

# Outcomes of Treatment of Partial Deafness With Cochlear Implantation: A DUET Study

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**Objectives:** To compare speech test performance of adults with partial deafness cochlear implantation (PDCI) with that of adults with cochlear implant (CI). Based on the results, our objective is to determine the efficacy of the two applications of cochlear implantation, the first characterized by a shallow electrode insertion and preservation of low-frequency natural hearing for partial deafness, and the second characterized by a very deep electrode insertion used in subjects with severe to profound deafness. All the PDCI participants in this study were fitted with a recently upgraded DUET Hearing System from Med-El Corporation, Innsbruck, Austria.

**Study Design:** This is a two-group comparison study. Eleven experienced PDCI adults and 22 postlingually deafened CI adults participated in this study. Subjects were implanted with either COMBI 40+ or PULSAR cochlear implant.

**Methods:** Subjects were tested with monosyllable and sentence tests in Polish in quiet and under various signal-to-noise ratio (SNR) in the conditions of DUET only, CI only, DUET hearing aid (HA) only, and best aided (DUET plus contralateral hearing). CI subjects were tested with their CI.

**Results:** PDCI subjects performed significantly better than CI subjects did. Speech tests demonstrated the best results in the conditions of best aided and DUET only. The poorest results were obtained in the condition DUET HA only. Results show a greater benefit for the PDCI group of subjects fitted with the DUET, compared to the CI alone group.

**Conclusions:** The shallow electrode array insertion with preserved low-frequency hearing is a highly effective method for the treatment of partial deafness. The combination of HA and CI processor, i.e., the DUET, is beneficial in noise and in quiet.

**Key Words:** Partial deafness, cochlear implantation, speech tests in noise.

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## INTRODUCTION

During recent years, a common procedure is that electrodes of neural prostheses for deafness are inserted to a shallow depth in the scala tympani of hearing-impaired persons who have some residual, low-frequency hearing. With appropriately designed and inserted electrodes, acoustic hearing can be preserved in the majority of subjects.<sup>1–6</sup> The concept of electric-acoustic stimulation (EAS) was introduced by von Ilberg in 1999.<sup>1</sup> The specific group of candidates called *partially deaf*<sup>7</sup> are characterized by normal or slightly elevated thresholds in the low-frequency band, with nearly total deafness at higher frequencies. The combination of residual low-frequency, acoustic hearing and high-frequency, electrical stimulation may allow a high level of speech understanding, particularly in a noisy environment.<sup>8–10</sup> Many of these subjects previously would not be considered for cochlear implantation as their speech test scores were either borderline or higher than the criterion for cochlear implantation and it was feared that this intervention would damage the functioning part of the cochlea. However, the partial deafness cochlear implantation (PDCI) group of subjects remain beyond the scope of satisfactory treatment by hearing aids (HA) only.

In 2002, we performed the first implantation of a partially deafened patient, pioneering the technique of partial deafness cochlear implantation.<sup>7</sup> Previously, our group demonstrated that PDCI subjects were able to use their natural low-frequency hearing without amplification together with their cochlear implant (CI) to obtain outstanding results in speech tests.<sup>10</sup> Recently, PDCI subjects were upgraded to the DUET Hearing System from Med-El Corporation, Innsbruck, Austria. The DUET accommodates a Tempo+ speech processor with precise Hilbert Transform envelope detection<sup>11,12</sup> and a two-channel HA in one unit (MED-EL Corporation, Innsbruck, Austria).

To our knowledge, there are no published studies comparing speech test performance between PDCI and CI subjects or normal hearing (NH) subjects. The goals of this study were to compare speech test performance of experienced

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PDCI adult subjects under various noise conditions with cochlear implant subjects with a full electrode insertion and with NH subjects and, based on the results, to compare the efficacy of the two applications of cochlear implantation. The first application is characterized by shallow electrode insertion and preservation of low-frequency natural hearing for partial deafness, and the second is characterized by deep electrode insertion and used in subjects with severe to profound deafness. All the PDCI participants in this study were fitted with the DUET.

## MATERIALS AND METHODS

The Ethical Committee of the Institute of Physiology and Pathology of Hearing, Warsaw, Poland approved the study protocol. Each prospective subject was given an informed consent that explained the purpose and procedures involved in the study. If the patient agreed to participate, the informed consent was signed. The procedures followed were in accordance with the ethical standards of the Helsinki Declaration.

