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Results of Partial Deafness Cochlear Implantation Using Various Electrode Designs

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Key Words
Partial deafness · Hearing preservation · Electric-acoustic stimulation · Cochlear implants

Abstract
Nineteen adults and 9 children who received a unilateral cochlear implant between 2002 and 2007 were included in the study. All subjects were preoperatively diagnosed with significant residual hearing in low frequencies, termed as 'partial deafness', and were implanted according to a 6-step round window surgical technique for partial deafness cochlear implantation. Hearing was preserved to a great extent in the partial deafness cochlear implantation (PDCI) group. After a short period following activation of the cochlear implant, highly significant improvement in the recognition of monosyllabic words was observed. With a developed round window surgical procedure and limited electrode insertion, hearing can be preserved in the majority of patients with partial deafness. PDCI is a feasible means of treating individuals who have good low-frequency hearing but severe to profound hearing loss in the mid to high frequencies.

Introduction

Recent advances in cochlear implant technology have resulted in the relaxation of the selection criteria for their use [Lenarz, 1998]. As the benefits of implantation have been more widely demonstrated, there has been increasing emphasis not only on implanting individuals who are totally deaf, but also those with residual hearing at low frequencies [Rizer, 1988; Brimacombe et al., 1994]. Moreover, recent studies have shown that residual hearing can be preserved after cochlear implantation [Lorens et al., 2000; Skarzynski et al., 2002]. Further extension of selection criteria and new perspectives for postoperative rehabilitation were proposed by von Ilberg et al. [1999]. They suggested that the use of a hearing aid and a cochlear implant in the same ear can result in better hearing and speech perception than when using either device on its own. This concept, known as electric-acoustic stimulation (EAS), was later successfully realized in practice [von Ilberg et al., 1999; Gantz and Turner 2004; Gstoettner et al., 2004; Kiefer et al., 2005].

However, there is another group of patients whose hearing impairment is characterized by normal or slightly elevated thresholds in the low-frequency region with almost total deafness at higher frequencies. Herein, we describe this type of hearing impairment as 'partial deafness'. Patients in this group remain beyond the scope of effective treatment using hearing aids alone. Cases of

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partial deafness are usually characterized by normal hearing at low frequencies, which are not generally amplified with a hearing aid. This could allow for the electrical stimulation of high-frequency signals via a cochlear implant and acoustic stimulation of low-frequency signals using preserved natural low-frequency hearing.

The International Center of Hearing and Speech reported their first case of partial deafness cochlear implantation (PDCI) in 2002 [Skarzynski et al., 2003]. In 2004, following the success in preserving the hearing of traditional cochlear implant users and the outstanding success of PDCI in adults, we implanted the first child suffering from partial deafness.

The benefits of preserving acoustic hearing over a 1-year observation period were demonstrated in the first 10 adults [Skarzynski et al., 2006, 2007a] and 9 children [Skarzynski et al., 2007b].

PDCI involves 3 challenging stages for its successful application:

(1) the careful selection of candidates who are most likely to gain substantial benefit from the procedure;
(2) a surgical technique based on the 'round window' approach that favors hearing preservation with the introduction of an electrode array directly into the scala tympani in a manner that minimizes trauma to the candidate;
(3) the transfer of sound information by optimally combining acoustic and electric stimulation.

The aim of this study was to evaluate the short- and long-term benefits of combined electric-acoustic stimulation following PDCI in a larger group of adults and children than has been used in previous studies.

Materials and Methods

Subjects

We tested 28 subjects, 18 adults and 10 children, diagnosed with partial deafness, who received either a Combi 40+ or a Pulsar cochlear implant through partial insertion of a 30-mm standard (n = 15) or Flex electrode (n = 3), as well as full insertion of a 20-mm M electrode (n = 10), using the round window technique for hearing preservation. The selected patients had at least 1 year's experience of using a cochlear implant. Table 1 presents their demographic data.

The mean age at implantation was 30.3 years (ranging from 4.2 to 65.9 years). Both pure tone audiometry and speech reception testing in quiet and speech-shaped noise were performed preoperatively, at implant fitting, and then at 3, 6, 12, 24 and 36 months after the initial fitting of the device. Tests of speech reception were performed using the Pruszewicz monosyllabic Polish word test (20 words per list, 20 lists) [Pruszewicz et al., 1994], with the lists of words being randomized between test conditions.

