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Hearing Preservation in Cochlear Implant Surgery: A Meta-Analysis

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Objective(s): The aim of the present meta-analysis is to assess the effects of hearing preservation (HP) methods on residual hearing in patients undergoing cochlear implant (CI) surgery and to look at the effect of follow-up time on HP outcome.
Data Sources: A systematic search was conducted in PubMed, Embase, and Cochrane Library. Only articles in English were included.
Study Selection: Prospective studies published until January 2018 on hearing preservation methods were included.
Data Extraction: Studies were assessed on unaided pre- and postoperative hearing thresholds, follow up time, and methodological quality.
Data Synthesis: A random-effects meta-regression was performed for the HP outcome in relation to surgical technique, electrode array design, inserted electrode length, insertion speed, and corticosteroid use for different follow up times (1 month, 6 months, and 12 months or more postoperatively).
Conclusion: Hearing preservation in cochlear implant surgery is feasible. A statistically significant difference was found between the round window procedure and cochleostomy approach, in favor of the round window procedure at 6 months postoperatively ($p = 0.001$). A statistically significant difference was found between the straight and the perimodiolar electrode array at 1 month postoperatively in favor of the straight electrode array ($p < 0.001$). No statistically significant difference was found between the other HP methods. The round window approach with the straight electrode array might result in a better HP outcome at 1 month and 6 months postoperatively compared with the cochleostomy approach with the perimodiolar electrode array. A declining trend in HP outcome in both combinations was seen over time. **Key Words:** Cochlear implantation—Hearing preservation—Meta-analysis—Residual hearing—Sensorineural hearing loss.
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Cochlear implantation (CI) is developed to restore hearing in patients with profound sensorineural hearing loss in whom hearing aids are not effective. Implant electrodes are designed to cover at least a substantial part of the cochlea in order to gain maximum frequency coverage. Continuous advances in CI-technology have led to an improved outcome in patients and thus relaxation of the implantation criteria. Nowadays, CI-candidates include hearing-impaired individuals with increasing amounts of residual hearing. The majority of these patients suffer mainly from high frequency loss, but still have residual hearing in the low frequencies. Hodges et al. (1) was the first to report that hearing preservation (HP) after cochlear implantation was possible in these patients. This preserved low frequency residual hearing was found to result in an improved speech understanding for CI recipients (2). This led to further optimization of electrode design and surgical technique to preserve the residual hearing in a more systematic way during and after CI surgery.

Lehnhardt (3) was the first to propose a soft-surgery technique to preserve residual hearing. Since then, many studies have been done on HP methods in CI surgery. These methods include different surgical techniques, different electrode array designs, and the administration of corticosteroids during surgery. Lately, studies also focus on pre-implantation imaging in consideration of the variability of the anatomy of the cochlea (4).

However, the current literature is not conclusive. A systematic review by Havenith et al. (5), on hearing preservation surgery did not show a benefit of the cochleostomy or the round window approach. However, follow up time was not taken into account. A meta-analysis by Santa Maria et al. (6), showed that the cochleostomy approach, a slow electrode array insertion, a soft tissue cochleostomy seal, and the use of postoperative systemic steroids were associated with better HP. However, this meta-analysis was not based on a systematic search. Since then, many new studies on HP have been performed.

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The aim of the present meta-analysis is to assess the effects of HP methods, including type of surgery, electrode array design, and steroid use on residual hearing in patients undergoing CI surgery. Furthermore, the effect of follow-up time on HP outcome will be looked at.

MATERIALS AND METHODS

Search Strategy and Study Selection

A systematic search on randomized controlled trials and prospective studies was conducted in PubMed, Embase, and Cochrane Library up until January 29, 2018. The search terms ''residual hearing'', ''cochlear implant'', and ''audiometry'' were combined along with their synonyms (Supplemental Digital Content 1, http://links.lww.com/MAO/A713). One author screened all identified studies on title and abstract. Subsequently, the full texts were screened for eligibility. When full text articles were not available the authors of the studies were contacted to retrieve the publication. The references of all relevant articles and reviews were searched for additional studies.

