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Cochlear Reimplantation Rate and Cause: a 22-Year, Single-Center Experience, and a Meta-Analysis and Systematic Review

Haotian Liu,[1,3] Xinyi Yao,[1,3] Weili Kong,[1] Lin Zhang,[1] Jingyuan Si,[2] Xiuyong Ding,[2] Yun Zheng,[1] and Yu Zhao[1]

Objectives: In terms of cochlear reimplantation, there is no consensus on the definition, range, or calculation formulation for the reimplantation rate. This study aims to put forward a relatively standardized and more explicit definition based on a literature review, calculate the rate of cochlear reimplantation, and examine the classification and distribution of the reimplantation causes.

Design: A systematic review and retrospective study. A relatively clearer definition was used in this study: cochlear reimplantation is the implantation of new electrodes to reconstruct the auditory path, necessitated by the failure or abandonment of the initial implant. Seven English and Chinese databases were systematically searched for studies published before July 23, 2021 regarding patients who accepted cochlear reimplantation. Two researchers independently applied the inclusion and exclusion criteria to select studies and complete data extraction. As the effect size, the reimplantation rate was extracted and synthesized using a random-effects model, and subgroup and sensitivity analyses were performed to reduce heterogeneity. In addition, a retrospective study analyzed data on cochlear reimplantation in a tertiary hospital from April 1999 to August 2021. Kaplan-Meier survival analysis and the log-rank test were adopted to analyze the survival times of cochlear implants and compare them among different subgroups.

Results: A total of 144 articles were included, with 85,851 initial cochlear implantations and 4276 cochlear reimplantations. The pooled rate of cochlear reimplantation was 4.7% [95% CI (4.2% to 5.1%)] in 1989 to 2021, 6.8% [95% CI (4.5% to 9.2%)] before 2000, and 3.2% [95% CI (2.7% to 3.7%)] after 2000 (P=0.003). Device failures accounted for the largest proportion of reimplantation (67.6% [95% CI (64.0% to 71.3%)], followed by medical reasons (28.9% [95% CI (25.7% to 32.0%)]). From April 1999 to August 2021, 1775 cochlear implants were performed in West China Hospital (1718 initial implantations and 57 reimplantations; reimplantation rate 3.3%). In total, 45 reimplantations (78.9%) were caused by device failure, 10 (17.5%) due to medical reasons, and 2 (3.5%) from unknown reasons. There was no difference in the survival time of implants between adults and children (P = 0.558), while there existed a significant difference between patients receiving implants from different manufacturers (P < 0.001).

Conclusions: The cochlear reimplantation rate was relatively high, and more attention should be paid to formulating a standard definition, calculation formula, and effect assessment of cochlear reimplantation. It is necessary to establish a sound mechanism for long-term follow-up and rigorously conduct longitudinal cohort studies.

Key words: Cochlear implants, Cochlear reimplantation, Device failure, Reimplantation rate, Literature review.

Abbreviations: CI = cochlear implantation; HERMES = The HIPAA-secure, Encrypted, Research Management and Evaluation Solution database.

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INTRODUCTION

Cochlear implantation (CI) is the most effective way to restore hearing for patients with severe to profound sensorineural hearing loss (Roche & Hansen 2015). Since the 1970s, CIs have been continuously upgraded and optimized, and the age range and indications have been expanded. Meanwhile, the incidence of complications is gradually increasing as well (Roche & Hansen 2015; Aldhafeeri et al. 2021; Dağkıran et al. 2020). As an implantable electronic device, cochlear implants require reoperation and reimplantation due to severe complications such as device failure, pain, and infection (Terry et al. 2015; Dağkıran et al. 2020).

Desoyer & Burian (1985) first reported two cases of cochlear reimplantation and proposed the concept of "electrode reimplantation." In a multicenter study, Parisier et al. (1991) reported a reimplantation rate of 11% (129/1175 patients). Henson et al. (1999) collected and tracked the status of 22 patients undergoing reimplantation in 18 hospitals across the United States. So far, a multicenter study by Hermann et al. (2020) evaluated the largest sample, in which they reported 4952 cases of initial implantation and 99 cases of reimplantation (2%).

There are further shortcomings in research on cochlear reimplantation. First, a standard definition of cochlear reimplantation is lacking. Robert K et al. (1989) first proposed "the removal of an indwelling cochlear implant electrode followed by reinsertion of a new device." Wang et al. (2014) also proposed a definition as "explantation of an existing device followed by replacement with a new implant." However, in most of the relevant studies, researchers did not clearly define cochlear reimplantation (Bhadania et al. 2018; Batuk et al. 2019). Therefore, a consensus on the definition is imperative.

Second, the requirements for cochlear reimplantation differ among studies. According to the European Consensus Statement on Cochlear Implant Failures and Explantations issued in 2005, there were four indications for reimplantation,

[1]Department of Otolaryngology-Head and Neck Surgery, West China Hospital of Sichuan University, Chengdu, China; and [2]Department of Otolaryngology-Head and Neck Surgery, XuanWu Hospital of Capital Medical University, Beijing, China. [3]These authors are co-first authors who have contributed equally to this work.

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including characteristic decrements, performance decrements, device failures, and medical reasons such as skin flap issues, cerebrospinal fluid leakage, pain, implant/electrode migration, and infection (O'Donoghue 2005). However, variation still occurs between studies. For example, in some studies, the reinsertion of the initial electrodes into the cochlea for misplaced and migrated electrodes was regarded as cochlear reimplantation (Gözen et al. 2019).

Third, the calculation of the reimplantation rate varied greatly among studies, which may result from the inconsistency of standards and chronological differences in sample collection. According to previous literature reviews, the overall reimplantation rate ranges from 0.48% to 30% (Qiu et al. 2010; Beadle et al. 2005). Among the published studies, four have reported a reimplantation rate higher than 20%. Such high reimplantation rates were mainly caused by premature operations, short study periods, and small sample size (N<70) (Kanchanalarp et al. 2005; Hamzavi et al. 2003). The reimplantation rate may be related to the surgeon's operating experience, implant material, postoperative wound care, and follow-up duration. In addition, the calculation method for the reimplantation rate is not unified.