The Pruszewicz monosyllable test is a consonant-nucleus-consonant test in Polish that is similar to the consonant-nucleus-consonant monosyllabic word test in English. Recorded words were presented in the sound field at 60 dB sound pressure level (SPL) in quiet and in competition with speech-shaped noise at a speech-to-noise ratio (SNR) of +10 dB.

The results shown are the mean values of the 3 test lists.

Recently, 11 PDCI subjects were upgraded to the Duet Hearing System (Med-El, Innsbruck, Austria). The Duet accommodates a Tempo+ speech processor with precise Hilbert transform envelope detection and a 2-channel hearing aid in 1 unit. Results from this group were reported separately [Lorens et al., 2007].

The subjects were tested using their natural bilateral acoustic hearing and electrically stimulated hearing via the cochlear implant in 1 ear, or using the Duet speech processor and contralateral acoustic hearing.

Surgery

The same surgical technique, i.e. the round window approach [Skarzynski et al. 2007a], was used to ensure hearing preservation in all subjects. In 3 subjects (all adults), surgery was conducted with an additional transmeatal approach to ensure the best possible visualization of the round window niche, because in these cases the niche could not be properly prepared using the facial recess approach.

Statistical Analysis

In order to facilitate comparison of hearing preservation between the 3 groups of subjects using 3 types of electrodes, the ANOVA single-factor test was used. For the post hoc comparisons, the Tukey-Kramer honestly significant difference was used. In order to study the development of scores over time for speech data, ANOVA for repeated measurements with time as a factor were performed for each test condition. To detect differences between the test intervals parametric paired Student's t tests were used. The analysis was performed for monosyllables presented in quiet and in competition with noise at +10 dB SNR. The statistical significance parameter was set at $p = 0.05$.

Results

Hearing Preservation

Hearing preservation immediately following the operation was achieved in 26 out of 28 (93%) PDCI subjects. Two other subjects experienced hearing loss over the subsequent 1- to 3-year period. Complete hearing preservation (within 10 dB of preoperative thresholds) was achieved in 13 (46.4%) subjects and found to be stable over the following 1–4 years. In 11 subjects (39.4%), low-frequency hearing remained partially preserved over the 1- to 3-year period. The average hearing thresholds, measured before surgery and 1–4 years afterwards, of the 3 groups who were implanted with 3 different electrodes are shown in figure 1.

Table 1. Demographic data of the group of subjects with PDCI

	Age at implantation years	Implant system	Electrode	Insertion	Hearing preservation previously reported
PDCI 1	25	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 2	48	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 3	43	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 4	66	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 5	49	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 6	26	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 7	30	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 8	27	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 9	32	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 10	43	Combi 40+	standard	partial 8 channels	yes[1, 2]
PDCI 11	9	Combi 40+	standard	partial 8 channels	yes[3]
PDCI 12	50	Combi 40+	standard	partial 8 channels	no
PDCI 13	57	Combi 40+	standard	partial 8 channels	no
PDCI 14	11	Combi 40+	M	full	yes[3]
PDCI 15	29	Combi 40+	M	full	no
PDCI 16	54	Combi 40+	standard	partial 8 channels	no
PDCI 17	33	Combi 40+	standard	partial 8 channels	no
PDCI 18	11	Combi 40+	M	full	yes[3]
PDCI 19	47	Combi 40+	Flex	full	no
PDCI 20	6	Pulsar	M	full	yes[3]
PDCI 21	4	Pulsar	M	full	yes[3]
PDCI 22	50	Pulsar	Flex	partial 8 channels	no
PDCI 23	9	Pulsar	M	partial 8 channels	yes[3]
PDCI 24	11	Pulsar	M	partial 8 channels	yes[3]
PDCI 25	9	Pulsar	M	partial 8 channels	yes[3]
PDCI 26	12	Pulsar	M	partial 8 channels	yes[3]
PDCI 27	17	Pulsar	M	partial 8 channels	no
PDCI 28	39	Pulsar	Flex	partial 8 channels	no

[1] Skarzynski et al. [2006]. [2] Skarzynski et al. [2007a]. [3] Skarzynski et al. [2007b].