Only articles in English were included. Only prospective studies were included for the homogeneity of the results. Furthermore, studies were included if hearing preservation was an outcome and pre- and postoperative hearing thresholds were reported. Case reports, reviews, editorial, and meeting abstracts were excluded. Animal and temporal bone studies were also excluded. Furthermore, articles of authors that described the same subject population with the same objectives to different journals were only included once.

In the literature, different definitions are used for defining HP. As in most hearing preservation studies the low frequencies 250, 500, and 1000 Hz are reported, we used the pure-tone average (PTA) of these frequencies in this meta-analysis. The HP definition that has been chosen is derived from the Hearing Preservation Classification System as reported by Skarzynski et al. (7), and is chosen to include as many studies as possible in this meta-analysis. The following formula for HP% that was first introduced by Skarzynski et al. (7) was used. HP% = [1 – (PTA postoperative – PTA preoperative)/(120 – PTA preoperative)] × 100.

There are four categories of HP%:

Category HP1 is complete or near-complete preservation with a HP of more than 75%.
Category HP2 is partial preservation with a HP of 25 to 75%.
Category HP3 is minimal HP with a HP 0 to 25%.
Category HP4 is loss of hearing/no hearing when no measureable hearing is preserved.

Quality Assessment

One author assessed the risk of bias of all included studies. The modified version of the ''Checklist for Measuring Quality'' by Downs and Black (8), was used. This tool includes the following five sections: study quality (10 items), external validity (three items), study bias (seven items), confounding and selection bias (six items), and the power of the study (one item), which results in a numeric score with a maximum of 28 points. A grade of ''excellent'' is appointed to 24 to 28 points, ''good'' to 19 to 23 points, ''fair'' to 14 to 18 points, and ''poor'' to less than 14 points.

Data Extraction

A data extraction sheet was made including study population, number of patients, pre- and postoperative hearing thresholds, surgical technique (cochleostomy or round window approach), electrode array (perimodiolar versus straight), inserted electrode length, insertion speed, use of corticosteroids, and follow-up time in months. The extended round window approach was categorized under the round window approach. All perimodiolar arrays were styletted electrode arrays. Inserted electrode length was categorized as a dichotomous variable (≤17 mm versus >17 mm). Insertion speed was also categorized as a dichotomous variable (not reported versus ≥120 s). Finally, the use of corticosteroids was categorized into four categories. A distinction was made between no corticosteroid administration, systemic administration, local application, and both systemic and local administration. If audiograms of individual subjects were reported, thresholds were extracted directly from the audiograms. Preferentially, individual data of patients were used. Authors were therefore contacted when no individual data were reported. However, if these were not available, the reported summary results were used. Follow-up time was categorized into three categories: 1 month postoperatively, 6 months postoperatively, and 12 months or more postoperatively.

Statistical Methods

A random-effects meta-regression was performed for the HP outcome (HP%) in relation to each of the different HP methods (surgical technique, electrode array design, inserted electrode length, insertion speed, and corticosteroid use) for the different follow up times 1 month, 6 months, and 12 months or more postoperatively, with a Hartung-Knapp-Sidik-Jonkman (9) adjustment and a restricted maximum likelihood (REML) estimator for the amount of heterogeneity. No data were available for the perimodiolar electrode array at 12 months or more postoperatively, which is why no comparison with the straight electrode array could be made at this follow up time. If the standard deviation (SD) of the HP outcome was not reported, we used the maximum SD of the studies in that specific meta-analysis to calculate the standard error. To estimate (pairwise) differences within the HP methods with more than two levels (e.g., corticosteroid use), we applied analysis of variance. To adjust for multiple testing issues a Bonferroni correction was performed, resulting in a two-sided significance level of 0.0029.

SPSS version 23 (10) and R version 3.4.3 (11), with packages meta (12) and metafor (13) were used for the analysis of the data.

RESULTS

Results of Systematic Search

The systematic search resulted in a total number of 2,463 articles. Duplicate studies were removed and titles and abstracts were screened on the exclusion criteria. This resulted in the exclusion of 2,123 articles. The full text of the remaining 340 articles was obtained and further screening on the inclusion criteria was performed (Fig. 1). Thirty-three articles were found eligible, of which the results of 26 articles (936 patients) could be analyzed (14–39). Results from seven studies could not be analyzed due to missing data or because the results did not fit the chosen HP definition, despite contacting the authors and asking for the original data. Study characteristics and the study selection criteria of the patients of the 26 included studies are presented in Table 1 and Supplemental Digital Content 2 (http://links.lww.com/MAO/A714).