Cochlear reimplantation is invasive, and implants are expensive, which may bring financial and mental burdens to patients and their families (Qiu et al. 2017; Chen et al. 2021). In addition, some studies reported that rehabilitation after reimplantation was not as effective as that after initial CI in some patients (Roßberg et al. 2021; Balakina et al. 2015). Hence, cochlear reimplantation needs more attention. Therefore, this study aimed to provide a standard definition of reimplantation and summarize the overall status of cochlear reimplantation, such as reimplantation rate, causes, and other details.

MATERIALS AND METHODS

Meta-Analysis and Systematic Review

Based on literature review and surgical characteristics, a relatively more precise definition (similar to that of Wang et al.) was proposed: cochlear reimplantation is the implantation of new electrodes to reconstruct the auditory path, necessitated by the failure or abandonment of the initial implant. In postoperative effect assessment, merely ipsilateral implantation can be considered reimplantation because the basic conditions of the contralateral ear, such as tone audiometry threshold and intervention history, are different from that of the ipsilateral ear. In cause analysis, both ipsi- and contralateral implantation should be considered cochlear reimplantation because they both result from various complications and are treated with new devices. In addition, if only components other than the electrodes are replaced, it should not be called reimplantation, because the old device is still being used, at least in part. When a patient needs reimplantation on one ear but undergoes simultaneous CI implantation on both ears, the contralateral CI implantation should be considered sequential instead of reimplantation. This definition had been used in the remaining part of the study.

This systematic review and meta-analysis was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (Moher et al. 2009). English (Web of Science, PubMed, Embase, Medline) and Chinese (Chinese National Knowledge Infrastructure, Wanfang Data, VIP Chinese Science and Technology Periodicals Database) databases were systematically searched for studies on cochlear reimplantation published before July 23, 2021. Search terms related to CI and cochlear reimplantation were comprehensively combined to locate relevant studies, like (((((re-implant*[Title/Abstract]) OR (reimplant*[Title/Abstract])) OR (reinsert*[Title/Abstract])) OR (re-insert*[Title/Abstract])) OR (reoperat*[Title/Abstract])) AND ("Cochlear Implants"[Mesh] OR "Cochlear Implantation"[Mesh]) for Pubmed. (Appendix 1 in the Supplemental Digital Content 1, http://links.lww.com/EANDH/B46).

YXY screened titles/abstracts of potentially eligible studies, using predetermined criteria to select studies for full-text review. The literature inclusion criteria included (1) calculable rate of cochlear reimplantation; (2) at least two causes of reimplantation reported; (3) sample size ≥5. The exclusion criteria included (1) not in English or Chinese; (2) using databases duplicated from other studies. Two researchers (YXY and LHT) independently assessed full-text articles for inclusion and extracted the following data: publication year, country, time period of cochlear implantation, sex, age, number of initial and reimplanted CIs, reimplantation rate, reimplantation side, reasons for reimplantation, and so on. If the reimplantation rate was not reported, it was calculated using the formula "reimplantation rate = reimplanted CIs/primary CIs". In cross-checking, disagreements regarding inclusion and data extraction were resolved by discussion, and a consensus was finally reached.

In the meta-analysis, methodological quality assessment was conducted to evaluate and decrease the risk of bias in each study. However, since cochlear reimplantation lacks a standard definition, only primary data from included studies were used without any statistical result, so almost all the assessment tools for cross-sectional studies were not suitable for this study. Quality assessment was not performed, which was compensated by sensitivity analysis exploring the impact of each study on the effect size.

The effect size, reimplantation rate, was calculated using original data, and a random-effects model with DerSimonian-Laird was used to pool the effect size. The weight of each study was determined by the sample size. Heterogeneity was calculated with the I^2 statistic, where values around 25% were considered low heterogeneity; around 50%, medium; and around 75%, high. Subgroup analysis was conducted to examine the origin of heterogeneity, including implantation age and time period. Sensitivity analysis was performed by eliminating each study sequentially to examine the impact of individual studies on the pooled effect size.

According to the European Consensus Statement, possible causes for reimplantation were selected: device failure/medical reasons/device upgrades/other or unknown. The proportions of reimplantation causes and reimplantation sides (ipsilateral/contralateral) were synthesized using methods similar to that of the reimplantation rate.

Publication bias was estimated by the Egger asymmetry test and funnel plots. A two-tailed α of 0.05 was regarded as the statistically significant level. All statistical analyses were carried out using Stata version 16.0 (Stata Corp LLC, College Station, TX).

Single-Center Data Review and Analysis

With the help of the Big-Data Platform and the Medical Records Department of West China Hospital of Sichuan University, the CI surgeries performed from April 1999 to August 2021 were reviewed. Patients with sufficient data for extraction were included. The extracted data were as follows: sex, age, CI manufacturers, surgical time, reasons for reimplantation, surgical details, postoperative rehabilitation information, and so on. The reimplantation rate and proportion of reimplantation reasons were calculated.

Continuous variables are described as means and SDs. Categorical variables are presented as numbers with percentages. Student's *t*-test and the Mann-Whitney *U* test were used to compare continuous variables among groups, and the chi-squared test or Fisher's exact test was used to compare categorical variables among groups, as appropriate. The Kaplan-Meier curve was used for survival analysis, and the log-rank test was used to compare the survival distribution of the different subgroups (age and CI manufacturers). The date of the initial CI operation was regarded as the initial event, and that of the reimplantation surgery was set as the failure event. The observation endpoint was August 16, 2021.