Speech Reception Testing

Three children out of 10 included in the current study could not be assessed using the standard monosyllable test because it was too difficult for them. For this reason, these 3 subjects were excluded from the speech reception evaluation, leaving 25 subjects with at least 1 year's experience of using the device.

Given that the results for children mirrored the improvement over time that was seen in our adult population (an average improvement of 42% was observed in children, compared to an average improvement of 49% in adults at 12 months), we decided to analyze the monosyllable scores for children and adults together.

The results of monosyllable testing under quiet conditions are presented in figure 2. The mean scores and standard deviations are shown. As mentioned earlier, the statistical significance was evaluated by means of ANOVA. The pairwise comparisons showed that the effects are significant between preoperative and 1-month ($p = 0.0006$) and between 1- and 3-month measurements ($p = 0.0057$). There were no significant differences between 3 and 6 months or between 6 and 12 months.

Figure 3 shows the scores for monosyllable testing under noisy conditions. There was a significant increase in scores between preoperative and 1-month ($p = 0.000$), 1- and 3-month ($p = 0.01$), and 3- and 6-month measurements ($p = 0.03$). There was no significant difference between the 6- and 12-month assessments.

The performance over time of 8 subjects (with 4 or more years' experience) under quiet conditions is shown in figure 4 and under noisy conditions in figure 5. The improvements between test scores over the intervals 3–6 months, 6–12 months, 1–2 years, 2–3 years and 3–4 years were not significant.