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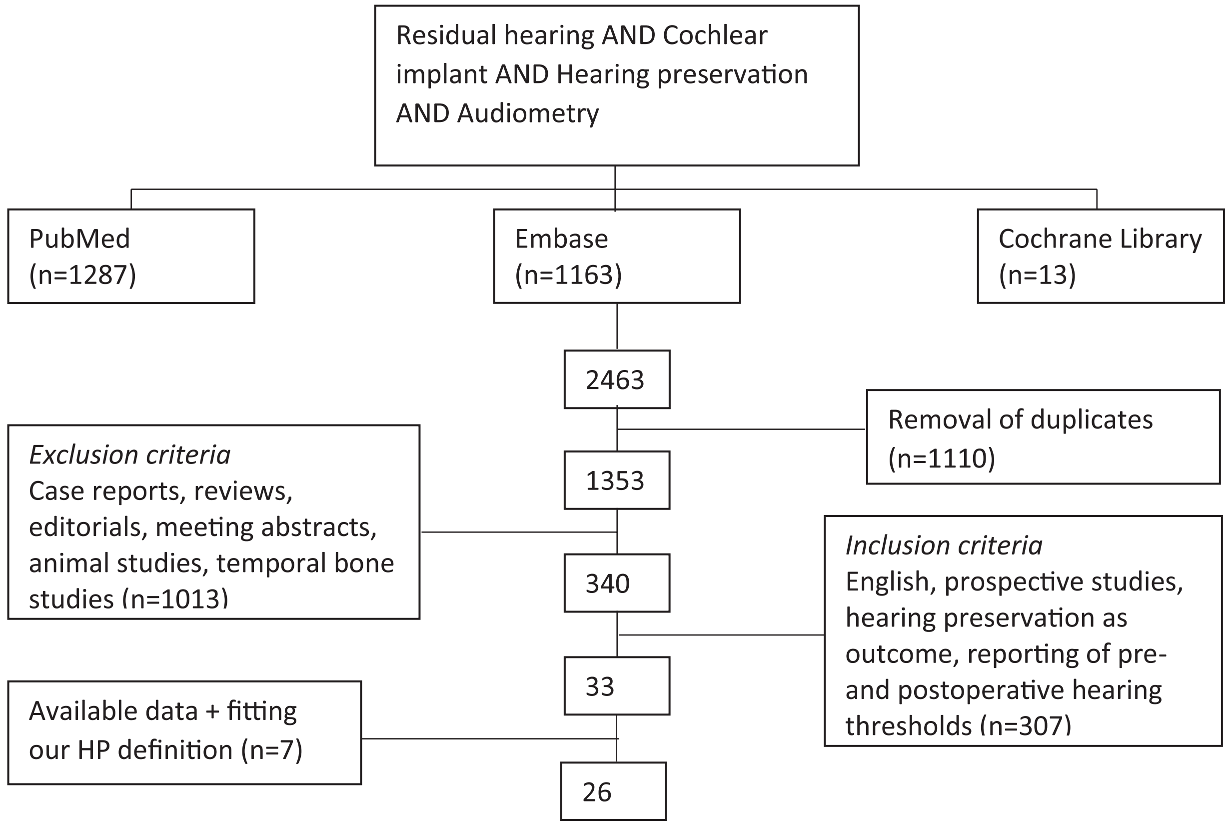

FIG. 1. Flow-diagram of search strategy. Final search: January 29, 2018.

Quality Assessment

Supplemental Digital Content 3 (http://links.lww.com/MAO/A715) shows the results of the quality assessment that is performed according to the modified version of Downs and Black (8). It can be seen that none of the studies is graded as excellent or good quality. Nine studies are graded as poor quality and 17 studies are graded as fair quality.