RESULT

Meta-Analysis and Systematic Review

After systematically searching 7 databases, 1888 articles were retrieved. After deduplication and selection, 144 articles were included (Fig. 1), among which 130 reported cochlear reimplantation rates and 128 reported the reimplantation causes. The studies were conducted in 32 countries; 31 were conducted in the United States and 24 in China (Fig. 2); 15 were published before 2000, 88 from 2000 to 2010, and 41 after 2011. The median sample size was 446 (range: 10 to 4952; interquartile range: 148 to 821). The included studies contained 85,851 initial CIs and 4276 reimplanted CIs (Appendix 2 in the Supplemental Digital Content 1, http://links.lww.com/EANDH/B46).

The reimplantation rate of included studies was from 0.48% to 30%. On the basis of the predetermined model of the meta-analysis, the pooled rate of cochlear reimplantation was 4.7% [95% CI (4.2% to 5.1%)] with $I^2 = 92.0\%$, and the overall forest plot is displayed in Figure 3. Due to the moderately high heterogeneity, the subgroup analyses were performed to explore the impact of the main study characteristics on the effect size. The pooled reimplantation rate in children was 5.4% [95% CI (4.5% to 6.2%)] with $I^2 = 90.9\%$ and that in adults was 4.4% [95% CI (3.4% to 5.4%)] with $I^2 = 90.0\%$ ($P = 0.150$) (Table 1, Appendix 3 and 4 in Supplemental Digital Content 1, http://links.lww.com/EANDH/B46). The reimplantation rate for CIs inserted before 2000 was 6.3% [95% CI (4.5% to 8.1%)], in 2001 to 2010 was 2.9% [95% CI (2.1% to 3.6%)], and in 2011 to 2021 was 4.2% [95% CI (2.8% to 5.6%)] ($P = 0.001$).

Sensitivity analyses were conducted to confirm the influence of individual studies on the pooled effect size. Except for studies conducted by Marlowe et al. (2010), Gosepath et al. (2009), and Cullen et al. (2008), sequentially eliminating each study did not significantly change the pooled effect estimate, which fluctuated around 0.467 (Appendix 5 in in Supplemental Digital Content 1, http://links.lww.com/EANDH/B46).

The funnel plot was not symmetrical, and the Egger test showed $Z = 9.70$ and $P < 0.001$, indicating the existence of publication bias (Appendix 6 in Supplemental Digital Content 1, http://links.lww.com/EANDH/B46).

In the analysis of reimplantation cause, device failure accounted for the largest proportion (67.6% [95% CI (64.0% to 71.3%)]), followed by medical reasons (28.9% [95% CI (25.7% to 32.0%)]). As for the reimplantation side, the combined proportion of ipsilateral reimplantations was 85.5% [95% CI (82.4% to 88.7%)], higher than that of contralateral reimplantations (13.7% [95% CI (10.6% to 16.7%)]).

Among the 144 studies, the effect of reimplantation was evaluated in only 68 (47.2%) articles. The assessment methods mainly included CI-aided pure-tone audiometry, the Categories of Auditory Perception scale, the Speech Intelligibility Rating test, Bamford-Kowal-Bench sentence lists, and the Pediatric Ranked Order Speech Perception score. The follow-up period was mainly within one year after the operation, and only 12 (17.6%) studies conducted follow-up for more than three years.

Single-Center Data Review and Analysis

From April 1999 to August 2021, 1775 CIs were performed in West China Hospital, of which 1718 were initial CIs and 57 were reimplanted CIs. After excluding four individuals with missing information, 153 adults (77 females and 76 males; average age: 35.3 ± 14.3 years) and 1561 children (647 females and 914 males; average age: 3.8 ± 3.4 years) were in the initial CI group, and three adults (3 females; average age: 39.7 ± 20.7 years) and 54 children (17 females and 37 males; average age: 2.8 ± 1.4 years) were in the reimplantation group (additional demographic information is shown in Tables 2 and 3). In the initial CI group, the age at cochlear implantation, sex distribution, implantation laterality, and manufacturer of the implants in children were significantly different from those of adults (all, $P < 0.05$).

The overall reimplantation rate was 3.3%; that for children was 3.5% and for adults was 2.0% ($P = 0.324$). The reimplantation rates with Advanced Bionics, Cochlear, Medel, and Nurotron devices were 1.5%, 1.3%, 0.46%, and 10.3%, respectively ($P < 0.001$). With regard to the reimplantation causes, there were 45 reimplantations caused by device failure (78.9%), ten for medical reasons (17.5%), and two for unknown reasons (3.5%); a significant difference in reimplantation causes between adults and children ($P = 0.515$) did not exist. In the analysis of the reimplantation side, there were 52 (91.2%) ipsilateral and 5 (8.8%) contralateral reimplantations (Table 3). In 50 cases, reimplantation was performed simultaneously with the removal of the initial implant, and in 7 cases, there was an interval between removal and reimplantation due to severe skin-flap infection.

In West China Hospital, the cumulative survival rate of cochlear implant was 96.25 ± 0.53% at 5 years and 95.31 ± 0.66% at 10 years. The subgroup analyses of cumulative survival rates found that there was no significant difference in the survival time between children and adults ($P = 0.558$), and a significant difference was observed between the four manufacturers ($P < 0.001$), as shown in Table 4 and Figure 5. Since most of the patients underwent CI surgeries in the past five years, and the follow-up period was relatively short, the survival analysis was limited to some extent, which might impact the results.

