as a result of bimodal stimulation.

Fig. 2. Mean of correct CID sentences with at three year's follow-up. Groups are described as following: CI ear (n=16); Bimodal (n=12); HA no implanted ear (n=12). The bimodal condition is statistically significant when compared to the other conditions studied.

For speech recognition, there were statistically significant differences ($p < 0.05$) showing that bimodal stimulation at one and two years follow-up is better than the unilateral HA-alone condition. There were no significant differences when comparing word scores at one-year follow up for CI alone use vs bimodal stimulation ($p = 0.125$). Statistically significant differences were observed for word scores at two years follow up between bimodal stimulation and CI-alone conditions ($p = 0.006$), as shown in Figure 1.

The CID sentences test in noise was administered after three years of implantation with a SNR of 10 dB at 0° azimuth and revealed statistically significant differences with a $p < 0.05$ when scores in the bimodal stimulation condition were compared with both unilateral conditions as demonstrated in Figure 2.

Conclusion: Our study supports the fact that binaural hearing provides additional benefit to CI users who have an appropriately fit hearing aid in the contralateral ear. Signals received at the CI and the HA appear to be integrated centrally to provide these additional improvements. This is most clearly demonstrated by a summation effect for the disyllabic word scores where binaural listening through bimodal stimulation provides a significant improvement over the monaural listening conditions for the CI alone or HA alone scores. Binaural squelch may also have played a role in the significant improvement in speech with noise conditions.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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Effects of Asymmetric Hearing Loss in Cochlear Implant Recipients

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Background: Traditional cochlear implant candidacy includes bilateral severe-profound hearing loss (SPHL) and lack of benefit from amplification. Many people have asymmetric hearing loss where one ear meets this criteria but the other ear has better hearing and receives benefit from a hearing aid [Firszt et al., 2008]. Amplification for the poorer ear is often impossible due to the severity of the hearing loss; therefore, these individuals function with unilateral input from the amplified ear. Listening with just one ear is problematic; the ability to communicate in noise, localize sound and hear at a distance is greatly reduced [Wie et al., 2010].

Aim: An ongoing longitudinal study was initiated at Washington University School of Medicine, St. Louis (IRB #201012936) in collaboration with Midwest Ear Institute, Kansas City. The purpose is to determine the benefits of cochlear implantation in adults with asymmetric hearing loss between ears.

Materials and Methods: Patients have one ear that meets cochlear implant criteria and one ear that has better hearing but is not in the normal-hearing range. A battery of speech recognition and localization measures is administered prior to implantation of the poorer ear and after activation of the implant at several intervals through one year. Here we present data from a single test designed to measure the binaural effects of summation, squelch and head shadow for the first 6 participants after 6 months of implantation.

Participants ranged in age from 26 to 59 years (mean=36 years). Participants 1–3 had postlingual onset of SPHL in the poorer ear (mean duration=4 years); each used bilateral amplification prior to implantation. Participants 4–6 had

pre/perilingual onset of SPHL in the poorer ear (mean duration=24.5 years); none had used amplification in that ear.

The BKB SIN Test [Etymotic, 2005] presents sentences in noise at various signal-to-noise ratios (SNR) resulting in an SNR-50 (SNR for 50% correct). A lower SNR-50 reflects better performance. Two list-pairs were presented from a loudspeaker three feet in front of the listener; the location of the noise (four-talker babble) varied (i.e., front, 90° right, 90° left of the listener). Participants were evaluated in three conditions; cochlear implant (CI) alone, hearing aid (HA) alone and both devices (Bimodal).