Hearing Preservation in Relation to the Different HP Methods

Figure 2 shows the estimated percentages of hearing preservation (HP%) for the different HP methods (see also Word document, Supplemental Digital Content 4, http://links.lww.com/MAO/A716, for a list of all included studies per HP method and follow up time). When looking at the estimated means of hearing preservation (HP%), they all fall in the categories complete (HP1 >75%) or partial HP (HP2, 25–75%). Overall, HP decreases over time.

Table 2 shows the number of studies and patients in each HP category.

Surgical Technique

The estimated mean differences in HP% outcome between the cochleostomy approach and the round window approach at 1 month, 6 months, and 12 months or more postoperatively were 13.1, 18.6, and 1.7%, respectively, in favor of the round window approach. Only the difference at 6 months postoperatively was statistically significant ($p = 0.001$).

Electrode Array

The differences in HP% outcome between the straight and the perimodiolar electrode array at 1 month and 6 months postoperatively were respectively 24.7 and 1.2%, in favor of the straight electrode array. Only the difference at 1 month postoperatively was statistically significant ($p < 0.001$). No comparison between both electrode arrays could be made at 12 months or more postoperatively, because the included studies did not report results at 12 months or more postoperatively for the perimodiolar electrode array.

Inserted Electrode Length

The differences in HP% outcome between a short insertion of the electrode (≤17 mm) and a long insertion of the electrode (>17 mm) at 1 month, 6 months, and 12 months or more postoperatively were respectively 0.2, 13.7, and 9.5%. None of the differences were statistically significant.

Insertion Speed

The difference in HP% outcome between a slow and not reported insertion speed at 1 month, 6 months, and 12 months or more postoperatively was respectively 0.7, 2.0, and 5.0%. None of the differences were statistically significant.

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TABLE 1. *Study characteristics*

Study	Mean Age in Years (range)	Gender	Cochleostomy (n)	Round Window (n)	Electrode	Insertion Length Electrode (mm)[a]	Insertion Speed (s)	Steroids	Follow-Up Range (mo)
Baumgartner et al. (14)	45.4 (17.5–67.8)	.	23	0	MED-EL FlexSOFT	21.5–31	.	No	1–12
Benghalem et al. (15)	4.6 (1.6–12.5)	.	0	19	Advanced Bionics HFMS/HF1J	18.5–24	.	Both[b]	6
Bento et al. (16)	52.4 (23–83)	Male: 1 Female: 6	2	5	Oticon EVO	21	.	Both	1–6
Cho et al. (17)	48.9 (±15.8) and 46.5 (±19.8)[c]	Male: 9 Female: 23	8	21	Med-El Flex28, Nucleus 422, Nucleus Contour Advance	17-28	.	No and both	1 to >12
Coordes et al. (18)	57 (29–80)	.	1	26	Nucleus Contour Advance	18–19	.	No	2
de Carvalho et al. (19)	47 (29–63)	Male: 5 Female: 1	1	5	MED-EL FlexEAS	18–24	180	Both	14–18
Erixon et al. (20)	58.6 (19–87)	Male: 11 Female: 9	0	20	MED-EL FlexEAS/ FlexSOFT	17.5–28.5	.	Local	1–13
Fraysse et al. (21)	50 (25–81)	.	27	0	Nucleus Contour Advance	17	.	Systemic[d]	1
Gantz et al. (22)	58.9 (19.6–82.3)	Male: 39 Female: 48	87	0	Nucleus Hybrid S8	10	.	No	1–12
Gantz et al. (23)	12.6 (11–15)	Male: 1 Female: 4	5	0	Nucleus Hybrid L24	16	.	Systemic	12–24
Garcia-Ibanez et al. (24)	44 (23–74)	.	28	0	Nucleus Contour Advance	17	.	?[d]	1–6
Gstoettner et al. (25)	46.13 (7.62–71.32)	Male: 2 Female: 7	2	7	MED-EL FlexEAS	18–22	180	Local	6–17
Gstoettner et al. (26)	49.9 (25.9–77.3)	Male: 8 Female: 15	23	0	MED-EL Standard/ Medium	18–24	.	Local	6–70
Helbig et al. (27)	51 (22–75)	Male: 6 Female: 12	13	5	MED_EL FlexEAS	24	.	Both	1–12
Kuthubutheen et al. (28)	8 (1–15)	Male: 2 Female: 3	0	5	MED-EL FlexEAS	18	120	Both	8–20
Lenarz et al. (29)	53.46 (21–81)	Male: 14 Female: 52	0	66	Nucleus Hybrid-L24	16	.	Systemic	1–14
Lenarz et al. (30)	.	.	0	4	Nucleus Hybrid-L	16	.	Systemic	1 d to 5 wks
Moran et al. (31)	62.3 (SD: 15.7)	Male: 71 Female: 68	0	139	Nucleus Slim straight	20–25	.	Systemic[e]	3–12
Pillsbury et al. (32)	53.7 (17–76)	Male: 31 Female: 42	17[f]	55[f]	MED-EL FlexEAS	20	.	Both	3–12
Skarzynski et al. (35)	29 (6–71)	.	0	55	Nucleus Slim straight	21.9–26.94	.	Local	36
Skarzyński et al. (33)	30.3 (4.2–65.9)	.	0	28	MED-EL Flex./ Standard/Medium	20	.	Local	12–48
Skarzynski et al. (34)	40.2 (12–70)	Male: 13 Female: 29	0	42	MED-EL FlexSOFT/ Standard	28	.	Local	13
Skarżyński et al. (36)	9.1 (6–18)	.	0	126	Nucleus Slim straight	Partial	.	Systemic	24
Skarzynski et al. (37)	11.9 (6–18)	Male: 10 Female: 9	0	19	Nucleus Slim straight	20–25	.	Systemic	24
Todt et al. (38)	66.1 and 52.8[c]	Male: 6 Female: 14	0	20	Advanced Bionics HFMS	18.5	120	Both	1–1.5
Usami et al. (39)[g]	47.47 (21–71)	Male: 10 Female: 22	0	32	MED-EL FlexEAS/ FlexSOFT/ Standard	31.5	.	Systemic	12