DISCUSSION

This study systematically reviewed the global status of cochlear reimplantation, proposed a relatively precise definition, and formulated a relatively representative formula for the

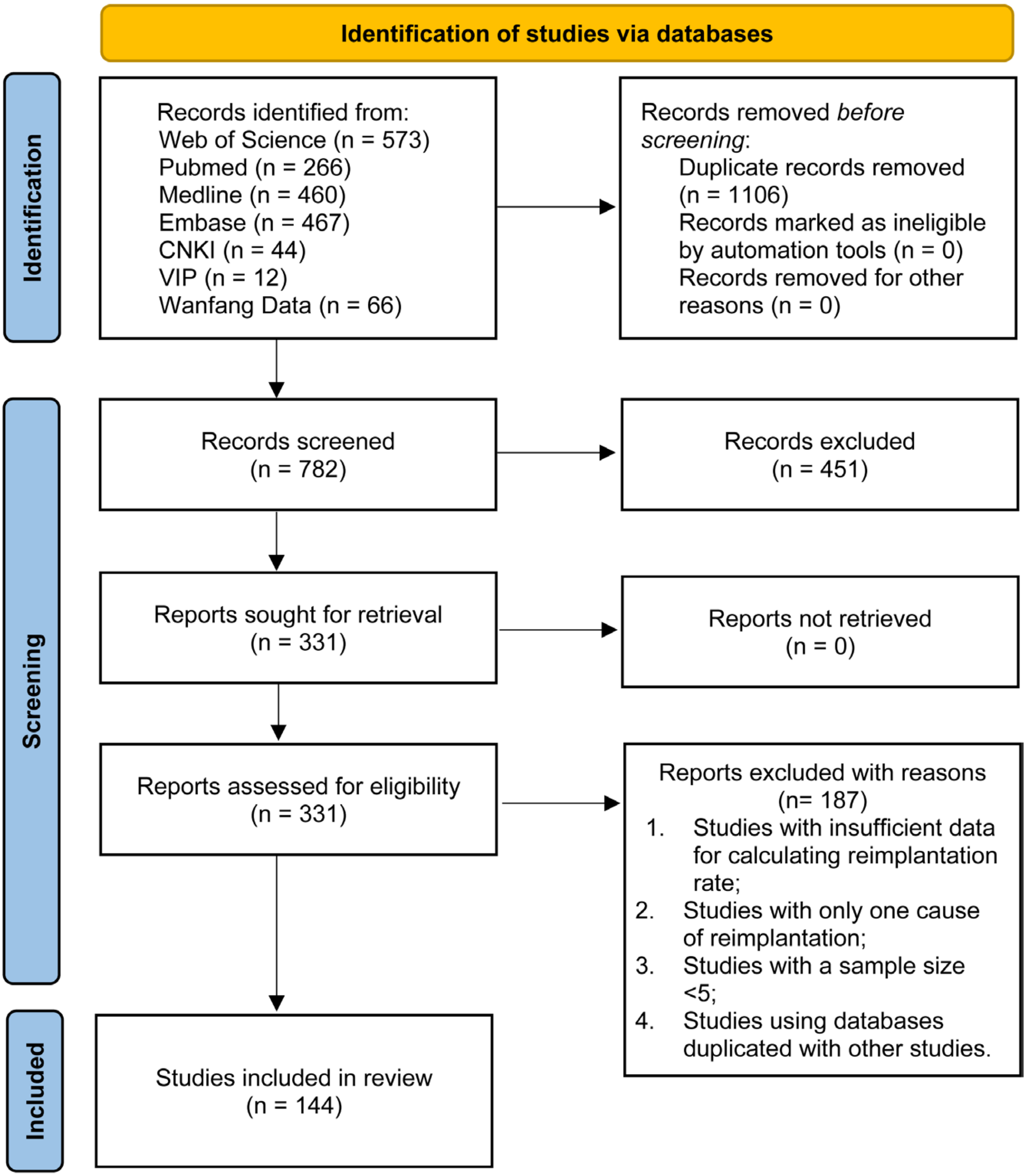

FIG. 1. Flowchart of literature search and selection. Studies on cochlear reimplantation were systematically searched in seven databases (CNKI: Chinese National Knowledge Infrastructure; VIP: VIP Chinese Science and Technology Periodicals Database). After independent selection by two authors and cross-checking, 144 studies were finally selected for data extraction and synthesis.

reimplantation rate for the first time. Synthesizing the reimplantation rate of 130 studies and analyzing the 22-year data on cochlear reimplantation in West China Hospital presented a relatively high cochlear reimplantation rate.

The definition of cochlear reimplantation was neglected in previous studies. Only Robert K et al. (1989) and Wang et al. (2014) provided preliminary definitions. Many studies equated reimplantation with revision and regarded the reinsertion of initial electrodes as reimplantation (Shin et al. 2013; Hwang et al. 2019; Lassig et al. 2005). However, this was not conducive to the normalization of research on cochlear reimplantation. We proposed a clear definition of cochlear reimplantation,