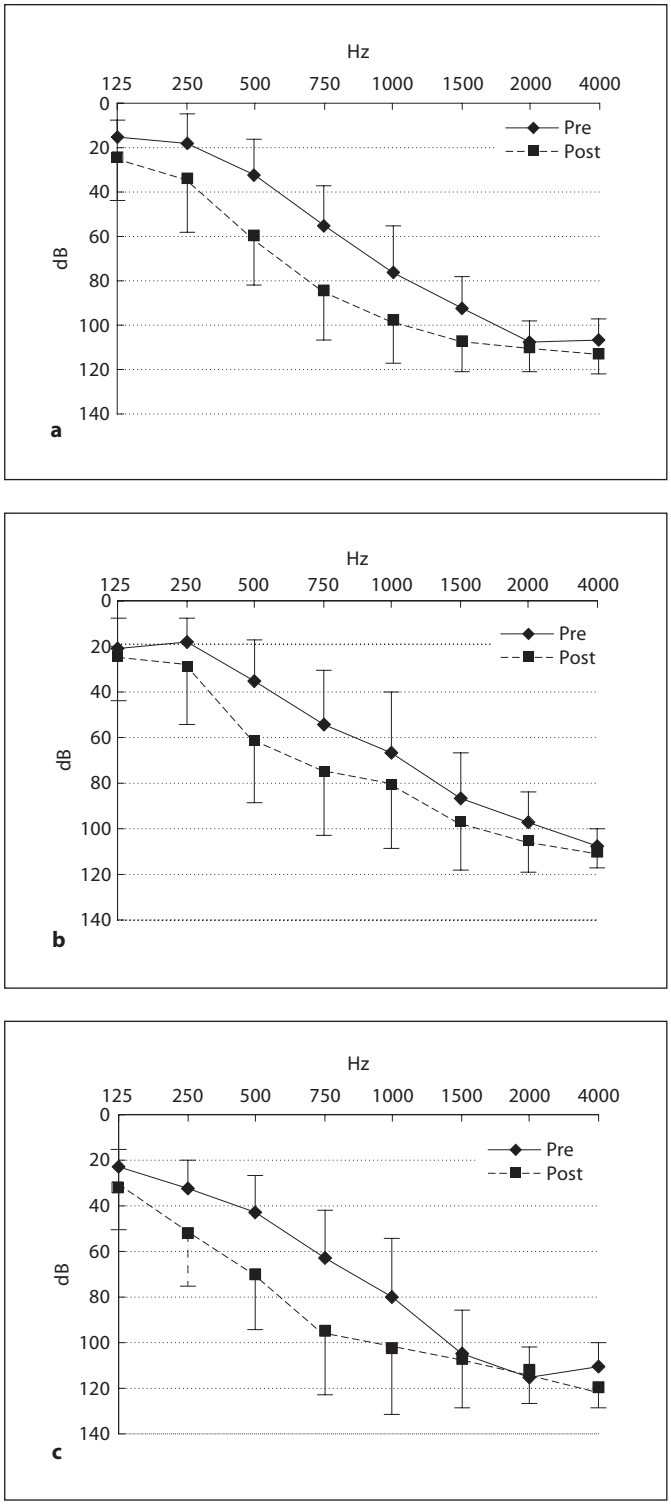

Fig. 1. Preoperative and postoperative audiograms showing the means and standard deviations in each frequency for 3 groups of patients (implanted ears): those implanted with partial insertion (8 channels) of the standard electrode (**a**), full insertion of the M electrode (**b**) and partial insertion (8 channels) of the Flex electrode (**c**).

Discussion

Hearing was preserved and found to be stable over the subsequent 1–4 years in 84% of subjects who were implanted using the same surgical technique, described as the round window approach. This is similar to the preservation rate of 90% in a group of 10 adult PDCI patients and to the preservation rate of 88% in the group of 9 child PDCI patients that was reported after 1 year of observation [Skarzynski et al., 2007a, b]. The data support the conclusion that hearing preservation could be maintained over time.

We based our choice of electrodes used in particular subjects on 2 factors. One factor was that the depth of insertion differed between the regular 30-mm Med-El electrode (C40+ and Pulsar) and the M electrode, which we began to use later and which carried the same number of activated electrodes on a 20-mm array. Our group was homogenous with respect to hearing impairment, defined as partial deafness, so the intended and achieved insertion depth was 20 mm. The later availability of a shorter 20-mm M electrode played a key role in our decision, because it became standard in our procedure shortly after its introduction to the market. We did not find any statistically significant difference in hearing preservation when 30-mm regular electrodes were inserted to a depth of 20 mm as compared to the full insertion of a shorter M electrode.

The other factor was the elasticity or flexibility of an electrode carrier, referred to as the Flex electrode. We decided to use this in 3 subjects. The decision was made during surgery where the view of the round window membrane through posterior tympanotomy guaranteed that the desired angle for an undisturbed hand-only insertion was reached. The Flex electrode also became available later, so it was used on only a small number of subjects.

After many years of experience in cochlear implant surgery, our surgical team decided to use the round window technique instead of cochleostomy in the belief that it would limit the loss of residual hearing. There are known potential problems with cochleostomy, such as perilymph loss and acoustic trauma caused by drilling, especially at the thickest part of the promontory. The bone dust, if present, may lead to the formation of new bone within the cochlea [Li et al., 2007]. There is also a risk of initiating osseous spiral lamina injury, because perilymph is toxic to hair cells. Some damage may occur due to infection, which may cause the formation of fibrous tissue [Nadol and Eddington, 2006; Skarzynski et al., 2007a]. Temporal bone studies have demonstrated

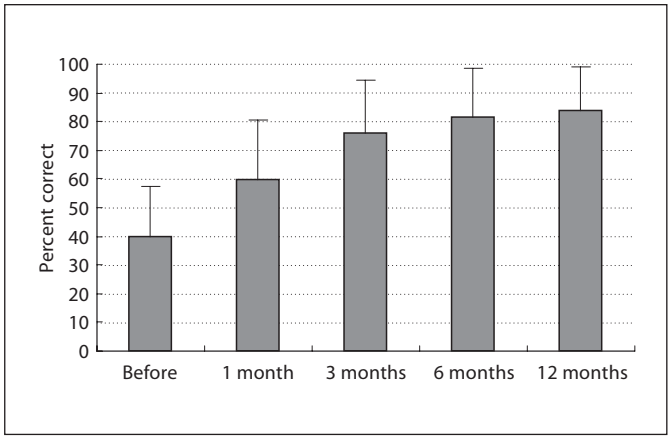

Fig. 2. Monosyllable scores under quiet conditions for PDCI subjects over time. The means and standard deviations for the electric-acoustic conditions are shown.