[a]As stated by the authors of the articles, not based on radiological evidence.
[b]Both = local and systemic.
[c]This study reported a mean for two groups of patients.
[d]Some patients in the study, not all of them.
[e]Some patients in the study received an additional high-dose intravenous steroid as part of another clinical trial.
[f]Unspecified in one patient.
[g]A follow up study by Moteki et al., (46) was not used for this systematic review, because the number of patients was less than the study by Usami et al., (39) and because a HP outcome of 12 months or more postoperatively was already provided by Usami et al., (39).
N means number of patients; ., not reported, +, yes, - , no, +/-, only a number of the included patients got steroids.

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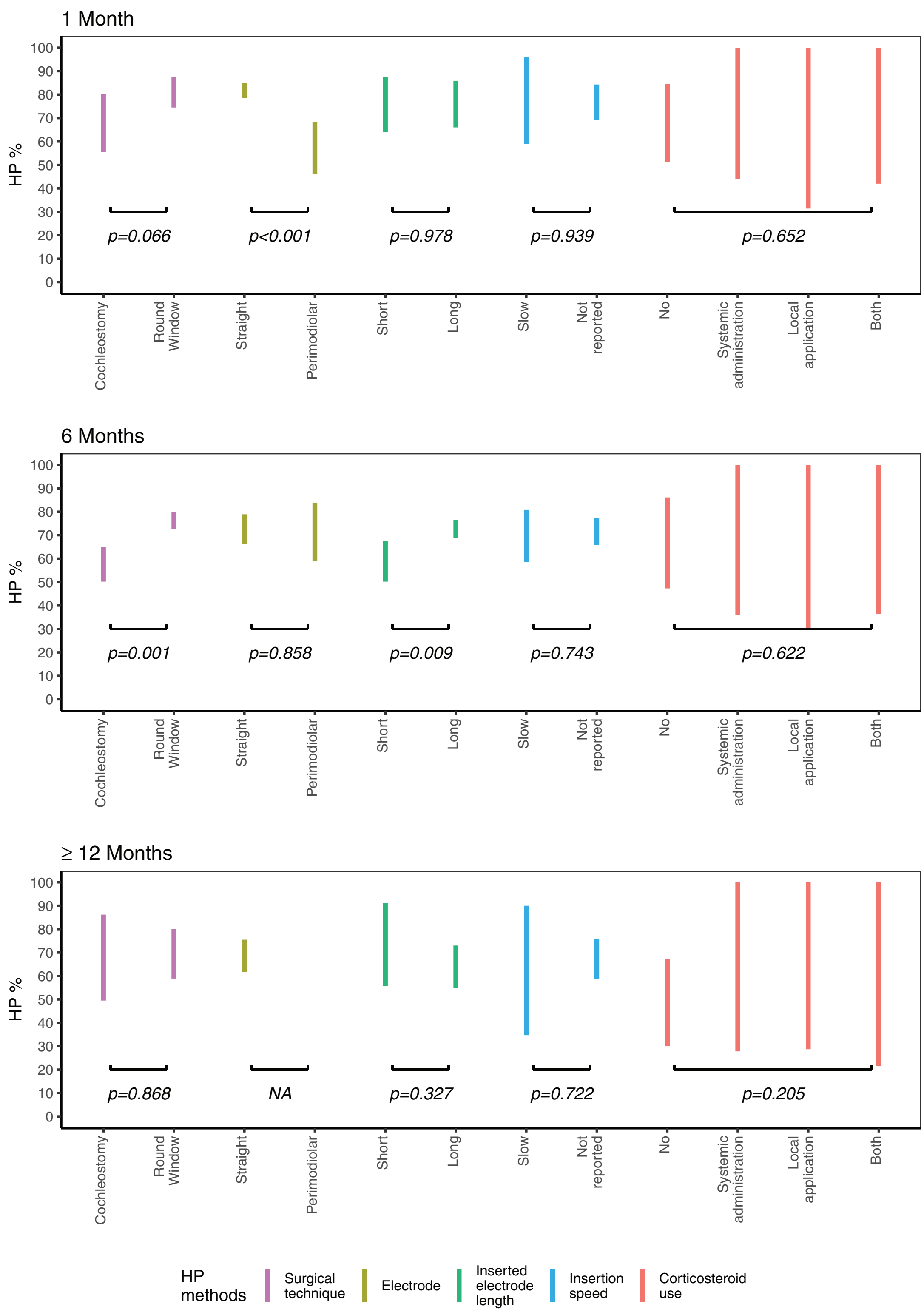

FIG. 2. Results random-effects meta-analysis with meta-regression of low-frequency hearing preservation (HP%).

Corticosteroid Use

No statistically significant difference was found between the four categories of corticosteroid use at 1 month, 6 months, and 12 months or more postoperatively. At 1 month postoperatively the differences between no administration of corticosteroids compared with systemic, local, or both systemic and local administration were respectively 11.8, 7.2, and 11.7% in favor of the

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TABLE 2. *Number of studies and patients in each HP category*

Follow Up Time	HP Method	n	npat
	Surgical technique		
1 month	Cochleostomy	4	137
	Round window	9	253