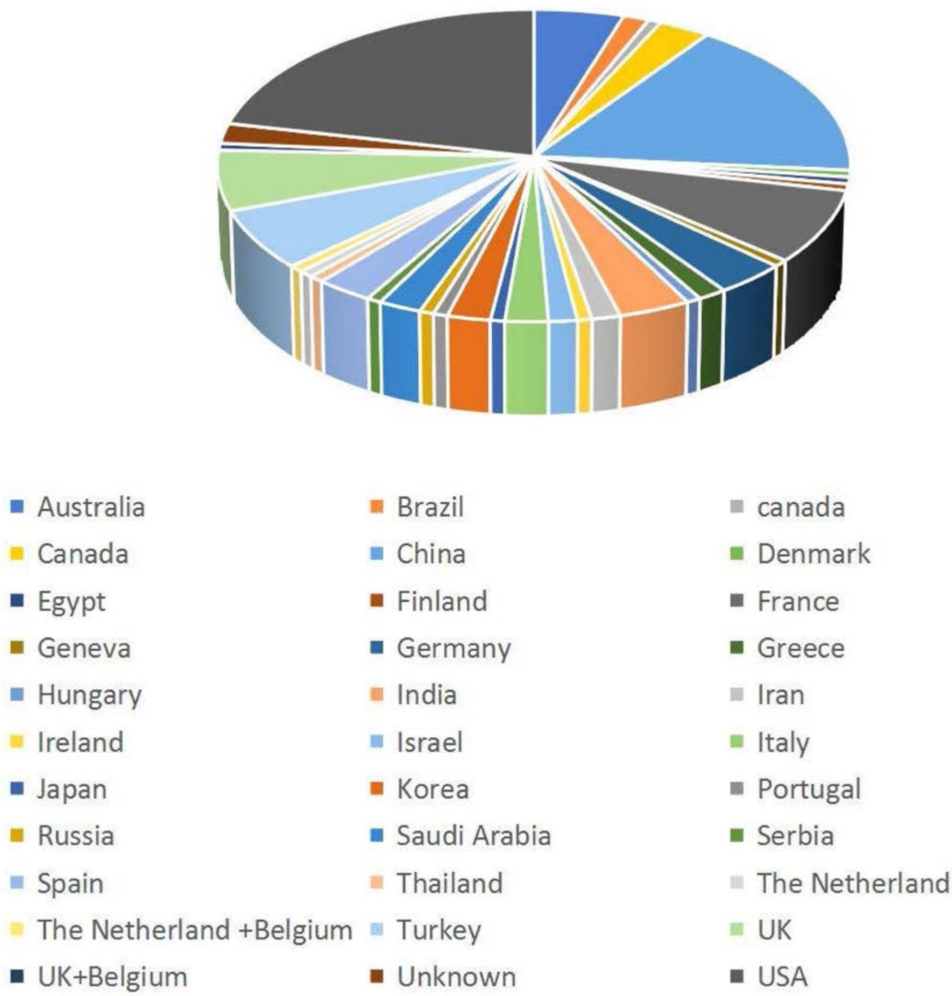

FIG. 2. Country distribution of the included 144 studies. This pie chart depicts the different countries where the 144 studies were conducted; each country is symbolized with a different color.

distinguishing between reinsertion, revision, and reimplantation, and laying the foundation for normalizing research in this field.

According to the review of the research published in the past 36 years, the pooled prevalence of cochlear reimplantation was 4.7% [95% CI (4.2% to 5.1%)]. The pooled reimplantation rate was 6.30% [95% CI (4.5% to 8.1%)] before 2000 and significantly decreased after 2000, which might have been the result of doctors' operative maturity, improvement in technology and materials of cochlear implants, postoperative wound care, and follow-up. The reimplantation rate in 2011 to 2021 was higher than that in 2001 to 2010, which possibly resulted from the exhaustion of the life expectancy of the early CIs, but the difference was not statistically significant (P = 0.101). Although the reported incidence of cochlear reimplantation or serious complications was low, it was relatively higher than expected when compared with other permanent or semipermanent implants, such as dental implants (3.2% [95% CI (2.0% to 4.5%)]) and artificial hip joints (2.5% [95% CI (1.9% to 3.2%)]; Huang et al. 2021; Abdel-Halim et al. 2021; Buser et al. 2012).

Concerning the cause of reimplantation, device failure was the reason for approximately 2/3 of all reimplantations, followed by medical reasons, consistent with the results of previous studies (Tang et al. 2019; Chen et al. 2021; Gumus et al. 2020). Therefore, the key to decreasing the reimplantation rate may be improving the materials and performance of cochlear implants and considerately reminding patients to avoid falling and trauma.

After excluding studies with only one reason for reimplantation, the present review included 101,878 initial CIs and 4855 reimplanted CIs. According to US Food and Drug Administration estimates, up to December 2019, approximately 736,900 CIs had been performed worldwide. With the pooled reimplantation rate of 4.7% obtained in this study, an estimated 34,634 cochlear reimplantations worldwide were calculated to have been performed by the end of 2019. However, the attention paid to cochlear reimplantation was insufficient. As the largest prospective and national cochlear implant database available in the United States, the HIPAA-secure, Encrypted, Research Management and Evaluation Solution (HERMES) database comprehensively collected data of CI patients during the candidate period, initial surgical consultation, preoperative and postoperative status, start-up, and follow-up. Although complications were noted during data collection, cochlear reimplantation was not mentioned at all in the HERMES database, which revealed insufficient attention to the population that underwent

