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Depression Risk After Cochlear Implantation Compared with Other Rehabilitation Strategies in Severe Hearing Loss: A Nationwide Cohort Study

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ABSTRACT

Hearing loss is a growing public health concern with substantial psychosocial consequences. This study investigated whether auditory rehabilitation, particularly cochlear implantation, reduces the long-term risk of depression in individuals with severe hearing loss. Using data from the Korean National Health Insurance System from 2002 to 2020, adults aged 20–69 years with severe hearing loss (bilateral ≥70 dB HL) were categorized into three groups: cochlear implant (CI), hearing aid (HA), and no rehabilitation (NR). A control group without hearing loss was included. Depression incidence was tracked through 2020. The cohort included 831,042 individuals: 661 in the CI group, 15,939 in the HA group, 5,039 in the NR group, and 809,403 controls. Depression occurred in 13.6%, 18.2%, 21.9%, and 15.9% of these groups, respectively. After adjusting for confounders, all hearing loss groups had a higher depression risk than controls, with a progressive increase from CI to HA to NR. Compared to the CI group, the NR group showed a 1.3-fold higher risk of depression (95% confidence interval 1.051-1.615). These findings highlight the mental health benefits of auditory rehabilitation and support expanding access to CI as a preventive mental health strategy.

Keywords: Depression, Cochlear Implantation, Hearing Aid, Hearing Rehabilitation

INTRODUCTION

Hearing loss is a widespread health problem that significantly impacts an individual's quality of life, often resulting in communication barriers that can affect overall well-being. According to the World Health Organization (WHO), more than 1.5 billion people globally live with hearing loss, of whom over 430 million experience disabling hearing loss, defined as a hearing threshold >35 dB HL in the better ear.[1-3] As life expectancy increases and the elderly population grows, age-related conditions such as hearing loss are becoming an increasingly important public health issue.[4] Hearing impairment not only interferes with communication, but can also increases vulnerability to psychological problems such as depression by contributing to social isolation, loneliness, heightened cognitive load from effortful listening, and potentially altered auditory–limbic neural interactions.[5-7]

Hearing aids (HAs), the most commonly known method of auditory rehabilitation, are known to improve speech perception for people with hearing loss.[8-10] In addition to these auditory benefits, numerous studies have reported that HA use may positively impact users' quality of life and mental well-being.[11-13] However, for people with severe to profound hearing loss, HAs often have limited effectiveness and do not provide sufficient support for speech perception.[14,15] In these cases, cochlear implantation (CI) can be an effective alternative for auditory rehabilitation. Previous studies have investigated the benefits of CI on auditory and speech perception,[16,17] but the mental health impact of auditory rehabilitation strategies at the population level remains poorly understood.

Untreated hearing loss is associated with social isolation and an increased risk of depression, suggesting that successful auditory rehabilitation might help mitigate this risk. A prospective study in older adults have reported that depressive symptoms improved significantly by 6 months after hearing intervention, with sustained benefits at 12 months only in those who received a CI.[18] Consistent with this, a systematic review noted that most studies reported reduced anxiety or depression levels following CI. However, a few studies have also found no measurable changes. In certain cohorts, no significant differences in depression or anxiety were observed after CI, and in some cases initial improvements at short-term follow-up were not maintained over longer periods.[19] These conflicting findings underscore the need for more definitive evidence on the psychological effects of CI. Many existing studies are limited by small sample sizes, short duration of follow-up, reliance on clinic-based cohorts, and the absence of normal-hearing control groups. Therefore, the long-term preventive effect of CI on depression, particularly in comparison to HAs or no rehabilitation, remains unclear at the population level.

To address this knowledge gap, we conducted a nationwide population-based cohort study using longitudinal data from a large national cohort in South Korea. By comparing outcomes across CI, HA, and no rehabilitation groups, and benchmarking against a normal-hearing control cohort, we sought to provide public health evidence on the mental health benefits of auditory rehabilitation, with implications for equitable access to hearing care.

MATERIALS AND METHODS

Data Sources

We conducted a nationwide retrospective cohort study using the National Health Insurance System (NHIS) database of South Korea, which covers approximately 97% of the population. The NHIS database, available for research with official approval, contains comprehensive records of healthcare services, including diagnoses, comorbidities classified according to the 10th version of the International Classification of Diseases and Related Health Problems (ICD-10), as well as demographic and socioeconomic information. Additionally, data on individuals with hearing disabilities were obtained from the Korean Ministry of Health and Welfare. This study utilized the NHIS database (NHIS-2023-4-001) from January 2002 to December 2020.