### PDCI Subjects

The study included 11 experienced adult PDCI subjects implanted at the International Institute of Physiology and Pathology of Hearing in Warsaw. The data includes subjects implanted before December 31, 2005. During the initial period of implant use, relatively large changes in speech performance in subjects using the EAS concept were found. To minimize the contribution of this learning effect, all PDCI subjects had at least 12 months of CI experience and had used their DUET Hearing System for at least 1 month prior to the speech tests. Up to December 31, 2005, 17 PDCI adults were implanted in Warsaw and all were considered for inclusion in the study. However, since their cochlear implant surgeries, two subjects lost their hearing ipsilateral to the implant. In one case, the loss was immediately after the PDCI surgery. In the second case, the subject lost hearing 2 years after the surgery, at the time of hormonal treatment that was not related to their CI. At the date of study submission, four additional subjects were not fitted with the DUET. For these reasons, the above 6 subjects were excluded from the study, leaving 11 subjects (7 females and 4 males), whose results are reported here. The mean duration of use of their CI and DUET prior to testing was 22.3 months (12–52 months) and 3.4 months (1–8 months), respectively. The mean

age of the PDCI subjects during the study was 43.2 years (29–69 years). Table I presents their demographic data. The mean duration of hearing impairment (calculated from the age at diagnosis to the time of the CI surgery) was 23.8 years (2–44 years).

### Inclusion Criteria for PDCI

During the preoperative assessment, the hearing levels assessed by pure tone audiometry for both ears was required to be better than 60dB hearing loss (HL) at the frequency 500 Hz and worse than 70 dB HL at the frequency 1.5 kHz. According to the audiograms, most of the subjects had symmetrical hearing preoperatively. In cases where HL was not completely symmetrical, the worse ear was implanted. The results of monosyllable tests for the best aided condition were required not to exceed 75% in quiet, and 40% at a 10 dB signal-to-noise ratio (SNR). Any subject with progressive HL was excluded. Progressive HL was defined as a 10 dB shift at two consecutive frequencies or a 15 dB shift at one frequency over a period of 1 year.

### Surgical Technique and Device Used

All PDCI subjects were implanted with a Med-El COMBI 40+, with either the standard or the medium electrode array. For the subjects in this study, six were implanted with the standard electrode array and five with the medium electrode array. Surgery was performed using the round-window technique developed by Skarżyński et al.<sup>2,8</sup> Based on the operating room report for each case, the insertion depth varied from 18 to 22 mm as noted by the surgeon.

### DUET HA and CI Programming

The fitting was performed based on the fitting guidelines provided by the Med-El Corporation. The DUET HA is a two-channel device amplifying the low-frequency region up to 1800 Hz. The COMBI 40+ is a 12-electrode CI with an electrode length of 26.4 mm (electrode spacing 2.4 mm) for the standard electrode array and 20.9 mm (electrode spacing 1.9 mm) for the medium electrode array. Only those electrodes inserted in the cochlea were activated, and electrodes were classified as intra- or extra-cochlear using impedance telemetry and reported hearing sensation. The number of active electrodes was usually 8 for the standard and 10 for the medium electrode array. The lower frequency end of the CI map varied from 300 to 850 Hz. The upper frequency end was 8.5 kHz in all cases.

TABLE I.  
Demographic Data of the Group of Subjects With Partial Deafness Cochlear Implantation (PDCI) (N = 11).

Subject	Age During the Study	Age at Diagnosis	CI Use (Months)	DUET Use (Months)	Etiology
PD 1	29	14	12	2	Idiopathic
PD 2	32	28	24	2	Idiopathic
PD 3	54	39	12	1	Idiopathic
PD 4	35	14	12	2	Idiopathic
PD 5	43	4	17	1	Ototoxic medications?
PD 6	52	41	42	3	Ototoxic medications
PD 7	47	5	12	6	Ototoxic medications
PD 8	29	Since birth	52	1	Ototoxic medications
PD 9	31	4	39	8	Meningitis
PD 10	69	31	30	2	Ototoxic Medications
PD 11	53	7	27	6	Ototoxic Medications?

CI = cochlear implant; PD = partially deaf.

## CI Subjects

The control group of CI subjects consisted of postlingually deafened adults implanted with the COMBI 40+ or PULSAR cochlear implant from the Med-El Corporation from January 1, 2004, to December 31, 2005. Children and prelingually deafened adults were excluded from the study. A retrospective review was performed on the clinical charts, and programming and operation reports. Patient demographic data, device type, electrode type, hearing loss (HL), etiology, and speech test results were noted for each patient.