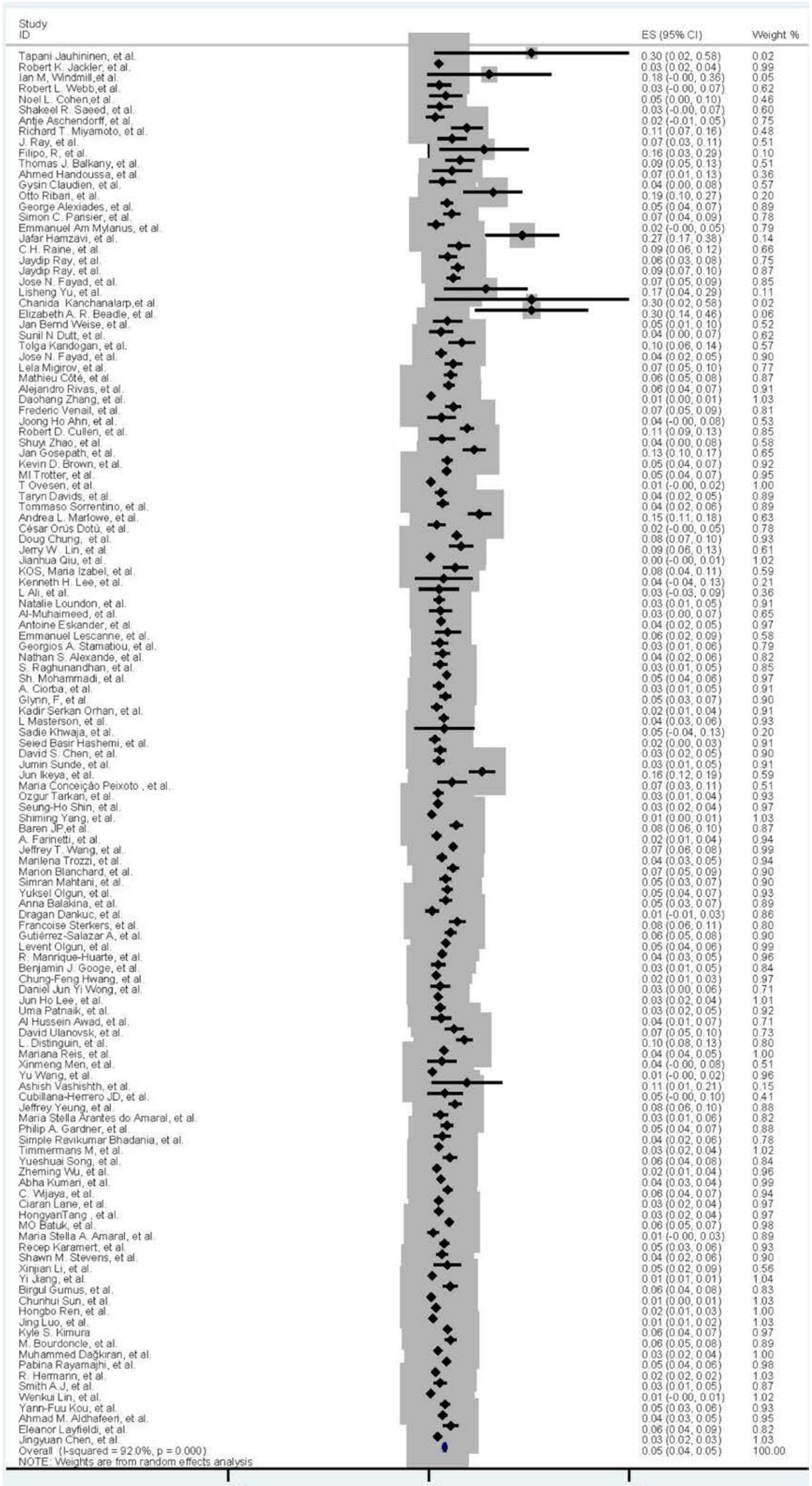

FIG. 3. Forest plot of the pooled prevalence of cochlear reimplantation of included studies. The effect size (SE) is the reimplantation rate, which is weighted by the sample size of each study. The rates of 130 studies that reported sufficient data for the calculation were synthesized using a random-effects model with DerSimonian-Laird.

TABLE 1. The subgroup analysis of pooled rate of cochlear reimplantation by age and time period of surgeries

Group	Pooled P	95% CI	I^2, (%)	*p*
Population				
Children	5.40%	(4.5%–6.2%)	90.0	0.150
Adults	4.40%	(3.4%–5.4%)	91.0	
Time period				
1979–2000	6.30%	(4.5%–8.1%)	73.9	0.001
2001–2010	2.90%	(2.1%–3.6%)	0.0	
2011–2021	4.20%	(2.8%–5.6%)	85.13	

cochlear reimplantation. Clinicians and researchers should raise awareness of cochlear reimplantation and pay more attention to hearing-related rehabilitation and the needs of this population.

In West China Hospital, the first CI surgery was performed in April 1999. Until August 2021, the overall cochlear reimplantation rate was 3.3%, consistent with the results of studies conducted by Tang et al. (2019), Sunde et al. (2013), and Googe & Carron (2016).

According to the data from West China Hospital, there was no significant difference in the cochlear reimplantation rate between children and adults, which was consistent with the results of some previous studies (Migirov et al. 2007; Distinguin et al. 2017; Manrique-Huarte et al. 2015). In the meta-analysis, no difference between adults and children was observed as well. However, in some other studies, the reimplantation rate in children was higher than that in adults, possibly because children were more likely to fall, more frequently experience otitis media, and were still undergoing skeletal growth (Weise et al. 2005; Gosepath et al. 2009; Kandogan et al. 2005). Two main reasons for the inconsistency were assumed: one was that there were many confounding factors in the studies included in the meta-analysis, and the other was that among the included 144 articles, only 22 reported reimplantation data of adults and children separately. Therefore, the pooled reimplantation rates of children and adults may not be representative, and further multicenter research is imperative to demonstrate the difference.

The reimplantation side varied by the cause of reimplantation. Based on the reviewed studies, we found new electrodes were difficult to implant in patients with complications like repeated skin-flap infections, fibrous-tissue proliferation, and occlusion, so the contralateral ear was chosen for the reimplanted cochlear implant (Trotter et al. 2009; Masterson et al. 2012; Ray & Gibson et al. 2004; Ray & Proops et al. 2004). In patients without other abnormalities, the ipsilateral ear was usually selected for reimplantation (Yeung et al. 2018; Wijaya et al. 2019). The reviewed literature suggested that nearly 90% of reimplantation operations were conducted in the ipsilateral ear. However, there were no issued criteria for side selection, and factors like intervention pattern, the interval period between initial implantation and reimplantation, and auditory input during the interval should be taken into consideration.