Study Design and Population

This study established two cohorts. The first cohort included individuals registered as having severe to profound hearing disability, defined as a bilateral hearing threshold of 70 dB HL or greater. From a total of 233,513 individuals registered with severe to profound hearing disability, those with changes in the grade of hearing disability, multiple disabilities, or missing major information were excluded. The remaining individuals, aged 20 to 69 years at the time of their auditory rehabilitation conducted between January 2007 and December 2012, were included. This cohort was divided into three groups based on the type of auditory rehabilitation: 973 individuals in the Cochlear Implant (CI) group, 20,997 in the Hearing Aid (HA) group, and 7,377 in the No Rehabilitation (NR) group. After excluding individuals with a prior diagnosis of psychiatric disorders, the final numbers were 661 in the CI group, 15,939 in the HA group, and 5,039 in the NR group. The index date was defined as the date of CI for the CI group and the date of hearing aid prescription for the HA group. For the NR group, the index date was defined as the date of hearing disability registration.

The second cohort comprised individuals without any hearing loss-related diagnoses. To establish a cohort without hearing loss, individuals with any history of chronic otitis media (ICD-10 codes H65-H67), mastoiditis (H70), cholesteatoma (H71), tympanic membrane perforation (H72-H73), mastoid disease (H74-H75), inner ear disease (H80-H83), and conductive & sensorineural hearing loss (H90-H95) were excluded. From this group, 933,227 individuals aged 20 to 69 years during the same period (2007-2012) were selected. After excluding individuals with a prior diagnosis of psychiatric disorders, the final control group consisted of 809,403 individuals. For the control group, the index date was defined as the date of the first outpatient visit to a medical institution between 2007 and 2012 during which no hearing loss-related diagnosis was recorded. All individuals were followed up for the occurrence of depression from one-year post-enrollment until December 2020. (Figure 1)

Assessment of Hearing Disability

Hearing disability was diagnosed at qualified otolaryngology centers using pure-tone audiometry, speech audiometry, and auditory brainstem response tests. These tests were conducted at intervals of 3-7 days, and the results were reviewed by two otolaryngologists. Eligibility for disability registration was determined based on the extent of hearing loss, with a hearing threshold calculated as the average pure-tone threshold across four frequencies (0.5 kHz to 4 kHz). Individuals with severe to profound hearing loss (bilateral hearing threshold ≥ 70 dB HL) were included in this study. Unilateral hearing loss was excluded.

Operational Definition of Psychiatric Disorder

Psychiatric disorders in this study were classified according to the ICD-10 codes encompassing the entire spectrum of F codes. This includes a broad range of mental, behavioral and neurodevelopmental disorders such as mental disorders due to known physiological conditions (F01-F09), mental and behavioral disorders due to psychoactive substance use (F10-F19), schizophrenia, schizotypal, delusional, and other non-mood psychotic disorders (F20-F29), mood [affective] disorders (F30-F39), anxiety, dissociative, stress-related, somatoform, and other nonpsychotic mental disorders (F40-F48), behavioral syndromes associated with physiological disturbances and physical factors (F50-F59), disorders of adult personality and behavior (F60-F69), intellectual disabilities (F70-F79), pervasive and specific developmental disorders (F80-F89), behavioral and emotional disorders with onset usually occurring in childhood and adolescence (F90-F98), and unspecified mental disorder (F99).

For the purpose of this study, depression was specifically defined using the following ICD-10 codes: mild depression (F32.0), moderate depression (F32.1), severe depression without psychotic symptoms (F32.2), severe depression with psychotic symptoms (F32.3), and recurrent depressive disorder (F33). To be included in the study, individuals had to have two or more clinical visits with these depression-related diagnostic codes.

Other Parameters

Sociodemographic factors such as age, gender, income level, and urbanization level were evaluated. To assess comorbidities that could influence mental health, the Charlson comorbidity index (CCI) and hypertension were specifically investigated. The CCI included conditions such as ischemic heart disease (I21-

I25), congestive heart failure (I09.9, I11.0, I13.0, I13.2, I25.5, I42.0, I42.5-I42.9, I43, I50, P29.0), peripheral vascular disease (I70, I71, I73.1, I73.8, I73.9, I77.1, I79.0, I79.2, K55.1, K55.8, K55.9, Z95.8, Z95.9), cerebrovascular disease (G45, G46, H34.0, I60, I69), dementia (F00, F03, F05.1, G30, G31.1), chronic pulmonary disease (I27.8, I27.9, J40-J47, J60, J67, J68.4, J70.1, J70.3), rheumatologic disease (M05, M06, M31.5, M32, M34, M35.1, M35.3, M36.0), peptic ulcer disease (K25-K28), mild liver disease (B18, K70.0-K70.3, K70.9, K71.3-K71.5, K71.7, K73, K74, K76.0, K76.2-K76.4, K78.8, K76.9, Z94.4), and moderate or severe liver disease (I85.0, I85.9, I86.4, I98.2, K70.4, K71.1, K72.1, K72.9, K76.5-K76.7). Other conditions included diabetes (E10-E14), hemiplegia or paraplegia (G04.1, G11.4, G80.1, G80.2, G81, G82, G83.0-G83.4, G83.9), renal disease (I12.0, I13.1, N03.2-N03.7, N05.2-N05.7, N18, N19, N25.0, Z49.0-Z49.2, Z94.0, Z99.2), any malignancy including leukemia and lymphoma (C00-C97), metastatic solid tumors (C77-C80), and acquired immune deficiency syndrome/human immunodeficiency virus (AIDS/HIV) (B20-B24).[20]