The group included 22 subjects (14 females and 8 males). Two patients used an additional contralateral HA due to their low-frequency moderate-to-severe HL. The rest of the subjects had at least a severe HL contralaterally, and therefore did not wear any additional HA. Twenty subjects had experienced long-term progressive HL, and two subjects with idiopathic etiology had experienced sudden HL. Three subjects with the idiopathic etiology had a familial history of deafness. However, our limited tests did not confirm any genetic etiology. The mean age of the CI subjects during the testing was 42.3 years (range 21–60 years). The mean use of their CI during the testing was 18 months (12–33 months). Table II depicts their demographic data. Twenty subjects were implanted with the COMBI 40+ and two subjects were implanted with the PULSAR cochlear implant. Each implant used a standard array. A full electrode insertion was reached in 21 subjects. In one case, one electrode pair was outside the cochlea. Both subjects implanted with the PULSAR were programmed in the same manner as the subjects with the COMBI 40+. None of the new features was applied. For each subject, the frequency range of his or her CI map was from 300 Hz to 8.5 kHz. Each CI subject used his or her TEMPO+ speech processor (Med-El). The

duration of hearing impairment varied from 3 months to 50 years (mean 19.3 years).

## Inclusion Criteria for CI

During the preoperative assessment, each subject scored less than 40% on a monosyllable test in the best aided condition, and HL for the ipsilateral ear was equal to or worse than 65 dB HL for each audiometric frequency and equal to 65 dB HL for maximum of one audiometric frequency.

## NH Subjects

A second control group, consisting of NH subjects, was comprised of 20 adults, age 18 to 23, who also participated in a separate study to validate the Pruszewicz monosyllable test.<sup>13</sup> Each subject passed a screening test for normal hearing function. Screening procedure included pure-tone testing in the frequency region from 1 through 4 kHz. The individual was considered to have normal hearing when unilateral HL was not greater than 25 dB HL. The group included 12 females and 8 males.

## Audiologic Testing

Pure-tone testing was performed using a Siemens SD5 audiometer (Earlangen, Germany) calibrated according to standards established by the American National Standards Institute (ANSI). Acquisition of unaided audiograms was performed in an IAC soundproofed booth under Sennheiser HDA 200 headphones (Sennheiser, Wednebstel, Germany). All the aided audiograms were performed in the free field with the contralateral ear plugged. Plugging was performed by filling the ear canal and pinna with impression mass using a syringe.

## Speech Reception Testing

Each group of patients was tested across multiple SNRs for monosyllabic word tests, which allowed us to estimate the 50% correct point for each group of subjects and for the multiple conditions within the PDCI group. Fifty percent word-recognition performance was estimated by linear interpolation. All speech tests we performed at the level of 60 dB HL.

At the Institute of Physiology and Pathology of Hearing, Warsaw, speech tests in quiet and in noise (10 dB SNR) are performed at regular intervals for CI subjects. However, these tests proved to be unsatisfactory for our PDCI population as many of them scored at or near 100% correct under both of these conditions. For this reason, testing at 0 dB SNR was added to the test battery.

To compare performance under various listening conditions, the Pruszewicz monosyllable test was performed in quiet, and at SNR of 10 dB and 0 dB, and the Polish Hochmair-Schulz-Moser (HSM) sentence test at a SNR of 10 dB. The Pruszewicz monosyllable test consists of 10 lists, each containing 20 words. The Polish HSM sentence test consists of 30 lists, each containing 20 sentences. For each SNR condition, two monosyllable test lists were run (giving 40 items) to reduce the variance. PDCI subjects were tested in four different conditions: 1) DUET HA only, 2) CI only, 3) DUET only, and 4) best aided (contralateral ear unplugged).

During the first three conditions, the contralateral ear was plugged. The order of testing and speech test lists were randomized. During the testing, no changes were made to the fitting parameters for the CI or for the HA part of the DUET. CI-only testing was performed on the day of upgrade to the DUET with the programming map that patients were accustomed to. All other testing was performed after a minimum of 1 month of DUET use (Table I).

The control group of CI subjects was tested with the Pruszewicz monosyllable test in quiet and at the SNR of +10 dB. Patients were tested with their CI. The contralateral ear was

TABLE II.

Demographic Data of the Control Group of CI Subjects (N = 22).