Results: In Figure 1, six panels show the mean SNR-50 (and standard deviation, SD) for the postlingual group (left panels) and prelingual group (right panels) for test conditions that reflect summation, squelch and head shadow at the 6-month post-implant interval. In the top panels (summation effect), when speech and noise were presented from the front, the postlingual group improved in the Bimodal condition (SNR-50 of 3.75 dB) versus the CI (8.42 dB) or HA (5.67 dB) alone. The prelingual group could not perform in the CI-alone condition (22.67 dB) and performed worse in the Bimodal condition (6.33 dB) than the HA alone (3.75 dB). The best SNR-50 was achieved in the Bimodal condition for the postlingual group and the HA-alone condition for the prelingual group.

The effectiveness of bimodal stimulation compared to using only the device positioned away from the noise is displayed in the middle panels (squelch effect). When noise was presented to the HA side (NHA), comparison of scores for the postlingual group in the CI-alone and Bimodal conditions demonstrated little difference (CI alone, 4.33 dB; Bimodal, 3.63 dB). Likewise, no squelch effect was evident from comparison of the two NCI conditions (HA alone, 1.67 dB; Bimodal, 1.75 dB). For the prelingual group and the same comparisons, the bimodal condition was substantially improved from the CI-alone condition, primarily due to floor effects with the CI alone. No squelch effect was evident.

The lower panels display results for head shadow effect. Comparisons were made for the CI- and HA-alone conditions, with noise to the side of the worn device versus noise moved to the opposite side. For postlingual participants, a head shadow effect was present for both the CI- and HA-alone. For prelingual participants, moving the noise to the opposite side of the worn device resulted in a lower SNR-50 with the HA only. No head shadow effect was present for the CI-alone.

Figure 2 shows the average (and SD) of all three noise conditions for the poorer hearing ear obtained pre-implant with a hearing aid (gray bars) and post-implant with the CI (dark bars) for both groups. The postlingual group improved

Fig. 1. Postlingual (left panels) and prelingual (right panels) group mean scores after six months of cochlear implant experience. Error bars represent 1 SD. Results are shown for the device and noise conditions that demonstrate Summation (top panels), Squelch (middle panels), and Head Shadow (bottom panels). SNR-50 = signal-to-noise ratio for 50% accuracy; dB = decibel; CI = cochlear implant alone; Bimodal = cochlear implant and hearing aid combined; HA = hearing aid alone; NHA = noise from the side that uses the hearing aid; NCI = noise from the side that uses the cochlear implant.

Fig. 2. Group mean scores across all noise conditions (noise front, noise from side that uses the hearing aid, noise from side that uses the cochlear implant) for the cochlear implant alone test condition. Error bars represent 1 SD. Light gray bars indicate performance in the ear to be implanted (poorer ear) prior to implantation; dark gray bars indicate performance in the same ear at six months, post-implant.

in the implanted ear after 6 months experience whereas the prelingual group did not.

Conclusion: Results after 6-months of cochlear implant use demonstrated binaural benefits for postlingual participants, primarily summation and head shadow effects. Prelingual participants were unable to recognize speech with the CI alone and did not demonstrate binaural effects. Additional longitudinal data are needed to explore the benefits of cochlear implantation in adults with asymmetric hearing loss, especially those with prelingual hearing loss who may require more time to show benefit.

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Surgical Aspects of Cochlear Implantation – Verification of Electrode Placement, Preservation of Residual Hearing and the Impact in Rehabilitation of Asymmetric Hearing Loss

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Background: Cochlear Implants are a well-established method for hearing rehabilitation in bilateral, congenital and acquired deafness. Current discussions are focused on the insertion mode (cochleostomy vs. round window insertion). It should be noted that the scala tympani is the general aim for insertion and that a number of different electrode arrays are available (Contour Advance™ and Modiolar Research array for cochleostomy insertion, Hybrid™ electrodes and Straight Research array for round

window insertions). In all of them, efforts have been made to analyze their usability for preservation of residual hearing. The general concept of modern CI surgery is that it should be as atraumatic as possible to inner ear structures; nevertheless, information on electrode placement following cochlear implant surgery is still sparse.