Another critical question was whether the auditory and speech performance of patients who underwent cochlear reimplantation were similar with that when they underwent the initial CI, which was assessed in <50% of studies. In some large cohort studies, effect evaluation or analysis was not performed (Rayamajhi et al. 2020; Aldhafeeri et al. 2021; Layfield et al. 2021). Because the follow-up data were not systematic

TABLE 2. Characteristics of primary cochlear implantation in West China Hospital of Sichuan University

Characteristics	Children (n = 1561)	Adults (n = 153)	*p*
Age, mean (SD), yrs	3.8 (3.4)	35.3 (14.3)	0.026
Sex, n (%)			
Female	647 (41.4)	77 (50.3)	0.034
Male	914 (58.6)	76 (49.7)	
Operation time, n (%)			
1999–2009	197 (12.6)	7 (4.6)	<0.001
2010–2019	1149 (73.6)	107 (69.9)	
2020–2021	215 (13.8)	39 (25.5)	
Laterality, n (%)			
Right	1266 (81.1)	107 (69.9)	0.001
Left	295 (18.9)	46 (30.1)	
Manufacture, n (%)			
Advanced Bionics	243 (15.6)	31 (20.3)	<0.001
Cochlear	661 (42.3)	51 (33.3)	
Medel	510 (32.7)	33 (21.6)	
Nurotron	147 (9.4)	38 (24.8)	

SD, standard deviation.

and complete in large cohort studies, the analysis was limited (Hermann et al. 2020). In addition, as the reimplantation surgery procedure improved, concerns about the effect of reimplantation decreased. In terms of assessment tools, aided pure-tone audiometry (Zhao et al. 2008; Gardner et al. 2018; Gumus et al. 2020), speech discrimination tests (Blanchard et al. 2015; Chung et al. 2010; Sterkers et al. 2015), and subjective questionnaire-based assessments (Ulanovski et al. 2017; Bhadania et al. 2018; Lu & Cao 2014) were the main methods for assessing the effect of reimplantation. There were few assessments for quality of life and electrophysiology of the auditory nerve in patients undergoing reimplantation. Previous studies revealed that most patients with reimplantation reached or exceeded the preoperative hearing level, although a small number of patients presented poorer performance (Shin et al. 2013; Blanchard et al. 2014; Dillon et al. 2015). Many factors would influence the reimplantation effect, including age, the interval between initial and reimplanted CIs, auditory input during the interval, reimplantation depth, activation of electrodes, device upgrades, and so on (Roßberg et al. 2021; Lenarz 2017; Marlowe et al. 2010). However, systematic discussion of above factors was lacking. In summary, the effect assessment of cochlear reimplantation received little attention, and a complete and comprehensive mechanism and system must be established for scientific assessment of the long-term effects as well as the factors affecting the outcome of reimplantation.

This study reviewed the global status of cochlear reimplantation by systematically searching large medical databases, which is the largest one to date with the largest number of included studies and sample size. Therefore, the results probably represent the state of the art in cochlear reimplantation. In addition, this study highlighted some deficiencies in this field and provided corresponding suggestions, such as conducting more multicenter research, establishing an evaluation mechanism for the reimplantation effect, and systematically discussing the influencing factors on the effect. Finally, data from many databases combined with data from a large hospital with 22 years of cochlear implant experience provided a comprehensive and representative report and summary of the current state of cochlear implantation.

TABLE 3. Characteristics of cochlear reimplantation in West China Hospital of Sichuan University

Characteristics	Children (n = 54)	Adults (n = 3)	*p*
Age at 1st CI, mean (SD), yrs	2.8 (1.4)	39.7 (20.7)	0.004
The interval between 1st and 2nd CIs, mean (SD), yrs	3.0 (2.6)	3.4 (3.1)	0.668
Sex, n (%)			
Female	17 (31.5)	3 (100.0)	0.039
Male	37 (68.5)	0 (0.0)	
Reimplantation reason, n (%)			
Device failure	43 (79.6)	2 (66.7)	0.515
Medical reason	9 (16.7)	1 (33.3)	
Other/unknown	2 (3.7)	0 (0.0)	
Laterality, n (%)			
Ipsilateral	49 (90.7)	3 (100.0)	1.000
Contralateral	5 (9.3)	0 (0.0)	
Manufacture of 1st CI, n (%)			
Advanced Bionics	3 (5.6)	1 (33.3)	0.089
Cochlear	9 (16.7)	0 (0.0)	
Medel	25 (46.3)	0 (0.0)	
Nurotron	17 (31.5)	2 (66.7)	
Manufacture change, n (%)			
Identical	51 (94.4)	3 (100.0)	1.000
Different	3 (5.6)	0 (0.0)	

CI, cochlear implantation; SD, standard deviation.

TABLE 4. Reimplantation survival for cochlear implants

	5-year cumulative survival	10-year cumulative survival
Age group		
Children	96.25 ± 0.53%	95.31 ± 0.66%
Adults	97.84 ± 1.6%	95.19 ± 3.04%
Manufactures		
Advanced Bionics	98.47 ± 0.89%	94.89 ± 3.62%
Cochlear	98.69 ± 0.46%	98.37 ± 0.56%
Medel	94.53 ± 1.19%	93.15 ± 1.42%
Nurotron	86.68 ± 3.06%	84.27 ± 3.81%

There were several limitations to this study. First, the inclusion of studies with different regions, populations, time periods, and methods of calculating reimplantation resulted in a moderately high heterogeneity. Meanwhile, because cochlear implantation notably lacked a standard definition, common tools for assessing study quality were not suitable for this study, and the methodological quality of the included studies was not assessed. Therefore, the reimplantation rate reported here should be considered as a rough estimate of the global reimplantation status. Second, to avoid bias in the analysis of reimplantation reasons,