Subject	Age During the Study	Age at Diagnosis	CI Use (Months)	Etiology
CI 1	33	13	16	Idiopathic
CI 2	27	24	24	Idiopathic; sudden
CI 3	31	6	20	Meningitis
CI 4	53	35	20	Idiopathic
CI 5	42	18	17	Viral
CI 6	47	43	23	Otosclerosis
CI 7	60	21	33	Idiopathic
CI 8	28	6	20	Idiopathic
CI 9	43	9	20	Idiopathic
CI 10	40	17	19	Idiopathic
CI 11	42	6	23	Viral
CI 12	55	46	18	Idiopathic; sudden
CI 13	23	7	18	Ototoxic medications
CI 14	43	23	18	Idiopathic
CI 15	28	8	12	Idiopathic
CI 16	54	49	12	Otitis media
CI 17	51	49	12	Idiopathic
CI 18	58	8	12	Meningitis
CI 19	47	37	12	Idiopathic
CI 20	21	7	12	Ototoxic medications
CI 21	48	18	12	Idiopathic
CI 22	56	53	13	Ototoxic medications

CI = cochlear implant.

unplugged. For the two subjects with some contralateral hearing, results may have been augmented by that hearing in addition to the hearing provided by the implant.

The group of normal hearing (NH) subjects was tested by the Pruszewicz monosyllabic word test in quiet, and at the SNRs of +3, -3 and -8 dB.

### Statistical Analysis

For comparison of speech test data between the three groups of subjects, ANOVA single-factor test was used. For the post hoc comparisons, the Tukey-Kramer honestly significant difference (Tukey-Kramer HSD) was used. Within the PDCI group, analysis was performed with the ANOVA two-factor-without-replication test. For the post hoc comparisons, paired two-tailed *t* test was used. The analysis was performed for monosyllables in quiet, 10 and 0 dB SNR, and sentence test for 10 dB SNR. Statistical significance was  $P = .05$ .

## RESULTS

Figure 1A and B depict the mean aided and unaided and individual unaided audiograms for the group of PDCI subjects acquired during the study. The unaided mean audiogram for the contralateral ears is shown in Figure 1C. For each audiogram, if the subject's response was anaacoustic, the level of 120 dB HL was substituted.

Results from the speech tests conducted with the PDCI subjects are presented in Figure 2. The tests included recognition of monosyllabic words in quiet and at the SNRs of +10 and 0 dB, and recognition of the Polish version of the HSM sentences at the SNR of +10 dB. Mean scores and standard deviations are shown. The highest mean scores were achieved in the condition best aided (plus contralateral ear) and DUET only (contralateral ear plugged). Scores for the sentence test approximated the ceiling of 100% correct for all conditions except DUET HA only. Thus, the sentence test is not sensitive for discriminating possible differences among the DUET, CI only, and best aided conditions. For comparisons between these three conditions, the results of the Pruszewicz monosyllable test at various SNR were used.

Within the PDCI group, comparisons revealed no significant differences between the condition best aided and DUET only for testing in quiet ( $P = .16$ , paired two-tailed *t* test) and 0dB SNR ( $P = .08$ , paired two-tailed *t* test), however, testing at a 10dB SNR showed significantly better results for the condition Best Aided ( $P = .007$ ; paired two-tailed *t* test). For comparisons between the condition CI only and DUET only, significantly better results for the DUET only condition were observed at all noise levels (quiet:  $P = .04$ ; 10 dB SNR:  $P = .008$ ; 0 dB SNR:  $P = .003$ ; paired two-tailed *t* test). Similarly, the best aided condition showed significantly better results than the results for the CI Only condition ( $P < .02$ ; paired two-tailed *t* test). The results for the condition HA only were significantly poorer than the results for any other condition ( $P = .000$ ; paired two-tailed *t* test).

Figure 3 shows the mean scores from the Pruszewicz monosyllable test for the three different groups of subjects: CI subjects, PDCI subjects (for various listening conditions) and NH subjects. For the group of NH subjects, the estimated 50% word-recognition performance was -5.4 dB. For the group of PDCI subjects, the esti-