Aim: To analyze a method to assess quality of insertion, the impact of electrode position on outcomes of rehabilitation and to understand the importance of both in restoration of acoustic hearing in patients with asymmetric hearing loss with cochlear implants.

Verification of Electrode Position: With digital volume tomography (DVT), a method is available that combines low-radiation exposure and excellent resolution properties for allocation of electrode position to scala tympani (Figure 1), scala vestibuli or a dislocation from one scala to the other. A necessary prerequisite for using this method *in vivo* is the evaluation of electrode placement in human temporal bones by DVT and comparing these results to histology. Our team has demonstrated the use of DVT for evaluation of electrode arrays and surgical results over time [Aschendorff et al., 2011]. Surgical quality can be determined by the surgeon's ability to place an electrode into scala tympani (resulting in a scala tympani insertion rate determined to be 84% in our Contour Advance series). The dislocation rate (number of arrays that move from scala tympani to scala vestibuli) is influenced by the surgeon's estimation of the position and course of the scala tympani, the experience of the surgeon, as indicated by individual learning curves, and the mechanical properties of the array. With the Contour Advance electrode, dislocations typically occur after inserting half of the array at 180 degrees in up to 22% of the cases following scala tympani insertions [Aschendorff et al., 2011]. Other electrodes show different characteristics with dislocation rates up to 80% (long electrodes, dislocation within the second turn, unpublished data). Although scala vestibuli insertions may be the only feasible method for complete electrode insertion in cases of obliteration or ossification within the scala tympani associated with post-meningitic deafness or other obliterating diseases, they will likely result in more damage to the inner ear and subsequently neural degeneration. Surgeons may use DVT for continuous feedback of surgical quality, which consequently may result in improved surgical quality.

Residual Hearing: The preservation of residual hearing will only be acceptable if scala tympani insertions are combined with an atraumatic access to the cochlea either by cochleostomy or the round window. With the different arrays available to date, the rate of preservation of residual hearing varies between 10 and 30 dB (mean pre- and postoperative difference of unaided thresholds for 125–1000kHz).

Fig. 1. Results of DVT evaluation following human cochlear implant surgery with a Contour Advance electrode array. **a** CT-like overview. **b** Small-volume reconstruction of the cochlea with perimodiolar electrode position. **c** Transmodiolar sagittal reconstruction indicating the electrode contacts in the scala tympani. **d** Transmodiolar coronal reconstruction (IAC: internal auditory canal, v: vestibulum, arrows: electrode).

Rehabilitation Results: The electrode position within the cochlea may influence the outcomes of rehabilitation; that is, an electrode position inside the scala tympani results in significantly better results compared to scala vestibuli insertions [Aschendorff et al., 2007]. Finley et al., 2008 confirmed that results of rehabilitation were positively correlated to the number of electrode contacts inside the scala tympani.

Binaural Hearing: A number of different cues are used to allow binaural processing. Interaural time differences (ITD) and interaural level differences (ILD) are analyzed to give spatial hearing. Common effects in binaural hearing are the (physical) head-shadow effect (improves detectability of a target sound, creates an ear with a better signal-to-noise ratio), the squelch effect (the brainstem processes differences in timing, amplitude and spectral signals and integrates signals from both ears so that a better signal is received by the auditory cortex) and the summation effect

(combined signals from both ears are perceived louder compared to monaural listening in quiet and in noise which may lead to improved intelligibility). These effects are utilized when restoration of hearing in asymmetrical hearing loss through cochlear implants occurs. Compared to a normal hearing ear, hearing with a cochlear implant still is somewhat compromised and results in an asymmetry between ears which affects binaural processing.

