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Clinical Study

The Benefits of Using RONDO and an In-the-Ear Hearing Aid in Patients Using a Combined Electric-Acoustic System

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People with residual hearing in the low frequencies and profound hearing loss in the high frequencies often do not benefit from acoustic amplification. Focus on this group of patients led to the development of the combined electric-acoustic stimulation (EAS) systems which can provide users with greater speech perception than can cochlear implant (CI) alone or acoustic hearing alone. EAS users wear a combined speech processor that incorporates a behind-the-ear audio processor that sits with an ear hook on the user's pinna and a hearing aid, which sits in the ear canal. However, with the introduction of single-unit processors, which combine the audio processor, coil, control unit, and battery pack into a single device that sits on the implant site, therefore off the ear, simultaneous electric (CI) and acoustic (hearing aid) stimulation is not currently possible with a combined processor. To achieve EAS with a single-unit processor, a CI user must also wear a hearing aid. This study seeks to determine if experienced users of combined EAS speech processors could also benefit from using a combination of a single-unit speech processor that sits off the ear and an in-the-ear hearing aid.

1. Introduction

It has been more than a decade since combined electric and acoustic stimulation (EAS) has been used in the auditory rehabilitation of people with residual low frequency hearing and profound hearing loss in the high frequencies, that is, a ski-slope type of hearing loss. These people usually achieve limited benefits from conventional amplification with hearing aids, especially in presence of reduced dynamic range [1–4]. Several studies investigated how to better preserve the low frequency hearing including the surgical technique, the electrode design, and depth of insertion [5]. These investigations have resulted in the development of shorter and atraumatic electrode arrays in order to maximize preservation of cochlear structures in the apex area and consequently preserve hearing in the low frequencies [1, 6–11].

The candidacy criteria for EAS system have been expanding for the last 10 years. Early candidacy included only people with poor low frequency hearing (>65 db at 125 Hz to 500 Hz; [12]) and then it expanded to include people with normal hearing in the frequencies from 125 to 1500 Hz [11]. Helbig and Baumann [13] showed that a cochlear implant is the most suitable device for subjects with hearing loss greater than 55 dB at 125 Hz and 70 dB at 250 Hz. Several studies have demonstrated that EAS significantly enhances speech understanding in quiet and in noise compared to best-aided acoustic hearing alone [1, 9, 10, 14, 15]. Other dimensions of hearing which have been reported to improve upon EAS use are sound quality [1, 10] and the perception and appreciation of music [16–20].

A substantial advance of the EAS system was the development of combined sound processors. These incorporate acoustic stimulation (via a hearing aid) and electrical stimulation (via the CI) into one device.

However, with the introduction of single-unit processors, which combine the audio processor, coil, control unit, and battery pack into a single device that sits off the ear on the implant site, simultaneous EAS is not currently possible with

Table 1: Subject demographic data.

Subject	Age (y)	Gender	Duration of deafness	Etiology	Implanted ear
S1	52	F	20 y	Unknown	L
S2	63	F	25 y	Hereditary	R
S3	61	M	25 y	Noise-induced	R
S4	50	M	50 y	Unknown	L
S5	66	M	30 y	Unknown	R

a combined processor. To achieve EAS with an off-the-ear single-unit processor, a CI user must also wear a hearing aid. Some EAS users, interested in not having to wear a traditional behind-the-ear device, have queried the possibility of wearing the off-the-ear single-unit processor combined with an in-the-ear (ITE) hearing aid. The aim of this study is to compare the objective and subjective outcomes provided by a combined EAS processor with those provided by an off-the-ear single-unit processor combined with an ITE hearing aid.

2. Materials and Methods

This study was designed and conducted in accordance with the Declaration of Helsinki.

Five EAS users participated in the study (Table 1). All subjects had been using a DUET (MED-EL, Innsbruck, Austria) speech processor for a minimum of 6 months. Subjects had similar ages and, except for subject 4, similar durations of deafness. Although it would appear from Table 1 that subject 4 was prelingually deaf, he was nonetheless included in the study because (1) his hearing loss was progressive and (2) he had been a hearing aid user since a very young age and was thus able to develop spoken language skills. All subjects wore a hearing aid in their contralateral ear.

Standardized preoperative evaluation of the subjects included high-resolution computed tomography (CT) and magnetic resonance imaging (MRI). Audiological workup included immittance measures, audiometry, and speech discrimination in quiet using the Arthur Boothroyd (AB) word list [21].

All subjects had been implanted with a MED-EL FLEX^{EAS} electrode array. For study purposes, subjects were tested after (a minimum) 6 months of DUET experience; then they were upgraded to a single-unit processor, the RONDO, and an ITE hearing aid and tested after 6 weeks of RONDO + ITE experience.

Hearing aid fitting was based on the NAL-NL1 hearing aid fitting prescription. To ensure subjects' acceptance of new speech processors, the setting of the acoustic/electric crossover frequency was calculated by the MAESTRO software (MED-EL, Innsbruck, Austria).

Speech perception testing in quiet and in noise was conducted in the best-aided conditions: before implantation with bilateral hearing aids and after implantation with contralateral hearing aids. Tests were performed in a free field with the subject seated 1 meter away from loudspeakers located at 0° angle. Speech perception in quiet was assessed using the City University of New York (CUNY) sentences [22]. Speech perception in noise testing was assessed using the Bamford-Kowal-Bench adaptive Speech-in-Noise (BKB-SIN) test [23]. The BKB-SIN investigates the signal-to-noise ratio needed to achieve a score of 50% of the words correct. The spatial configurations used for speech testing were *S*0/*N*0, speech and noise presented from the front.