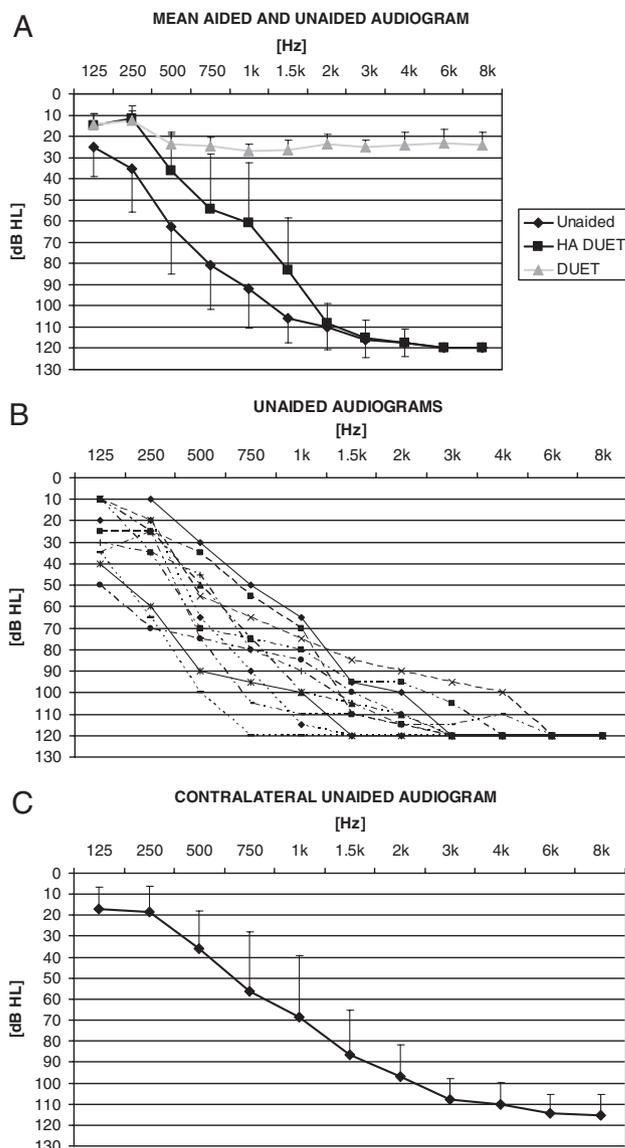


Fig. 1. Aided and unaided audiograms for the group of PDCI subjects (N = 11). (A) Mean audiograms for the implanted ear; (B) Individual unaided audiograms for the implanted ear; (C) Mean unaided audiograms for the contralateral non-implanted ear. Error bars depict standard deviations for each listening condition.

mated level was 3.3, 4.2 and 8.4 dB in the conditions best aided, DUET only and CI only, respectively. For the group of CI subjects, the estimated 50% word-recognition performance was 14.1 dB.

The means for testing in quiet and at 10 dB SNR for the PDCI group of subjects tested in the condition DUET only and best aided were significantly higher than the means for the CI group of subjects ( $P < .01$ ; Tukey-Kramer HSD). There were no significant differences between the PDCI group of subjects tested in the condition CI Only and the CI group of subjects in quiet ( $P = .07$ ; Tukey-Kramer HSD). However, for testing in 10 dB SNR, the speech test results were significantly higher for the PDCI group in the condition CI Only ( $P = .04$ ; Tukey-Kramer HSD).

## SPEECH TESTS IN PDCI

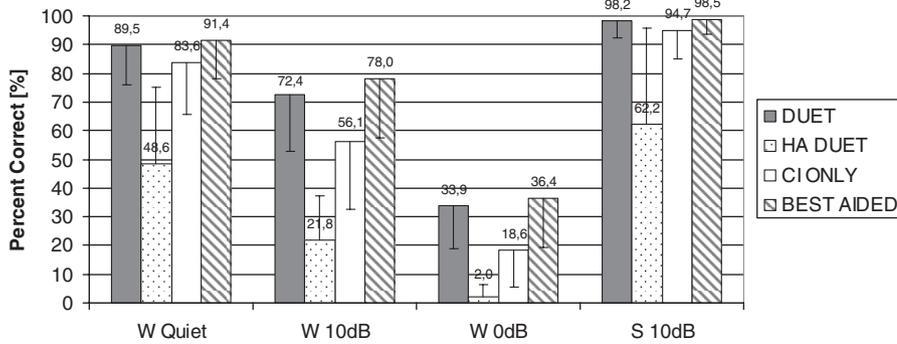


Fig. 2. Pruszewicz monosyllable test results in quiet, 10 and 0 dB SNR and Polish HSM Sentence test results in 10 dB SNR for the group of PDCI subjects (N = 11). Mean and standard deviations for the conditions DUET Only, DUET HA Only, CI Only and Best Aided (plus contralateral ear) are shown. W stands for the monosyllabic word test and S stands for the sentence test.

Using the linear approximation, the estimated mean percentage word score increase per 1 dB SNR for the CI-, PDCI- and NH subject groups were 6.3%, 4.2%, and 3.0%, respectively. For each group, the best aided condition was used (plus contralateral unaided ear). PDCI subjects used their DUET Hearing System on their implanted ear.

### DISCUSSION

Within the PDCI group, comparisons suggested that subjects performed best in the condition best aided (plus contralateral ear) for the 10 dB SNR condition. Best aided was not different from the DUET alone for the other two SNR conditions. Significance levels were quite high, suggesting that differences might have been revealed using more subjects.