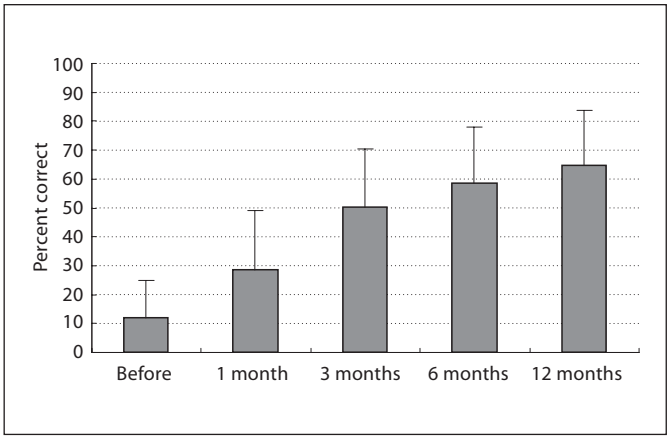

Fig. 3. Monosyllable scores under noisy conditions for PDCI subjects over time. The means and standard deviations for the electric-acoustic conditions are shown.

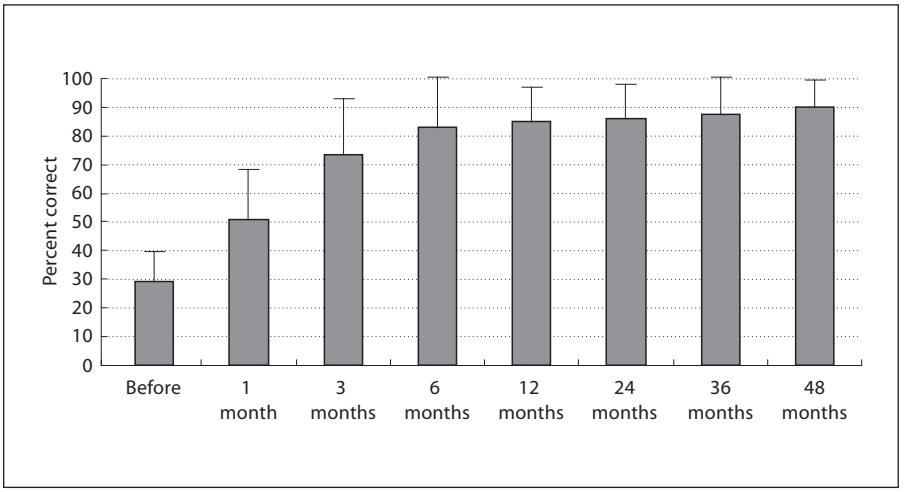

Fig. 4. Performance under quiet conditions over a 4-year period. The means and standard deviations of monosyllable scores for the electric-acoustic conditions are shown.

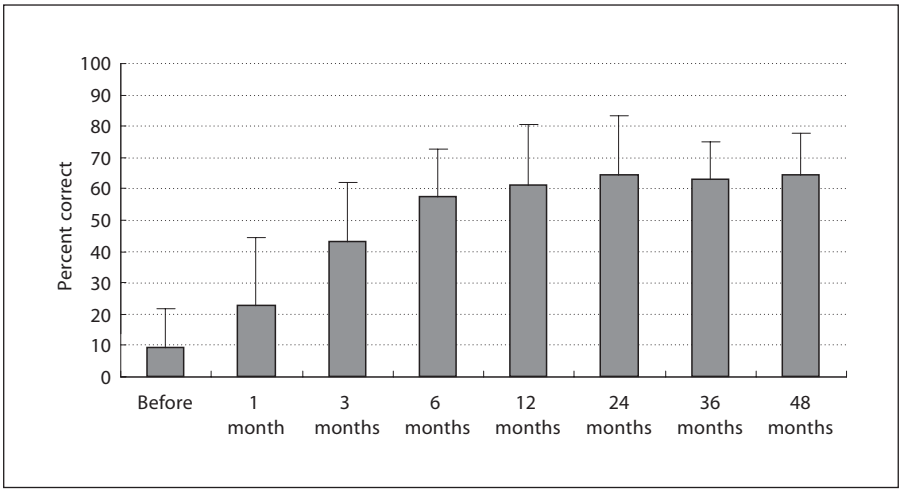

Fig. 5. Performance under noisy conditions over a 4-year period. The means and standard deviations of monosyllable scores for the electric-acoustic conditions are shown.

that the round window approach can be considered when avoiding trauma to cochlear structures is the main issue [Adunka et al., 2004; Roland and Wright, 2006].