Conclusion: The electrode position following cochlear implantation yields improved results in speech understanding with scala tympani insertions. Improved results may ease binaural processing and lessen the asymmetry of hearing, which will also increase squelch and summation effects. The preservation of residual hearing may preserve the normal access to binaural cues like ITD and ILD, which will further increase localization abilities. Therefore, the general concept of modern cochlear implant surgery is equally

important in rehabilitation of asymmetric hearing loss and restoration of binaural hearing.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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Probability of Improvement After Cochlear Implantation as a Function of Preoperative Residual Hearing

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Background: Cochlear implantation is recognized as an effective treatment for severe-profound to total bilateral

deafness restoring a substantial level of open-set speech recognition performance. Asymmetrical and severe hearing losses potentially represent new indications but are still under investigation (see this issue). In these cases, residual hearing performance raises two main concerns. Firstly, speech recognition performance after cochlear implantation should not only be an improvement on the pre-operative performance but also provide a clinically significant benefit. Secondly, the risk of a decrement in speech recognition performance should ideally be nil or at least very minimal.

Aim: The aim of this study was to evaluate the probability of improvement and the risk of decrement according to the level of preoperative functional hearing.

Materials and Methods: In this retrospective study, we analyzed data from a sequential population of 144 unilateral cochlear implanted adult patients. This population was divided into three groups according to preoperative dissyllabic 'Fournier' word recognition (60dB SPL, 20 words) in the best-aided condition: group 1 (n=65; 0-9% correct), group 2 (n=43; 10-29%) and group 3 (n=36; ≥30%). We analyzed scores for dissyllabic word recognition in quiet and MBAA2 sentence recognition in noise (65dB SPL at +10dB SNR). We considered speech recognition improvement as clinically significant if it was greater than 20% points. This 20% criterion was suggested as a 'minimal worthwhile improvement' by Summerfield, et al. [2004]. The risk of decrement in performance was evaluated using distribution curves for each group, which display the proportion of patients showing a decrease in performance. To perform this benefit/risk evaluation, we used one-year postoperative speech scores obtained in optimal conditions; that is, cochlear implant in one ear and, where applicable, together with a contralateral hearing aid.

Results: In best-aided conditions for words in quiet, the mean improvement in percentage points was 69.0 (standard deviation, 24.0) for group 1, 57.6 (SD=14.8) for group 2 and 35.8 (SD=16.3) for group 3. Differences in

Table 1. Mean pre and post operative speech scores in groups 1, 2 and 3

	Group 1 (n=65)	Group 2 (n=43)	Group 3 (n=36)
Mean pre op dissyllabic words recognition (SD) *	0.23% (1.06)	19.53% (7.22)	48.08% (12.13)
Mean post op dissyllabic words recognition CI alone (SD)	68.70% (24.13)	72.56% (15.17)	72.36% (18.80)
Mean post op dissyllabic words recognition CI and HA (SD)**	70.42% (23.02)	77.09% (14.23)	83.47% [†] (14.87)
Mean pre op sentences in noise recognition (SD)*	0%	10.36% (16.36)	32.64% (21.88)
Mean post op sentences in noise recognition CI alone (SD)	70.24% (24.12)	72.95% (22.17)	76.48% (22.65)
Mean post op sentences in noise recognition CI and HA (SD)***	70.96% (24.53)	76.74% (21.50)	80.56% (20.21)

Key: SD – Standard Deviation; CI – Cochlear implant; HA – Hearing aid

*: Significant difference between groups 1 and 2, 1 and 3, 2 and 3 ($p \leq 0.01$).

**: Dissyllabic words recognition significantly better with CI and contra lateral HA than CI alone in groups 1, 2 and 3 ($p \leq 0.01$).

***: Sentences in noise recognition significantly better with CI and contra lateral HA than CI alone in groups 2 and 3 ($p \leq 0.01$).

[†]: Dissyllabic words recognition with CI and HA ($p \leq 0.01$) significantly better in group 3 than in group 1.