Additionally, subjects were asked to assess their own hearing ability/disability in daily life by completing the standardized Speech, Spatial, and Qualities of Hearing (SSQ) questionnaire [24] at the following 3 intervals: preoperatively, after 6 months of experience with the DUET, and after 6 weeks of experience with the RONDO + ITE hearing aid. The SSQ questionnaire consists of 50 "vignettes" most of which are answerable on a simple numeric rating scale in which a score of 10 indicates that a subject believes he/she can perform the vignette "perfectly"; and a score of 0 indicates that he/she can perform it "not at all." Thus, the higher the SSQ score, the greater the subject's self-perceived ability.

3. Results

All subjects had a ski-slope high frequency hearing loss bilaterally. They had worn hearing aids for over 20 years at the time of cochlear implantation. They had from 6 to 18 months of experience with the EAS system before enrolling in the study.

3.1. Speech Understanding. Speech understanding quiet improved from preoperation to 6 weeks of experience with the DUET. All subjects achieved 100% or near to 100% scores. These scores remained stable after upgrading to RONDO + ITE hearing aid. Speech understanding in noise improved remarkably from preoperatively to 6 months of experience with the DUET and remained similar after upgrading to RONDO + ITE hearing aid (Table 2).

3.2. Subjective Assessment. Generally, subjects had higher self-perceived hearing ability with the RONDO than they did preoperatively or with the DUET. Speech scores and Quality scores tended to clearly increase from preoperation to DUET and again, although less markedly, from DUET to RONDO. Spatial scores, however, were more variable: 3/5 subjects had worse scores with the DUET than they had had preoperatively, 2/5 subjects had worse scores with the RONDO than they had had preoperatively, and although all subjects reported greater or equal spatial scores with RONDO as compared to the DUET, only 1/5 subjects reported an increase greater than 0.1 between preoperation and the RONDO (Table 3).

4. Discussion

People with severe to profound high frequency hearing loss obtain better speech perception scores when using EAS than when using only hearing aids [14]. Hearing in the low frequencies is beneficial for better speech discrimination in noise, sound localization, and music appreciation [25]. Therefore preservation of low frequency hearing has been

Table 2: Speech perception scores in quiet and in noise preoperatively, after 6 months of DUET experience, and after 6 weeks of RONDO + ITE hearing aid experience.

Subject	Speech perception scores in quiet (%)			Speech perception scores in noise (dB SNR)		
	Preoperation	DUET	RONDO	Preoperation	DUET	RONDO
S1	90	100	100	12	6.5	6.5
S2	64	99	98	18	13.5	12.5
S3	87	100	100	13	8	7
S4	93	96	100	11	8	8
S5	80	100	100	9	6.5	4.5

Table 3: SSQ scores preoperatively, after 6 months of DUET experience, and after 6 weeks of RONDO + ITE hearing aid experience. The higher the score, the greater the self-perceived ability (10 max, 0 min).

	Speech			Spatial			Quality		
	Preoperation	DUET	RONDO	Preoperation	DUET	RONDO	Preoperation	DUET	RONDO
S1	2	5.2	5.3	6.2	4.1	4.3	3.5	7	6.1
S2	2.5	6	6.5	6.5	6.5	6.5	3.1	6.9	7.1
S3	2.2	6.7	7.8	8.3	7.2	8.4	6.4	7.6	8.3
S4	2.7	2.7	4.5	7.5	2.5	5.3	2.9	2.9	4.6
S5	0.6	4.2	5.8	2.5	3.8	4	3.4	4.3	5.9

the research focus of several studies looking at surgical techniques, electrode length and design, and speech processor/acoustic amplification combination.

The development of the EAS systems, namely, the Cochlear Hybrid and MED-EL DUET, introduced the combination of electrical and acoustic stimulation into one unit. This made the programming of such devices much easier as the electric/acoustic crossover is automatically calculated taking into account the acoustic hearing thresholds [13].

Since 2013, CI users have been offered the option to select a speech processor that sits behind the ear or that sits off the ear on the magnet site on the head (RONDO, MED-EL). RONDO users usually report that it is the most comfortable option when wearing glasses. In view of the clinical demand for the RONDO speech processor by some EAS system users, this study was set up to investigate if the combination of the RONDO with an ITE hearing aid would provide similar, increased, or diminished benefit compared to the conventional MED-EL EAS system.

The results of all Speech-in-Noise tests and the subjective hearing performance (except spatial subscale) demonstrated that subjects benefit from the EAS system when compared to the acoustic hearing alone through hearing aids. The speech perception in quiet tests proved to be too easy for the subjects, especially after implantation. Similar improvement over acoustic alone hearing was noted when subjects were fitted with the RONDO speech processor combined with an ITE hearing aid. The fitting of the new speech processor followed the same parameters of the DUET to avoid major change in hearing characteristics through the electric stimulation. This is probably why there was no substantial difference between the speech perception results and subjective performance. The most important piece of feedback from the subjects was that the ITE hearing aid was more comfortable to wear than the tight fitting of the ear mold of the DUET.

It must however be noted that the results of this study have some limitations. Firstly, the small sample size ($n = 5$) allows us to only make tentative assertions. Similar studies with a larger study sample would be necessary before firmer conclusions could be drawn. Secondly, users may have found the RONDO + ITE hearing aid preferable to the DUET in part because the ITE hearing aid provides more amplification than does the DUET hearing aid.

5. Conclusion

The subjects adjusted well to the RONDO speech processor worn with an ITE hearing aid. Speech perception scores in quiet and in noise did not reveal a substantial difference between the two wearing options. EAS candidates who decline or delay surgery for cosmetic reasons may view the wearing option of the RONDO with an ITE hearing aid more favorably than a behind-the-ear speech processor.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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