The feasibility of the round window technique was demonstrated with the application of the Hybrid-L electrode by Lenarz et al. [2006].

Other surgical teams had previously made use of the standard cochleostomy technique in both the hybrid electric-acoustic stimulation [Briggs et al., 2005; Kiefer et al., 2005; James et al., 2006] and in subjects with substantial residual hearing, where the preservation of preoperative residual hearing was not intended as the outcome of the surgery [Cullen et al., 2004]. The preservation of residual hearing when using the round window technique to insert the electrode into the scala tympani, together with stability of the speech results, was reflected in the results presented in our study.

Monosyllabic word recognition increased in the PDCI group from 40 to 84% under quiet conditions and from 12 to 65% under noisy conditions over a period of 12 months.

We observed a significant increase in the performance of our study group during the first 3 months after the activation of the implant, under both quiet and noisy conditions. There appears to be a plateau effect after 3 months for quiet conditions and after 6 months for noisy conditions, the evidence for this claim being that there are only small increases in scores after these times.

The speech test results are stable over time, which was demonstrated in the group of patients with more than 4 years of experience.

The subjects that lost hearing immediately, or at some time after surgery, were able to obtain a significant advantage by using a cochlear implant in one ear and relying on natural hearing in the other. The 1-year scores under quiet and under noisy conditions for the entire group of 28 subjects presented in this study were 84 and 64%, respectively. These results are almost the same as were achieved previously in a subgroup of 10 adults (85% in quiet, 60.5% in noise) [Skarzynski et al., 2006] and comparable to those achieved in a subgroup of 9 children (69% in quiet and 62% in noise) [Skarzynski et al., 2007b]. The data support our conclusion that the results of PDCI are highly reproducible. Moreover, if another subgroup of Duet-using patients was created (11 subjects) their scores in quiet (91.4%) and in noise (78%) are better than those of patients in the current study using both Duet and natural unamplified low-frequency hearing.

The benefit of preserving residual hearing with 20-mm insertion via cochleostomy was demonstrated by Kiefer et al. [2005] and Gstoettner et al. [2004]. The long-term evaluation of residual hearing has shown preservation and stability in about 75% of subjects [Gstoettner et al., 2006]. In their study, a monosyllabic word recognition score of 75% was reported in the group of patients with complete hearing preservation. This is slightly lower than the scores reported in our current study (84%), although we included patients with partial preservation and with loss of hearing. However, if the preoperative scores of 13.1% presented in their study are compared to our 40% scores, it becomes clear that the 2 implanted populations were rather different.

Similar results were accomplished with another approach to acoustic + electric speech processing using the application of a 10-mm hybrid electrode [Gantz et al., 2006]. In the group of hybrid users, hearing within 10 dB of preoperative thresholds was maintained in 52% of subjects, compared to the 46.4% reported in this paper. Hybrid users who had more than 1 year of experience achieved an average score of 75% correct monosyllabic words compared with 90% in the group of PDCI subjects with 4 years of experience.

Conclusions

Low-frequency hearing was preserved during surgery and conserved over time in 84% of all PDCI cases where the round window technique was used to insert 3 different electrodes to a 20-mm depth. Shortly after the cochlear implant was activated, a significant improvement in the recognition of monosyllabic words was observed when electric-acoustic stimulation was used. This improvement was maintained at the same high level over time. PDCI is a viable means of treating individuals who have good low-frequency hearing, but suffer severe or profound hearing loss in the mid- to high-frequency range.

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Disclosure Statement

There is no conflict of interest to be disclosed.

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