The significant differences obtained between the conditions DUET only and CI only for the PDCI group suggest that application of an additional HA allows use of the

low-frequency hearing to a greater extent. For the best aided condition (plus contralateral ear) our subjects scored 91.4% in quiet on average and 78% at the SNR of 10 dB. This compares favorably to the mean scores of 85% and 60.5% achieved in a previous study without amplification in the ipsilateral ear.<sup>10</sup>

These data place the PDCI subjects in an intermediate position between CI and NH groups (Fig. 3). This indicates efficacy of PDCI approach and also the remaining gap between prosthetic and normal hearing.

The results showed significant differences in speech performance between the groups of CI subjects and PDCI subjects (conditions DUET, best aided and CI only). We performed testing in the CI only condition with the map settings our experienced subjects were accustomed to in the condition cochlear implant with the contralateral ear plugged. The programming parameters may change when an additional HA is applied. The influence of the PDCI

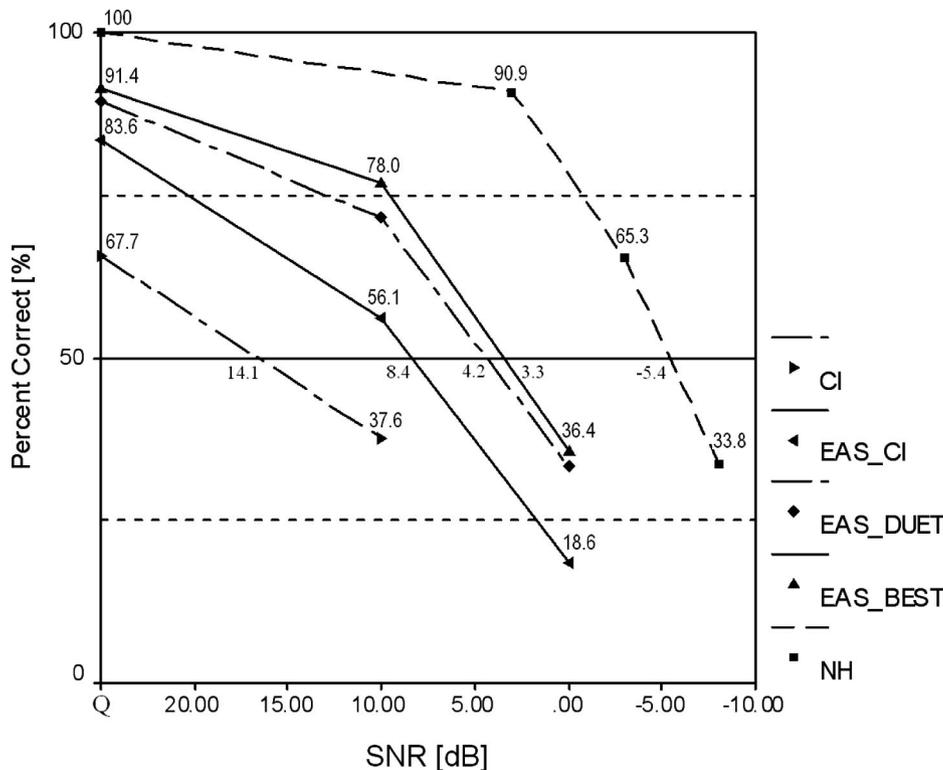


Fig. 3. Comparison of Pruszewicz monosyllable test results for three groups of subjects: 1) CI subjects (N = 22) tested with their CI (contralateral ear was unplugged); 2) PDCI subjects using the EAS concept (N = 11) tested in three conditions: CI only (contralateral ear plugged); DUET only (contralateral ear plugged) and best aided (plus contralateral ear); and 3) Normal hearing (NH) subjects (N = 20) tested for both ears. For each condition, 50% word-recognition performance was estimated using the linear approximation.

group's CI and HA programming parameters on outcomes was not investigated in this paper. Despite this fact, a significant difference was obtained compared with the scores from the speech tests performed by the control group of CI users.

As we mentioned in the material and methods section, six of our PDCI subjects were not fitted with the DUET for various reasons. Thus their scores were excluded from the data presented in the results section. None of these subjects use any additional hearing aid. Thus, their best aided condition was CI ipsilaterally plus contralateral ear unplugged. For this condition, the mean Pruszewicz monosyllable test scores in quiet and at a 10 dB SNR for the excluded group of PDCI subjects were  $94.3 \pm 5.7$  and  $69.7 \pm 5.3$ , respectively ( $N = 6$ ). When we added these data to the PDCI study group as presented in the results section to the best aided condition ( $N = 17$ ), the post hoc analysis again showed a significant difference between the mean Pruszewicz monosyllable test score for the PDCI group and the control group of CI subjects in quiet and 10 dB SNR for the group of CI subjects ( $P = .000$ ; Tukey-Kramer HSD). This suggests that even if PDCI subjects lose their ipsilateral hearing, they still have substantial benefit from their PDCI surgery.