6 months	Cochleostomy	4	124
	Round window	8	172
12 months or more	Cochleostomy	4	102
	Round window	10	441
	Electrode array		
1 month	Straight	12	363
	Perimodiolar	4	75
6 months	Straight	15	372
	Perimodiolar	2	33
12 months or more	Straight	18	653
	Perimodiolar	0	n/a
	Inserted electrode length		
1 month	Short	5	199
	Long	10	150
6 months	Short	2	110
	Long	13	235
12 months or more	Short	3	142
	Long	14	465
	Insertion speed		
1 month	Slow	2	24
	Not reported	14	414
6 months	Slow	2	6
	Not reported	14	399
12 months or more	Slow	2	10
	Not reported	16	548
	Corticosteroid use		
1 month	No	3	104
	Systemic administration[a]	6	235
	Local application	1	20
	Both systemic and local	5	62
6 months	No	2	96
	Systemic administration	3	110
	Local application	4	42
	Both systemic and local	6	131
12 months or more	No	3	97
	Systemic administration	6	266
	Local application	5	183
	Both systemic and local	5	117

[a]One study only used steroids on some patients.
HP includes hearing preservation; n, number of studies; npat, number of patients.

corticosteroid administrations. At 6 months postoperatively the differences between no administration of corticosteroids compared with systemic, local, or both systemic and local administration were respectively 11.3, 4.4, and 9.8% in favor of the corticosteroid administrations. At 12 months or more postoperatively the differences between no administration of corticosteroids compared with systemic, local, or both systemic and local administration were respectively 21.4, 26.2, and 19.6% in favor of corticosteroid administrations.