Statistical Analysis

Data were analyzed using R Studio, Integrated Development Environment for R Version 1.3.1093 (R Studio Inc., Boston, USA, https://www.rstudio.com) and SAS Enterprise Guide software version 7.1 (SAS Institute, Inc., Cary, NC). Person-years were calculated by summing observation years per patient from enrollment to the relevant endpoint, which could be the diagnosis of depression, death, or the end of the study period. Incidence rate ratios (IRR) were calculated relative to the control group. Kaplan-Meier survival curves were used to analyze the incidence of depression over the observation period, with differences between groups analyzed using the log-rank test. Cox proportional hazards regression models were employed to determine the risk of depression among groups, with hazard ratios (HR) and 95% confidence intervals estimated.

Sensitivity Analysis

To assess the robustness of our findings against potential confounding due to imbalanced group sizes and baseline characteristics, we conducted a sensitivity analysis using inverse probability of treatment weighting (IPTW). Propensity scores were estimated via multinomial logistic regression using variables including age, sex, income level, urbanization, CCI, and major comorbidities. IPTW was then applied to balance these covariates across the CI, HA, NR, and control groups. Covariate balance before and after weighting was evaluated using standardized mean differences (SMDs), with values below 0.1 indicating adequate balance.

Ethical consideration

This study was approved by the ethics committee of the Institutional Review Board (IRB) of Hanyang University (HYUIRB-202311-017). The requirement for informed consent was waived by the IRB due to the retrospective nature of the study and the use of anonymized administrative data. All methods were performed in accordance with the Declaration of Helsinki and relevant guidelines and regulations.

RESULTS

Study Population

A total of 831,042 individuals were included in the final analysis: 661 in the CI group, 15,939 in the HA group, 5,039 in the NR group, and 809,403 in the control group without hearing loss. Across all groups, the proportion of individuals who developed depression during the follow-up period was 13.6% in the CI group, 18.2% in the HA group, and 21.9% in the NR group, compared to 15.9% in the control group. Higher rates of depression were observed with increasing age, and were more prevalent among females, individuals with the lowest income, residents of rural areas, and those with higher CCI scores. (Table 1)

After IPTW adjustment, all baseline covariates were well balanced across groups, with all SMDs below 0.1 (Supplementary Table 1).

Incidence of Depression

The crude incidence rate (IR) of depression per 100,000 person-years was 1,327.93 in the control group. In the CI group, the IR of depression was 1,337.62 per 100,000 person-years, and the IRR was 1.01 (95% confidence interval, 0.82–1.24), indicating no significant difference compared to the control group. In contrast, the HA group showed a higher IR of 1,822.25, with an IRR of 1.37 (95% confidence interval, 1.32–1.42), reflecting a significantly increased risk of depression. The NR group demonstrated the highest incidence, with an IR of 2,311.24 and an IRR of 1.74 (95% confidence interval, 1.64–1.85), indicating a markedly elevated risk of depression compared to the control group. (Table 2)

Risk of Depression (adjusted analysis)

Adjusted for age, gender, income level, urbanization level, CCI score, and comorbidities, the risk of depression was significantly higher in all hearing loss groups compared to the control group. The adjusted hazard ratio (HR) was 1.242 (95% confidence interval, 1.010–1.527) in the CI group, 1.323 (95% confidence interval, 1.275–1.373) in the HA group, and 1.617 (95% confidence interval, 1.524–1.716) in the NR group (Table 3). These findings demonstrate a stepwise increase in depression risk across auditory rehabilitation strategies, with the CI group showing the lowest risk and the NR group the highest. This trend remained consistent in the IPTW-adjusted analysis. (Table 3)

When using the CI group as the reference, the NR group showed a significantly higher risk of depression (HR 1.303; 95% confidence interval, 1.051–1.615), while the HA group showed a non-significant trend toward increased risk (HR 1.066; 95% confidence interval, 0.864–1.314). The control group had a comparable or slightly reduced risk relative to the CI group (HR 0.805; 95% confidence interval, 0.655–0.990). The results were similarly observed in the IPTW-adjusted analysis. (Table 4)