Fig. 1. MBAA2 sentences recognition in noise (65 dB SPL at +10 dB SNR), in best aided conditions: Distribution curves for groups 1, 2, 3.

improvement were significant between all groups (ANOVA, group 1 vs 2, $p < 0.01$, 2 vs 3, $p < 0.001$). For sentences in noise, the mean improvement was 70.2 (SD=24.0) for group 1, 68.2 (SD=22.2) for group 2 and increased up to 53.0 (SD=23.7) for group 3. The difference in mean improvement was significant between group 1 and group 3 ($p < 0.01$). For patients using a contralateral hearing aid, mean speech recognition scores were greater when compared to using a CI alone in all groups for words in quiet, and in groups 2 and 3 for sentences in noise (see Table 1).

We used a cumulative distribution curve for each group (see Figure 1) to highlight the proportions of patients showing: a decrease in performance or an improvement >20% points.

Whether in quiet or in noise, no patient in any group decreased his/her best-aided speech recognition score. For word recognition, proportions of patients with an improvement exceeding 20% points were 97% in group 1, 100% in group 2 and 78% in group 3. These proportions were respectively 96%, 100% and 94% for sentences in noise.

A separate subgroup of 14 patients was identified in group 3 based on their best-aided preoperative word recognition score exceeding the current criterion for CI defined by the *Haute Autorité de Santé* (i.e. >50% correct). Ten of these patients displayed an asymmetrical hearing loss with a total or near-total deafness in the ear to be implanted. The remaining 4 patients had significant preoperative residual hearing in the operated ear. Improvement of greater than 20% points for disyllabic words was shown in 10/14 patients and 13/14 for sentences in noise.

Conclusion: Patients with substantial residual hearing can receive benefit from cochlear implantation. Gains in speech recognition scores were greater for sentences presented in a moderate level of background noise (10dB SNR), especially for patients with significant preoperative scores

(>30%) for words in quiet. In no case did we find poorer postoperative scores for either test in the best-aided condition. Expansion of cochlear implant candidacy might be considered but relies on two prerequisites: first, audiological evaluation of cochlear implant candidates and recipients should be standardized to allow strong multicenter studies and international comparisons. Speech recognition in noise, besides being a relevant criterion in cochlear implant indications, may be a simple measure to standardize. Second, research concerning cochlear implant indications and outcomes should include studies of correlations with changes in quality-of-life indices. This would allow the determination of candidacy criteria for which a clinical and societal benefit is likely.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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Baha® in Single-Sided Deafness: Factors Influencing the Decision for a Baha and the Benefit of Low-Frequency Attenuation

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Background: Besides improving hearing in conductive or mixed hearing loss, bone-anchored bone conduction systems (Baha®) are used increasingly to overcome the negative effects of the acoustic head shadow in single-sided sensorineural deafness (SSD) [Flynn et al., 2010]. Today, recipients with SSD account for more than 17 % of all Baha users in Bern. Despite the proven advantages of Baha in SSD, it has been estimated that only about 20% of all candidates will decide to use a Baha if given the choice. It is unclear, which candidates will benefit from a Baha and which will

Fig. 1. Comparison of 2 groups of Baha candidates with single sided deafness. Data of candidates who chose a Baha permanently after a 7 to 10-day trial period are shown in grey, those who declined a Baha are shown in white. Box plots denote quartiles, whiskers highest and lowest group values, crosses (+) show averages. There is no significant difference in age, duration of deafness or transcranial attenuation between the 2 groups. Candidates who chose to use a Baha permanently score significantly higher in the *Bern Benefit in Single Sided Deafness* (BBSS) questionnaire.

not. Furthermore, as Bahas were developed to improve hearing primarily in conductive hearing loss, it is possible that different processor settings might be better suited for users with SSD.

Aim: The aim of our research was twofold: in part (a) of our study, we looked for factors that might influence the decision for or against Baha in candidates with SSD; in part (b) we investigated the effect of different low-frequency attenuation settings in Baha users with SSD.