Our results suggest the following differences between the PDCI and CI subjects. The difference between the group of PDCI and NH subjects in the linearly approximated 50% word-recognition performance was 8.7 dB. For the group of CI subjects, the difference from the NH subjects was 19.5 dB (Fig. 3). Five CI subjects did not reach 50% correct for testing in any SNR conditions.

Schleich et al.<sup>14</sup> tested 21 experienced bilateral COMBI 40+ adults in noise using an adaptive Oldenburg sentence test. The study showed that 50% sentence recognition performance was reached at 0.9 dB SNR for a single cochlear implant condition and -1.2 dB SNR when tested with two cochlear implants. This gives as a total improvement of 2.1 dB. For our group of PDCI subjects, adding the contralateral ear increased 50% word recognition performance by 0.9 dB (from 4.2–3.3 dB SNR). Mean audiograms for the contralateral non-implanted ear are in Figure 1C.

The postlingually deafened experienced CI subjects reached 67.7% in monosyllable tests in quiet. This result is consistent with the previously reported outcomes in tests in different languages.<sup>15,16</sup>

Despite the similar duration of hearing impairment (23.8 years for the PDCI group, and 19.3 years for the CI group) and mean age between both groups (43.2 years for the PDCI group, and 42.3 years for the CI group), one possible explanation of our results may be in the remaining low-frequency hearing. The CI group included 13 postlingually deafened subjects with the hearing deprivation greater than 10 years. The monosyllable test results for this group of subjects were  $63.1 \pm 23.6\%$  in quiet and  $33.0 \pm 22.9\%$  at 10 dB SNR. The PDCI group included one prelingually and three perilingually deafened subjects. Two of the perilingually deafened subjects were diagnosed at age 4 or 5, however it is most likely that the HL was congenital. The monosyllable test results for this group of subjects were  $77.5 \pm 13.5\%$  in quiet,  $58.8 \pm 21.4\%$  at 10 dB SNR, and  $23.8 \pm 7.5\%$  at 0 dB SNR. These data suggest

that the duration of hearing deprivation may influence the PDCI outcomes.

The data support our previous findings that partial deafness cochlear implantation is a highly effective method of treatment for selected group of subjects.<sup>10</sup> Additionally, the data support the conclusion that the PDCI method of treatment is more effective than a regular CI for these subjects.

This study included only speech test comparisons. It would be of further interest to compare long-term audiologic data, e.g., from 5 years after the implantation. This study includes PDCI subjects implanted for duration from 12 to 53 months, and only three of its subjects were implanted more than 3 years ago.

Kiefer et al.<sup>17</sup> also achieved a significant improvement in speech test scores in his group of partially deafened COMBI 40+ subjects. Twelve months after the initial stimulation, his group of subjects reached a mean score of 62% on monosyllable speech tests in the condition CI and unplugged contralateral ear, and 75% in the best aided conditions. Our group of PDCI subjects was not tested in the condition CI plus contralateral ear. However, based on our results, we may expect scores higher than 83.6% (Fig. 2). For the best aided condition (plus contralateral ear) our subjects scored 91.4% in quiet and 78% at the SNR of 10dB. One of the reasons underlying such a large difference in speech performance between both groups may be in the selection criteria. While the majority of subjects presented by Kiefer were CI candidates based on the speech test results (the mean preoperative speech test score was 7%) and none of the subjects scored better than 40% in the monosyllable test preoperatively, for the subjects of this paper, five scored either equal to or higher than 50% and thus they would not be considered for a regular CI. Despite this, all of the subjects gained great benefit in the EAS condition, either in the CI only or in the CI plus HA condition. Another difference is based on the audiogram. While Kiefer included subjects with hearing levels poorer than 60 dB HL at 1 kHz, our selection criteria included subjects with hearing levels worse than 70 dB HL at the frequency 1.5 kHz. For our five PDCI subjects with preoperative speech test scores higher or equal than 50%, the mean monosyllabic test score in quiet and at the SNR of 10dB acquired during the study were  $99.0 \pm 2.2\%$  and  $91.6 \pm 10.5\%$ , respectively. The mean preoperative score for our whole PDCI group was 45.4% in quiet and 13.7% at 10 dB SNR. These data were published by Skarzynski for our first 11 subjects.<sup>10</sup>

We note that these conditions could be supported by the better hearing (and most likely better preservation of cochlear structures) in the PDCI group compared with the CI group. However, the data also show efficacy of the PDCI approach.