Time-to-event analysis

Kaplan-Meier survival analysis demonstrated a graded risk of depression over time. The CI group had a similar cumulative incidence curve to the control group, whereas the HA and NR groups showed progressively higher cumulative incidence of depression throughout the follow-up period (log-rank $p < 0.001$). (Figure 2)

DISCUSSION

Auditory rehabilitation, including CI and HA, plays an important role in mitigating the consequences of severe to profound hearing loss. CIs are widely recognized as an effective intervention for individuals with severe to profound hearing impairment, often enabling substantial gains in speech perception and communication even when conventional hearing aids provide limited benefit.[21] In this large, nationwide cohort study, we found that individuals with severe to profound hearing loss who received cochlear implants had a significantly lower risk of developing depression compared to those who used hearing aids or received no auditory rehabilitation. The incidence of depression in the cochlear implant group was comparable to that of individuals without hearing loss, suggesting that cochlear implantation may restore not only auditory function but also psychosocial well-being. A clear gradient in depression risk was observed across auditory rehabilitation strategies: lowest in cochlear implant recipients, followed by hearing aid users, and highest in the untreated group. To ensure the robustness of these findings, we conducted a sensitivity analysis using IPTW to balance baseline characteristics across groups. The IPTW-adjusted results were consistent with the main analysis, reinforcing the reliability of the observed association between auditory rehabilitation and depression risk. These findings underscore the preventive mental health benefits of timely and effective auditory intervention.

Untreated hearing loss has been increasingly linked to adverse mental health outcomes, particularly depression. In the U.S. National Health and Nutrition Examination Survey (NHANES), the prevalence of moderate-to-severe depression to be 11.4% among adults with hearing impairment, versus 5.9% in those with normal hearing. Even after adjusting for demographics and health covariates, any self-reported hearing difficulty remained significantly associated with increased depression risk.[22] Similarly, longitudinal data from the Health, Aging, and Body Composition (Health ABC) study demonstrated that individuals with moderate or greater hearing loss had a 2.45-fold increased likelihood of exhibiting depressive symptoms at baseline and a 1.26-fold higher hazard of developing depression over a 10-year period.[23] In the present study, individuals with severe to profound hearing loss who did not receive auditory rehabilitation showed a markedly higher prevalence of depression compared to those without hearing loss. This finding is consistent with previous population-based studies that have identified hearing impairment as a risk factor for depression. Taken together, these data underscore that unaddressed hearing loss is an independent risk factor for depression in adults. The absence of auditory stimulation and the social difficulties stemming from hearing loss likely set the stage for chronic depressive outcomes if left untreated.

Our findings provide new evidence that effective auditory rehabilitation may mitigate the risk of depression among those with severe to profound hearing loss. The group without any rehabilitation (NR group) had the highest incidence of depression, whereas those who received interventions (CI or HA groups) had significantly lower rates. In fact, the depression risk followed a graded pattern across the groups: lowest in the CI users, intermediate in the HA users, and highest in the NR group. After adjusting for potential confounders, all hearing-loss groups still exhibited higher depression risk than the normal-hearing control group, but the magnitude of risk was greatest for NR, followed by the HA group, and the CI group showing the best results. This gradient strongly suggests a protective effect of auditory rehabilitation on mental health. Notably, the incidence rate of depression in CI group was not significantly different from that of controls without hearing loss in our cohort. These findings imply that while any auditory rehabilitation may reduce depression risk, CI may provide the most substantial mental health benefits among individuals with severe hearing loss. In a previous prospective study of older adults, both CI and HA use led to significant improvements in depressive symptom scores at 6 months post-intervention. By 12 months, the benefit was sustained in the CI recipients, whose Geriatric Depression Scale (GDS) scores had improved by ~38% from baseline, whereas the initial improvements in the HA group plateaued.[18] The results of our study are consistent with these findings, suggesting that CI may provide a greater and more sustained reduction in depressive symptoms over the long term than HA by providing more complete hearing correction in severe to profound hearing loss. When considering these results collectively, any form of auditory rehabilitation appears to have a more positive impact on mental health than no intervention at all, although CI may offer superior protective effects against depression in eligible patients. This provides important insights into auditory rehabilitation and emphasizes the importance of recommending CI in a timely manner for CI candidates, such as those with severe to profound hearing loss who have not achieved sufficient effects with HAs, as it may reduce not only hearing impairment but also the risk of depression.