Hearing Preservation in Daily Practice

A further meta-regression has been done on a combination of HP methods that are most used in daily practice. Most surgeons prefer to combine a straight electrode with a round window insertion, whereas perimodiolar electrodes are often inserted through a cochleostomy. Therefore, an analysis with a combination of surgical technique and electrode array design has been performed. A round window approach was combined with a straight electrode array and a cochleostomy approach with a perimodiolar electrode array.

One Month Postoperatively

Ten studies (16,20,21,24,28–30,36,37,39), including 277 patients, were included of which two studies (21,24) used a cochleostomy/perimodiolar approach. The estimated mean HP% of the cochleostomy/perimodiolar approach was 58.5% (standard error (SE) 6.1), partial HP. The estimated mean HP% of the round window/ straight approach was 82.2% (SE 6.3), (near-) complete HP. The estimated mean difference was 23.7% (95% CI: 9.1–38.3) and was not statistically significant ($p = 0.006$).

Six Months Postoperatively

Nine studies (15,16,20,24,28,34,36,37,39), including 191 patients, were included of which one study (24) used a cochleostomy/perimodiolar approach. The estimated mean HP% of the cochleostomy/perimodiolar approach was 53.7% (SE 7.9), partial HP. The estimated mean HP% of the combination round window approach with a straight electrode array was 76.3% (SE 8.4), (near-) complete HP. The estimated mean difference was 22.5% (95% CI: 2.6–42.5) and was not statistically significant ($p = 0.032$).

Twelve Months or More Postoperatively

Ten studies (20,28,29,31,33–37,39), including 336 patients were selected of which all studies used a round window/straight approach. Therefore it was not possible to perform a meta-regression at this follow up time for the comparison between a cochleostomy/perimodiolar and the round window/straight approach. The estimated mean HP% of the combination round window approach with a straight electrode array was 69.0% (SE: 4.8), partial HP.

DISCUSSION

Hearing Preservation Methods

A statistically significant difference was found between the round window procedure and cochleostomy approach, in favor of the round window procedure at 6 months postoperatively. A systematic review of Havenith et al. (5) found no clear benefit of the round window approach over the cochleostomy approach. However, Havenith et al. (5), did not take follow up time in account. Their included studies had a mean follow up time of 1 to 30 months.

Also, a statistically significant difference was found between the straight and perimodiolar electrode array, in

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favor of the straight electrode array, at 1 month postoperatively. This is in line with the results of Briggs et al. (40) who found that the straight arrays were the least traumatic and that insertion with perimodiolar arrays, which are stiffer and pre-curved, were associated with a perforation of the basilar membrane in temporal bones. Mittmann et al. (41) found higher intracochlear pressure changes when inserting a perimodiolar electrode array in an artificial cochlea compared with the insertion of a straight electrode array. A higher intracochlear pressure is thought to result in more intracochlear damage.

In this meta-analysis the variable insertion depth was defined as insertion length of the electrode as reported by the authors and categorized as a dichotomous variable (short: $\leq$17 mm versus long: $>$17 mm). However, the angular insertion depth as measured on CT is a better measure of insertion depth. It was not possible to include the angular insertion depth, because there were not enough included articles that reported these data. When looking at the literature, van der Marel et al. (42) found that insertion depth and modiolus proximity is significantly influenced by the size of the cochlea. They found that variance in insertion depth was explained by cochlear size alone for approximately 13% (42). This could indicate that anatomy plays a part in HP outcome.

No definite conclusions can be drawn concerning insertion speed and hearing preservation. Very few studies reported the insertion speed used. Those studies that did report an insertion speed, reported an insertion speed of 120 seconds or more. Some articles reported that they used a slow insertion speed, without mentioning how long the duration of insertion precisely was. When looking at the literature, Todt et al. (43) found a direct correlation between insertion speed and intracochlear pressure in an artificial cochlear model. This indicates that a slower insertion speed results in less intracochlear pressure which is presumed to result in less intracochlear damage.