## CONCLUSIONS

The PDCI subjects of this study performed significantly better in speech tests than a control group of standard cochlear implant subjects. This suggests that shallow electrode array insertion with preserved low-frequency hearing is more efficient method of treatment than a cochlear implantation without hearing preservation technique for the selected group of subjects. The results show greater

benefits for the PDCI group of subjects when fitted with the DUET Hearing System than when using their cochlear implant alone.

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### BIBLIOGRAPHY

1. von Ilberg C, Kiefer J, Tillien J, et al. Electric-Acoustic Stimulation (EAS) of the Auditory System. New Technology against severe hearing loss. *ORL J Otorhinolaryngol Relat Spec* 1999;61:334–340.
2. Skarzynski H, Lorens A, Piotrowska A, Anderson I. Preservation of low frequency hearing in partial deafness cochlear implantation (PDCI) using the round window surgical approach. *Acta OtoLaryngol* 2007;127:41–48.
3. Gantz BJ, Turner C. Combining acoustic and electrical speech processing: Iowa/Nucleus hybrid implant. *Acta Otolaryngol* 2004;124:344–347.
4. Gstöttner W, Kiefer J, Baumgartner W, Pok S, Peters S, Adunka O. Hearing preservation in cochlear implantation for electric acoustic stimulation. *Acta Otolaryngol* 2004; 124:348–352.
5. Lorens A, Geremek A, Walkowiak A, Skarżyński H. Residual acoustic hearing in the ear before and after cochlear implantation. In: Jahnke K, Fischer M, eds. *4th European Congress of Oto-Rhino-Laryngology Head Neck Surgery*. Bologna: Monduzzi; 2000:1:135–138.
6. Skarżyński H, Lorens A, D'Haese P, et al. Preservation of residual hearing in children and post-lingually deafened adults after cochlear implantation: an initial study. *ORL J Otorhinolaryngol Relat Spec* 2002;64:247–253.
7. Skarzynski H, Lorens A, Piotrowska A. A new method of partial deafness treatment. *Med Sci Monit* 2003;9:CS20-24.
8. Wilson BS, Lawson DT, Muller JM, Tyler RS, Kiefer J. Cochlear implants: some likely next steps. *Annu Rev Biomed Eng* 2003;5:207–249.
9. Kiefer J, Tillein J, von Ilberg C, et al. Fundamental aspects and first results of the clinical application of combined electric and acoustic stimulation of the auditory system. In: Kubo T, Takahashi T, and Iwaki T. eds. *Cochlear Implants—An Update*. The Hague, Netherlands: Kugler Publications; 2002:569–576.
10. Skarzynski H, Lorens A, Piotrowska A, Anderson I. Partial deafness cochlear implantation provides benefit to a new population of individuals with hearing loss. *Acta OtoLaryngol* 2006;126:934–940.
11. Eddington DK, Noel VA, Rabinowitz WM, Svirsky MA, Tierney J, Zissman MA. Speech processors for auditory prostheses. *Ninth Quarterly Progress Report 1994*, NIH Project NO1-DC-2-2402.
12. Ondráček O: *Discrete Signals and Systems*. Bratislava, Slovakia: STU Bratislava Publications; 2002.
13. Lorens A, Obrycka A, Piotrowska A. The validation of Pruszewicz Monosyllabic Word Test lists for auditory word recognition in noise. *Audiofonologia* 2006;28:71–72.
14. Schleich P, Nopp P, D'Haese P. Head shadow, squelch, and summation effects in bilateral users of the MED-EL COMBI 40/40+ cochlear implant. *Ear Hear* 2004;25: 197–204.
15. Hochmair I, Arnold W, Nopp P, Jolly C, Muller J, Roland P. Deep electrode insertion in cochlear implants: apical morphology, electrodes and speech perception results. *Acta Otolaryngol* 2003;123:612–617.
16. Bassim MK, Buss E, Clark MS, et al. MED-EL Combi 40+ cochlear implantation in adults, *Laryngoscope* 2005;115: 1568–1573.
17. Kiefer J, Pok M, Adunka O, et al. Combined electric and acoustic stimulation of the auditory system: results of a clinical study. *Audiol Neurootol* 2005;10:134–144.