Several mechanisms can explain why individuals with uncorrected severe hearing loss are at heightened risk for depression.[12,24-28] Social isolation is a key pathway. Hearing loss can compromise an individual's ability to communicate effectively, leading to increased effort during conversations and resulting in feelings of frustration or embarrassment.[24] Over time, many individuals begin to withdraw from social activities, family gatherings, and interactions that they fear will be challenging or fatiguing. This retreat from social engagement can foster loneliness, which is a well-known precipitant of depressive symptoms. A systematic review by Shukla et al.[25] confirmed that hearing loss is strongly associated with greater loneliness and social isolation in older adults, highlighting the psychosocial impact of hearing impairment. Hearing loss can also impact an individual's quality of life and sense of autonomy. Routine activities that are often taken for granted—such as engaging in telephone conversations, watching television, or responding to doorbells and alarms—may become challenging and stressful. These difficulties can lead to feelings of inadequacy or a perceived loss of control. Such experiences may contribute to a diminished sense of independence, which could, in turn, increase the risk of developing depressive symptoms.[26] Furthermore, there may be neurobiological mechanisms underlying the association between hearing loss and depression. Cognitive depression theory postulates that increased cognitive demands, such as the continuous effort to decode unclear auditory inputs, may activate negative schemas and increase the load on limited cognitive resources. According to Beck's schema-based model, maladaptive cognitive schemas are readily activated under stress and can dominate information processing, leading to a sustained negative emotional state. In the context of hearing loss, the chronic challenge of interpreting degraded auditory signals may activate negative schemas related to self-worth, competence, and social belonging. Over time, this biased information processing may reinforce negative automatic thoughts and impair access to more adaptive modes of thinking, thereby increasing vulnerability to depression.[27] All these factors – social isolation, loneliness, reduced quality of life, and increased cognitive strain – likely interact to elevate depression risk in those with unrehabilitated hearing loss. In our NR group, many of these elements were probably present. Indeed, such patients may experience a downward spiral whereby poor hearing leads to communication difficulties, then to social withdrawal, and ultimately to depressive illness. By contrast, individuals who received HA or CI in our study could remain more connected with their environment and social network, thereby breaking this cycle of isolation. Improved hearing facilitates active participation in conversations and community life, which in turn supports emotional well-being. This is consistent with the observed mental health advantage in the HA and CI groups.

The findings of this study highlight the importance of early intervention and access to auditory rehabilitation services. Despite the demonstrated mental health benefits of auditory rehabilitation, utilization rates for both HAs and CIs remain suboptimal, with especially low uptake observed for CI.[29,30] Many individuals with severe to profound hearing loss remain unrehabilitated due to various barriers, including lack of awareness, limited referral pathways, financial constraints, and stigma associated with hearing devices.[31,32] In our cohort, only a small fraction of eligible individuals received CIs, highlighting a significant health equity gap in access to high-impact interventions. While both HA and CI were associated with reduced depression risk compared to no rehabilitation in this study, CIs may provide superior benefit in cases where HAs are insufficient, as is often the case in severe to profound hearing loss.

These findings support the consideration of CI not only as a rehabilitative tool but also as a preventive intervention for mental health. By mitigating depression risk in a high-risk population, CI may contribute to broader public health goals, including improved quality of life, increased social participation, and reduced healthcare utilization related to untreated mental illness. Therefore, public health policies should address the underutilization of CIs by expanding screening and referral pathways, reducing financial barriers, and educating both providers and patients. Integrating hearing rehabilitation into mental health prevention strategies may offer a cost-effective approach to reducing the burden of depression in aging societies.

The strength of this study lies in the use of a large-scale, nationwide cohort based on comprehensive data from the Korean NHIS, allowing for long-term follow-up of individuals with severe to profound hearing loss. By including all four groups—cochlear implant (CI), hearing aid (HA), no rehabilitation (NR), and no hearing loss (Control)—and applying appropriate adjustment for demographic and clinical covariates, we were able to make meaningful comparisons across rehabilitation strategies and assess the associated risk of depression.

However, this study has several limitations. First, observational study designs cannot draw definitive conclusions about causality. Although we adjusted for multiple confounding variables, residual confounding due to unmeasured factors cannot be excluded. Second, depression was identified through diagnostic codes in administrative data and defined as at least two outpatient visits to reduce potential misclassification due to coding errors or transient diagnoses. However, this approach may have underestimated the true prevalence of depression, particularly in individuals who do not seek medical help or have limited healthcare utilization, such as those in the NR group. Third, treatment assignment was not randomized, and CI or HA use may reflect underlying differences in health awareness, socioeconomic status, or access to care, which themselves could influence depression risk. Fourth, information on the actual use patterns, duration, and adherence to auditory devices was not available, limiting interpretation of long-term effectiveness. Fifth, potential mediators such as social participation, loneliness, or cognitive function were not included in the analysis, making it difficult to explore mechanistic pathways. Fifth, although the sample size of the HA and NR groups was sufficient, the relatively small number of CI recipients may limit the statistical power in certain subgroup analyses. Lastly, although we only included individuals with bilateral hearing thresholds ≥70 dB HL, some participants may still have had marked asymmetry between ears. In such cases, it was not possible to determine which ear received the auditory device, and this may have influenced the outcome. Future research should incorporate ear-specific audiologic data and device laterality to better understand the impact of asymmetrical hearing loss on rehabilitation outcomes. Despite these limitations, the findings of this study contribute to expanding the evidence on the mental health benefits of hearing rehabilitation and emphasize the importance of increasing access to CI and HA interventions for individuals with severe to profound hearing loss.