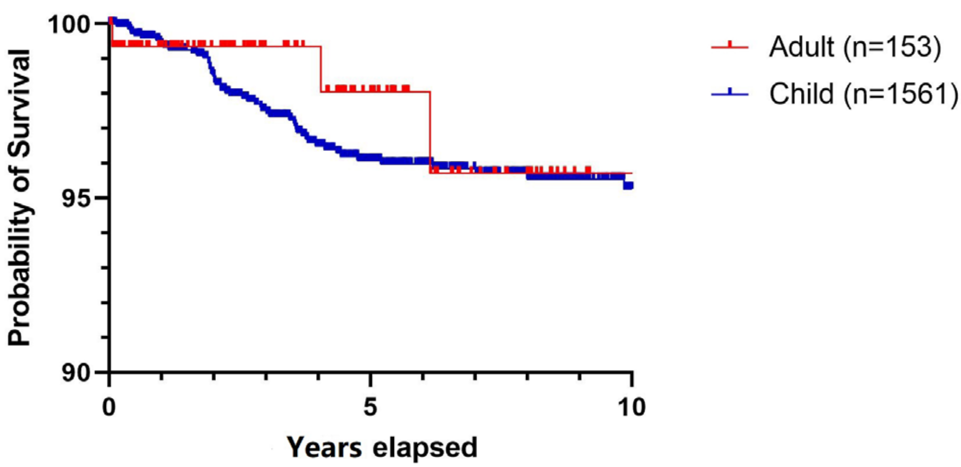

FIG. 4. Kaplan-Meier survival analysis of cochlear implant cumulative survival by age group. The date of the initial CI operation was regarded as the initial event, and that of the reimplantation surgery was set as the failure event. The censored values (the short and vertical lines) mainly result from the end of observation. The survival probability of cochlear implants was not significantly different between children and adults ($P = 0.558$).

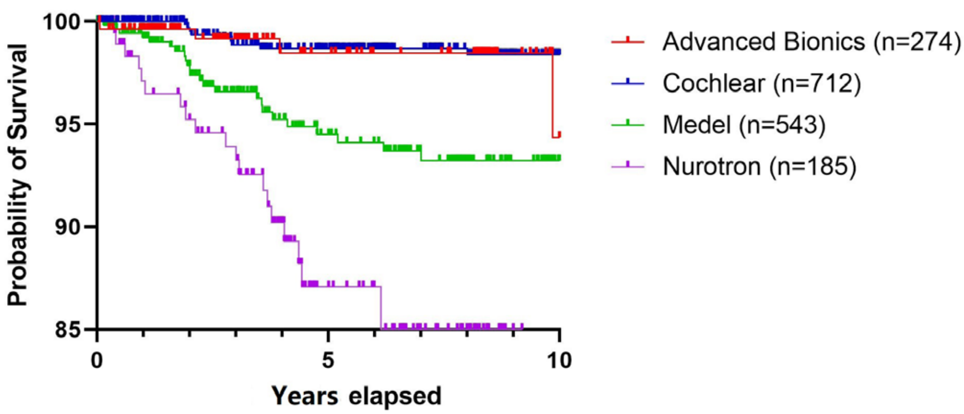

FIG. 5. Kaplan-Meier survival analysis of cochlear implant cumulative survival by manufacturer. The date of the initial CI operation was regarded as the initial event, and that of the reimplantation surgery was set as the failure event. The censored values (the short and vertical lines) mainly result from the end of observation. The survival probability of cochlear implants is significantly different among four CI manufactures ($P < 0.001$).

26 articles were excluded that included only one reason for reimplantation, which resulted in a reduced sample size and ultimately reduced the representativeness and comprehensiveness of this study. Third, the follow-up duration was relatively short in many studies, and some reimplantation effects are only observed after an extended period of time. Therefore, the pooled reimplantation rate and that of West China Hospital may both be underestimated. Fourth, although the overall number of initial implantations and reimplantations was relatively large in West China Hospital, it was only a single-center study and cannot reflect the full picture of cochlear reimplantation worldwide.

CONCLUSION

In this study, the cochlear reimplantation rate was found to be relatively high, and the reimplantation population was relatively large, requiring more attention and care. No unified definition of cochlear reimplantation and no unified method of calculating the reimplantation rate was found in previous studies worldwide. Therefore, a more precise definition was proposed. Previous studies focused more on CI complications and the reasons for reimplantation, and there is an absence of research on the reimplantation effects and follow-up cohorts. The crucial issues related to the reimplantation effect, like the remodeling of the auditory cortex and side selection for reimplantation, have not been fully resolved. Thus, more attention should be given to assessing postoperative effects, establishing a long-term follow-up mechanism, and improving the quality of longitudinal cohort studies. In addition, new methods such as cortical auditory evoked potentials and functional neuroimaging can be used to study cochlear reimplantation and actively explore the factors affecting reimplantation-mediated rehabilitation.

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As the co-first author, H.L. designed this study, researched and selected the literature in Chinese and English database, collected and cleared the data, and drafted the manuscript. As the co-first author, X.Y. also designed this study, researched and selected the literature in Chinese and English database, collected and cleared the data, and drafted the manuscript. W.K, L.Z and J.S collected the data in West China Hospital and Xuanwu Hospital; X.D. have raised substantial suggestions to the definition and status of cochlear reimplantation, and to the revising the manuscript critically for important intellectual content; Y.Z. (Yun Zheng) put forward critical thought and point in conception of cochlear reimplantation, especially in the effect assessment of cochlear reimplantation; Y.Z. (Yu Zhao) have raised substantial suggestions to the surgery information of cochlear reimplantation, and to the revising the manuscript critically for important intellectual content. All author gave final approval of the version to be published and agreed to be accountable for all aspects of the work.

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Address for correspondence: Yu Zhao, Department of Otolaryngology-Head and Neck Surgery, West China Hospital of Sichuan University, 37 Guo Xue Lane, Chengdu, Sichuan 610041, People's Republic of China. E-mail: yutzhao@163.com or Yun Zheng, Department of Otolaryngology-Head and Neck Surgery, Hearing Center/Hearing and Speech Science Laboratory, West China Hospital of Sichuan University, 37 Guo Xue Lane, Chengdu, Sichuan 610041, People's Republic of China. E-mail: 1141679315@qq.com or Xiuyong Ding, Department of Otolaryngology-Head and Neck Surgery, XuanWu Hospital of Capital Medical University, No. 45 Changchun St, Xicheng District, Beijing 100053, People's Republic of China. E-mail: 1141679315@qq.com

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