Materials and Methods: In part (a) of our study, the demographic and audiological data of 46 SSD patients who were evaluated for Baha at our center were analyzed. Twenty-nine subjects chose to use a Baha permanently after a 7–10 day trial, the remaining 17 candidates declined. Twenty-eight of these subjects, 16 of whom became permanent Baha users, were asked to fill in a newly developed questionnaire named ‘Bern Benefit in Single-Sided Deafness’ or BBSS [Kompis et al., 2011]. This questionnaire was designed to help candidates assess their subjective benefit from a Baha or any other CROS-device during a home-trial period. It consists of 10 visual analog scales in which the benefit of the device is rated in 10 different situations. The BBSS-questionnaire has been translated into six languages and can be downloaded at www.hno.insel.ch/bbss.html.

In part (b) the study, speech understanding in noise of 10 adult Baha users with SSD was measured in two different

spatial settings. In setting S_0N_{90} , speech-babble noise was emitted from a loudspeaker located at the front of the Baha user and test sentences from the Baha side. In setting $S_{90}N_0$, the spatial arrangement of the two sound sources was reversed. The improvement of speech understanding with Baha vs. the unaided condition was analyzed. Three different low-cutoff settings with attenuation of sounds for frequencies below 270, 630 or 1500 Hz, respectively, were compared [Pfiffner et al., 2011].

Results: Figure 1 shows a synopsis of the results of part (a) of our study. When comparing the group of candidates who chose a Baha permanently and those who declined a Baha, there is no significant difference in terms of age (average age 50.2 vs. 45.2 years, $p=0.28$, unpaired 2-sided Mann Whitney-Test) or duration of the deafness (average of 16.0 vs. 15.5 years, $p=0.97$). The middle panel of Figure 1 shows a substantial variation in the transcranial attenuation (pure tone average 500 to 4000 Hz) between subjects, but there is no significant difference between the two groups (group averages 3.3 dB vs. 3.5 dB; $p=0.67$). In contrast, the score of the BBSS-questionnaire shows a significant difference ($p=0.0003$) between those who subsequently chose a Baha (average score 35.9 points) and those who declined (average score 5.2 points).

In part (b) of our study, we found an average benefit for the Baha of 2.9 dB in setting $S_{90}N_0$. This improvement is sta-

tistically significant ($p=0.006$; 2-sided Wilcoxon signed rank test) and independent of the low-frequency attenuation setting chosen. Average improvements vary only between 2.8 to 3.1 dB for the different low-cut adjustments. In setting S_0N_{90} , in which a detrimental effect of the Baha was expected, an average loss of 0.9 to 1.7 dB in signal-to-noise ratio was found. The highest loss (1.7 dB) was found at the Baha low-pass setting of 270 Hz, and the lowest (0.9 dB) at 1500 Hz. The difference between the two settings was statistically significant ($p<0.05$; Dunn's multiple comparison test).

Conclusion: Our results suggest that the decision for or against a Baha in SSD is highly subjective. Neither age, duration of deafness nor the amount of transcranial attenuation seemed to be relevant predictive factors. In contrast, the subjectively perceived benefit, as measured with the BBSS questionnaire, is significantly different for those who chose a Baha permanently from those who decline.

Our results from part (b) suggest that low-frequency portions of the incoming sound should be attenuated in Baha users with SSD, preferably up to frequencies between 630 and 1500 Hz. Such low-frequency attenuation settings do not influence speech understanding adversely when speech comes from the side of the Baha but reduce the detrimental effect of noise arriving from the side of the Baha.

Disclosure Statement

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Binaural Hearing with Baha® in Symmetric and Asymmetric Hearing Loss

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Background: The advantages of binaural hearing over monaural hearing have been well documented and are based on the proper detection of interaural cues. We have been investigating the use of the Baha® bone-anchored hearing system in individuals with conductive and/or mixed severe-profound losses since the year 2000 in different populations using the same protocol. This allows direct comparisons between our patients.