In conclusion, CI was associated with a substantial reduction in depression risk among individuals with severe to profound hearing loss, to a level comparable with that of the normal-hearing population. These findings highlight the importance of timely auditory rehabilitation not only for communication but also for mental health protection. Ensuring equitable access to CIs must be a public health priority.

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Conflict of interest

All authors declare no competing interests.

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Author contributions

JHC had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Conceptualisation: JHC. Data curation: HWS, SR, and JHC. Formal analysis: SR, and JHC. Funding acquisition: JHC. Investigation: HWS, and SR. Methodology: SHL, and JHC. Supervision: JHC, and SHL. Validation and visualization: HWS, SYH, and JHC. Writing – original draft: HWS, and SR. Writing – review & editing: SYH, SHL, and JHC.

Data sharing

The Korean NHIS database was used with permission. The data that support the findings of the study are available from the corresponding author upon reasonable request.

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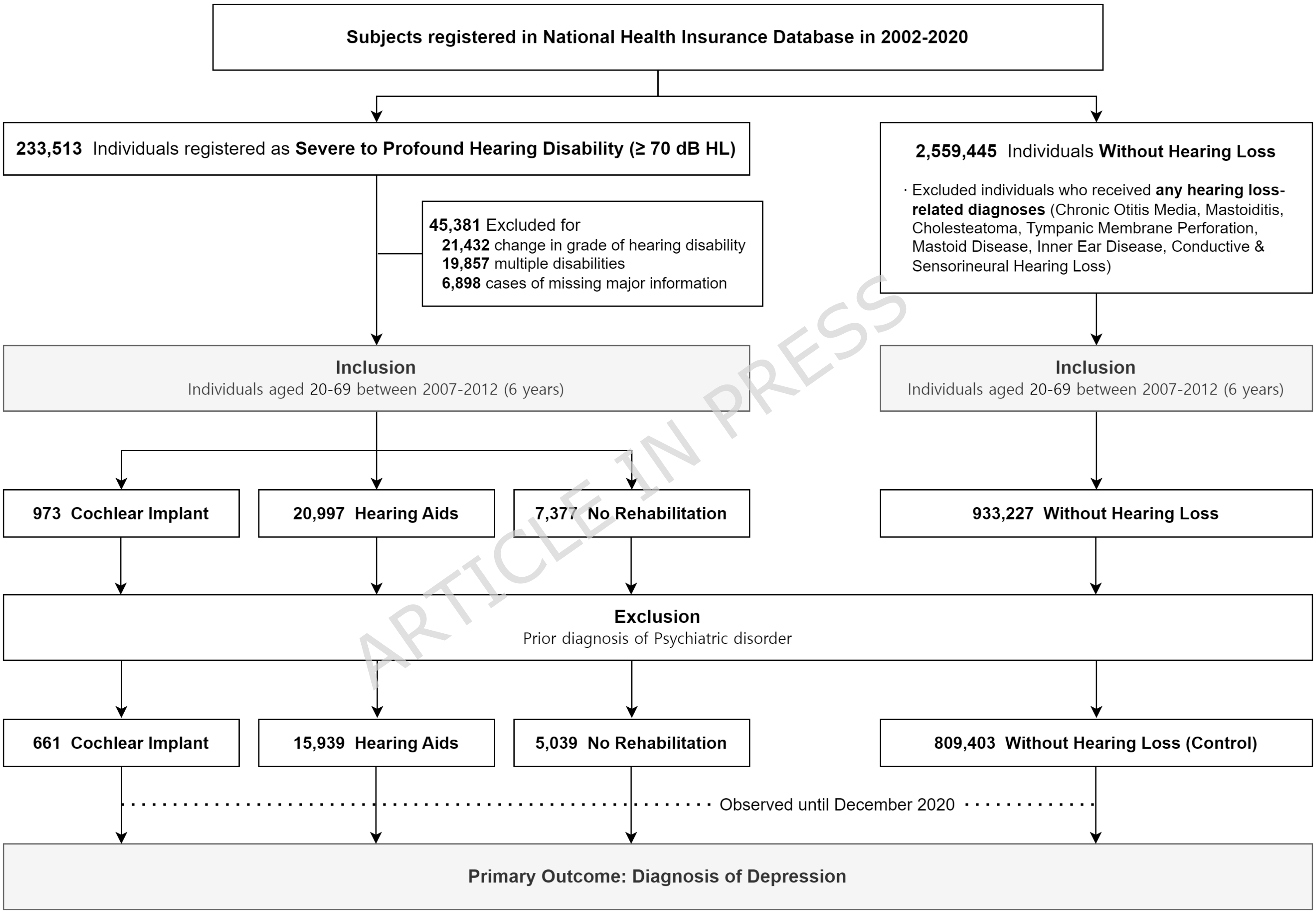
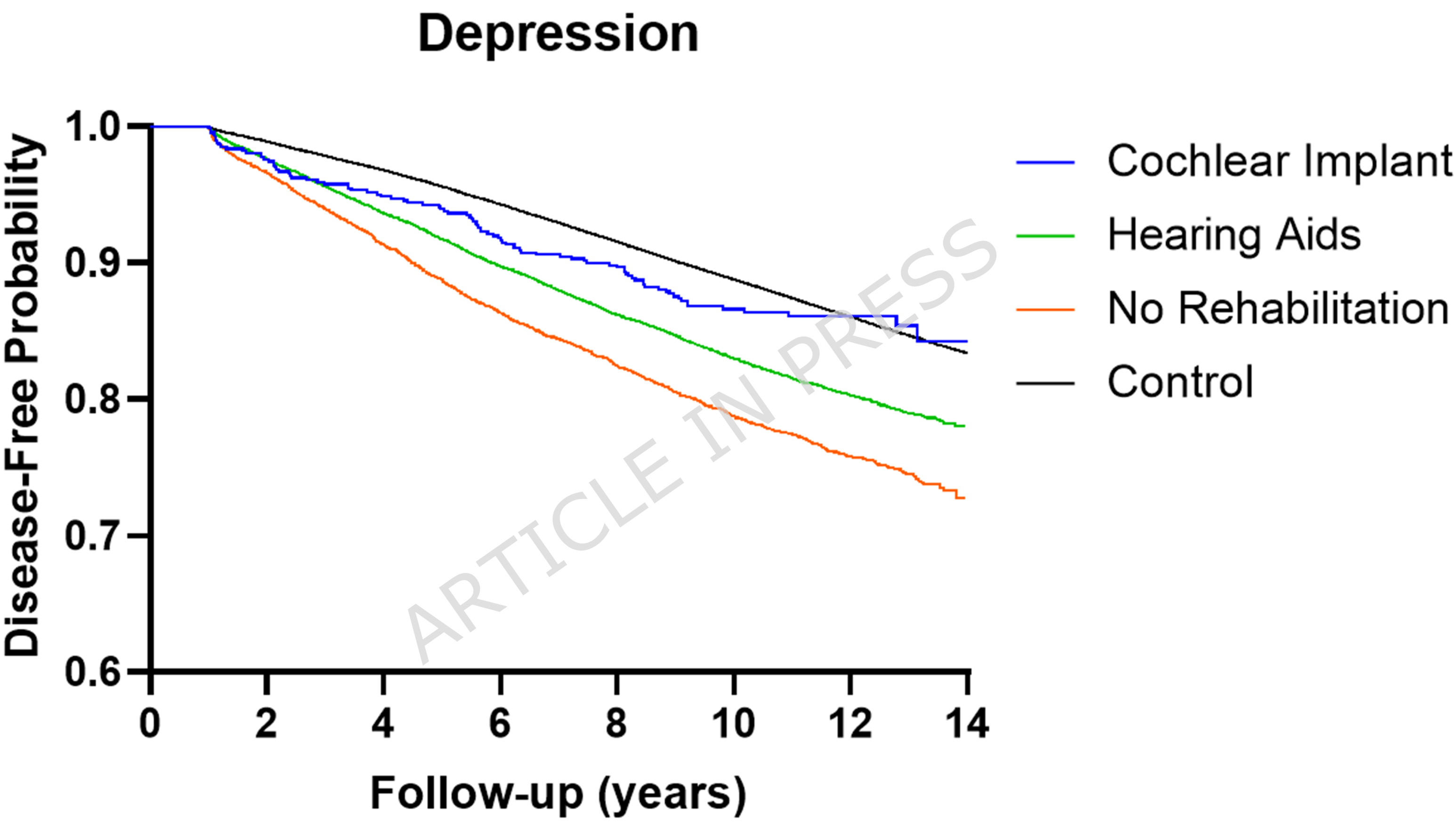
FIGURE LEGENDS