Although all different routes of administration of corticosteroids resulted in a higher HP outcome compared with no administration of corticosteroids, this was not statistically significant. A possible explanation could be that the different categories contained too little studies to reach statistical significance. When looking at the literature, Kuthubutheen et al. (44) found that preoperative systemic administered steroids for 1 day or more before surgery were beneficial on residual hearing and spiral ganglion neuron density in an animal model. This can be explained by the results of Lee et al. (45). This study showed systemically, but also locally, delivered dexamethasone reduced the tissue response after electrode insertion in a Guinea pig model of cochlear implantation.

Daily Practice

The analysis showed that a round window/straight approach resulted in a better HP% outcome compared with a cochleostomy/perimodiolar approach at 1 month and at 6 months postoperatively, although these results were not statistically significant. When looking at the different follow up times, a comparable declining trend in HP% is seen over time in both approaches. Inserted electrode length, insertion speed, and the use of corticosteroids were not used in the analysis because these did not notably effect the HP results in our first meta-regression. Furthermore, literature suggests that inserted electrode length is less relevant due to the fact that it does not take cochlear duct length into account (42). Also, most included studies did not report insertion speed and all studies in the first analysis used corticosteroids except one study who did not report whether corticosteroids were used at 1 month postoperatively and at 6 months postoperatively (24).

Because the included studies are very heterogeneous and because the set of studies varies per analysis, the results of this meta-analysis should be interpreted with care.

Limitations

Some limitations must be taken into account when reading this study. First, there are very few comparative studies on HP methods. Furthermore, no randomized controlled trials have been done on this subject. This means that there is limited valid data that can be used as evidence for the superiority of one or more of the HP techniques studied. Second, the included studies showed a great heterogeneity in inclusion criteria for their patients and in the HP methods that they used (Supplemental Digital Content 2, http://links.lww.com/MAO/A714). Therefore, the results of the meta-analysis should be interpreted very cautiously. Third, the quality of the included studies was fair to poor. This results in the inclusion of data from studies that could be subjected to a high risk of bias. Fourth, not all studies that were found during the systematic search could be used for this meta-analysis due to missing data. The authors of all articles with missing data were contacted. However, not all of them replied with the requested data. This could therefore also result in bias. It should be mentioned that a follow up study by Moteki et al. (46) was not used for this meta-analysis, because the number of patients was less than the study by Usami et al. (47), and because a HP outcome of 12 months or more postoperatively was already provided by Usami et al. (47). Fifth, not all studies could be included for all follow up time points, which is why we could not perform an analysis on follow up time. Sixth, almost all included studies did not mention intrascalar location data. Therefore we could not take this variable into account. Finally, not all individual data of patients from the included studies could be used due to non-measured pure-tone thresholds at specific frequencies. However, by using the HP definition that was used in this meta-analysis, data of most patients could be included.

As a remark, the perimodiolar electrode arrays in this meta-analysis were not designed for hearing preservation, but to lie close to the modiolar wall (48). The newer perimodiolar electrode array Nucleus 532 was developed for hearing preservation purposes. However, at the time

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of conducting the systematic search no suitable prospective studies on the Nucleus 532 were published, which is why this electrode is not included in the meta-analysis. The future will show what perimodiolar electrodes like the Nucleus 532 do for hearing preservation. A study in 45 patients by Aschendorff et al. (49), suggested a low level of intracochlear trauma due to the fact that the electrode was placed in the scala tympani in all cases. However, two cases with a tip fold-over existed in the initial insertion of the array due to surgical error.

CONCLUSION

The results of this meta-analysis indicate that hearing preservation in cochlear implant surgery is feasible. The round window approach with the straight electrode array might result in a better HP outcome at 1 month and 6 months postoperatively compared with the cochleostomy approach with the perimodiolar electrode array, however, a declining trend in HP outcome in both combinations was seen over time. It should be noted that the systematic literature search showed that very few comparative studies on HP methods have been performed. Most authors report their own HP results of the methods that they deem to be best for preserving residual hearing. Also, a lot of the studies on HP use different inclusion criteria for their patients on pre- and postoperative residual hearing, which results in large heterogeneity. We recommend prospective comparative studies to obtain more evidence for which HP methods result in better postoperative residual hearing.

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