Aim: A comparative review of four studies conducted in our clinic for patients receiving a Baha who had either conductive, mixed hearing loss or single-sided deafness, and for a group of normal-hearing listeners with respect to directional hearing and head shadow effects was analyzed.

Materials and Methods: The studies concerned bilateral Baha application in 19 adults with acquired bilateral conductive or mixed hearing loss [Bosman et al., 2001], 13 unilaterally fit adults with acquired unilateral conductive hearing loss, second ear was normal [Hol et al., 2005], 56 adults with SSD using the Baha as a CROS device [Hol et al., 2010], unilateral congenital conductive hearing loss (aural atresia) with unilateral Baha in 10 adults [Kunst et al., 2008] and 10 normal-hearing controls. Benefit (score for bilateral vs. unilateral listening) was derived for directional hearing experiments, lifting of acoustic head shadow tests and binaural squelch tests (release from masking). Measurements were performed after an acclimatization period of at least 10 weeks [Agterberg et al., 2011] except for the congenitally deaf hearing-loss group who were tested after 9 months of experience. Normal-hearing subjects were evaluated either bilaterally or unilaterally with one ear plugged and isolated with an ear muff.

Results: Bilateral Baha application was beneficial in the adults with bilateral conductive or mixed hearing loss, but their scores were poorer than those found in the controls. Head shadow was lifted quite effectively and directional hearing improved for the bilateral and acquired unilateral groups (see Table 1). Binaural squelch could not be demonstrated. However, benefit in patients with unilateral conductive hearing loss and congenital onset (unilateral aural atresia) yielded the poorest results where, on average, non-significant changes were observed for either directional hearing or lifting of the acoustic head shadow, even after a prolonged trial period of

Table 1. Mean localization error for the 5 groups of subjects

	500 Hz		3000 Hz	
	One ear	Two ears	One Ear	Two Ears
Controls	66°	7°	82°	8°
Bilateral CHL /bilateral Baha	66°	26°	56°	25°
Acquired unilateral CHL	46°	16°	58°	20°
Congenital unilateral CHL	34°	30°	39°	31°
SSD	65°	69° CROS	65°	70°

CHL = conductive hearing loss; CROS refers to the Baha-CROS application. 80°=chance level; 0°=perfect localization (adapted from Agterberg et al., 2011).

nine months and adequate Baha-aided thresholds [Agterberg et al., 2011].

In the SSD patients with a Baha-CROS device, small but statistically significant benefit was found in lifting of the head shadow; however, only when the speech source was near the deaf side. When the noise source was near the deaf side, the Baha had an equally large detrimental effect [Hol et al., 2010]. Directional hearing scores remained near chance level with the Baha-CROS device.

Conclusion: Patients with bilateral conductive or mixed hearing loss and those with acquired unilateral conductive hearing loss showed benefit from bilateral listening with their Baha device(s). However, on average, short- and long-term results in patients with unilateral congenital conductive hearing loss were poor. To explain this result, two interacting factors seem to be of importance; namely, the sensitive period for the development of binaural hearing and the degree of cross-over stimulation of the contralateral normal-hearing ear. This suggests that to derive benefit from the Baha, patients with congenital hearing loss should be fitted at an early age (at least earlier than 6 years of age). As expected, effective binaural hearing with the Baha-CROS in SSD patients was not found, however, there was partial relief from acoustic head shadow. Binaural hearing in hearing-impaired subjects implies bilateral fittings, which potentially means double costs; therefore, studies addressing binaural hearing remain of importance both in symmetric and asymmetric hearing loss.

Disclosure Statement

The author states that there is no conflict of interest to be disclosed.

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Unilateral Conductive and Sensorineural Hearing Loss with BC Direct

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Background: In conventional bone-conduction (BC) threshold testing, a transducer is placed on the mastoid bone and the sounds are presented through the transducer, the skin, the soft tissue and then the bone. This resulting threshold is affected by the following factors: implant and transducer placement; contact with the pinna; previous history of mastoid surgery; soft tissue thickness and skull thickness which impacts transcranial sound transmission.

BC Direct is a feature of the Cochlear™ Baha® Fitting Software which allows the measurement of the patient's hearing thresholds directly through the Baha BP100 Sound Processor (SP), as well as through the abutment, the fixture

Fig. 1. Case study patient. Audiogram displaying BC threshold measures using BC Direct, conventional methods and air-conduction thresholds for the normal hearing left ear. Key: × = Left AC; Δ = conventional BC; □ = BC Direct.

and skull to the receiving cochlea. This allows for a stable position during the measurement, ensuring that the transducer does not touch the pinna and is not affected by soft tissue thickness. This means that the transcranial transmission is being accurately measured.

Aim: This report provides an overview of the clinical benefits of using BC Direct over conventional fitting in the daily clinical practice for optimizing the fitting of the BP100 SP, with particular reference to patients suffering from unilateral conductive and sensorineural hearing loss. Clinical experience using BC Direct is illustrated through a case report with patient data showing the differences that occur in BC thresholds and prescribed output gain using the two BC-threshold measurement methods and associated fitting targets provided in the software.

Materials and Methods: The patient underwent fitting via conventional and via BC Direct methods. Thresholds obtained for each method are plotted on an audiogram and then compared as were the subsequent prescribed output gains.

The features in the Baha Fitting Software include: Cochlear Baha Prescription (CBP) algorithms specifically designed for conductive, mixed and unilateral hearing losses; dedicated fitting formulas to individually set and

Fig. 2. Output gain curves of the BP100 prescribed from the conventional BC threshold method.

program the 12-channel digital SP based on calculations derived from BC thresholds measured through BC Direct and conventional methods. These features assist in fine tuning and tailoring the required output signal specifically to suit a patient's hearing loss configuration.

Pure-tone threshold measures are performed in a similar fashion as for conventional audiometry. With a muted internal microphone, threshold testing commences at 1000Hz followed by all other frequencies between 250 to 4000Hz. Frequencies above 4000 Hz are excluded from our evaluations as experience has shown they have little impact upon the output of the device and reduce efficiency in terms of test time.

Results for BC thresholds obtained via the conventional and BC Direct methods are plotted and compared on the same audiogram. The output gain prescribed for each test method is also compared.

Results: Results for our case study are shown in Figure 1. The patient displays a significant asymmetrical loss with normal hearing in the left ear and a total loss in the right ear following removal of an acoustic neuroma. BC thresholds via conventional BC are shown with the triangle symbol (Δ = conventional BC) and via BC Direct as shown by the square symbol (□ = BC Direct). Air-conduction thresholds are also plotted for the better hearing left ear (X = Left AC).

Fig. 3. Output gain curves of the BP100 prescribed from the BC Direct threshold method.

The results highlight the differences in BC thresholds obtained between the two methods. Clinically significant differences are noted for frequencies 500Hz and 4000Hz showing poorer thresholds measured using the BC Direct method and consequently prescribing a higher level of gain than would be recommended conventionally.

The subsequent prescribed output gains for the fitting of this patient's processor derived from the respective methods are illustrated in the software screen printouts in Figures 2 and 3. Subjective reports from the patient note a preference for the loudness and overall sound quality delivered from the BP100 fitted via the BC Direct method. Specifically, the patient reported the sound was more natural, clearer and improved speech understanding.

Conclusion: The findings in this case study demonstrate the BC thresholds obtained via conventional and BC Direct test methods differ and illustrate the advantages of BC Direct in fine tuning and tailoring the fitting for the individual. Subjective reports also suggest differences in loudness levels perceived between the two fitting methods.

BC Direct is a tool that helps to verify the sound processor fitting, provides greater accuracy in the fitting and reduces the amount of fine tuning required. We believe that BC Direct may help to further optimize Baha fittings for all patients and especially for more challenging patients such as those with asymmetrical hearing loss.

Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.