Fig 1. Flow diagram of the study

Fig 2. Kaplan–Meier analysis of incidence of depression


Subjects registered in National Health Insurance Database in 2002-2020
233,513 Individuals registered as Severe to Profound Hearing Disability (≥ 70 dB HL)
2,559,445 Individuals Without Hearing Loss
· Excluded individuals who received any hearing loss-related diagnoses (Chronic Otitis Media, Mastoiditis, Cholesteatoma, Tympanic Membrane Perforation, Mastoid Disease, Inner Ear Disease, Conductive & Sensorineural Hearing Loss)
45,381 Excluded for
21,432 change in grade of hearing disability
19,857 multiple disabilities
6,898 cases of missing major information
Inclusion
Individuals aged 20-69 between 2007-2012 (6 years)
Inclusion
Individuals aged 20-69 between 2007-2012 (6 years)
973 Cochlear Implant
20,997 Hearing Aids
7,377 No Rehabilitation
933,227 Without Hearing Loss
Exclusion
Prior diagnosis of Psychiatric disorder
661 Cochlear Implant
15,939 Hearing Aids
5,039 No Rehabilitation
809,403 Without Hearing Loss (Control)
Observed until December 2020
Primary Outcome: Diagnosis of Depression



Depression
Disease-Free Probability
1.0
0.9
0.8
0.7
0.6
0
2
4
6
8
10
12
14
Follow-up (years)
Cochlear Implant
Hearing Aids
No Rehabilitation
Control

Table 1. Demographics of the study population, and the occurrence of depression in the study period

	N	With hearing loss			Control	Depression
		Cochlear Implant	Hearing Aids	No Rehabilitation		
Group						
Cochlear Implant	661					90 (13.6%)
Hearing Aids	15,939					2,908 (18.2%)
No Rehabilitation	5,039					1,103 (21.9%)
Control	809,403					129,044 (15.9%)
Age (years)						
20-29	30,491	130 (0.4%)	1,026 (3.4%)	136 (0.5%)	29,199 (95.8%)	2,012 (6.6%)
30-39	61,904	124 (0.2%)	1,443 (2.3%)	379 (0.6%)	59,958 (96.9%)	4,583 (7.4%)
40-49	142,383	130 (0.1%)	2,274 (1.6%)	850 (0.6%)	139,129 (97.7%)	14,618 (10.3%)
50-59	239,384	169 (0.1%)	4,086 (1.7%)	1,437 (0.6%)	233,692 (97.6%)	35,140 (14.7%)
60-69	356,880	108 (0%)	7,110 (2.0%)	2,237 (0.6%)	347,425 (97.4%)	76,792 (21.5%)
Gender						
Male	546,118	313 (0.1%)	9,551 (1.8%)	3,356 (0.6%)	532,898 (97.6%)	78,160 (14.3%)
Female	284,924	348 (0.1%)	6,388 (2.2%)	1,683 (0.6%)	276,505 (97.1%)	54,985 (19.3%)
Income level						
Lowest	181,801	174 (0.1%)	4,223 (2.3%)	1,853 (1.0%)	175,551 (96.6%)	32,514 (17.9%)
Lower mid	168,505	146 (0.1%)	3,902 (2.3%)	1,031 (0.6%)	163,426 (97.0%)	25,929 (15.4%)
Upper mid	213,197	150 (0.1%)	4,066 (1.9%)	1,089 (0.5%)	207,892 (97.5%)	33,703 (15.8%)
Highest	267,539	191 (0.1%)	3,748 (1.4%)	1,066 (0.4%)	262,534 (98.1%)	40,999 (15.3%)
Urbanization level						
Metropolis	386,613	325 (0.1%)	7,297 (1.9%)	2,426 (0.6%)	376,565 (97.4%)	58,333 (15.1%)
Rural	444,429	336 (0.1%)	8,642 (1.9%)	2,613 (0.6%)	432,838 (97.4%)	74,812 (16.8%)
CCI score						
0	548,748	374 (0.1%)	8,941 (1.6%)	2,652 (0.5%)	536,781 (97.8%)	72,666 (13.2%)
1	181,070	182 (0.1%)	4,015 (2.2%)	1,178 (0.7%)	175,695 (97.0%)	34,846 (19.2%)
2	59,361	67 (0.1%)	1,671 (2.8%)	547 (0.9%)	57,076 (96.2%)	14,342 (24.2%)
≥3	41,863	38 (0.1%)	1,312 (3.1%)	662 (1.6%)	39,851 (95.2%)	11,291 (27.0%)
Comorbidity						
Hypertension	187,891	107 (0.1%)	3,969 (2.1%)	1,445 (0.8%)	182,370 (97.1%)	40,417 (21.5%)
Ischemic heart disease	15,579	13 (0.1%)	342 (2.2%)	154 (1.0%)	15,070 (96.7%)	3,540 (22.7%)
Congestive heart failure	11,733	10 (0.1%)	286 (2.4%)	122 (1.0%)	11,315 (96.4%)	2,868 (24.4%)
Peripheral vascular disease	23,621	44 (0.2%)	1,134 (4.8%)	427 (1.8%)	22,016 (93.2%)	5,977 (25.3%)
Cerebrovascular disease	10,125	10 (0.1%)	319 (3.2%)	225 (2.2%)	9,571 (94.5%)	2,725 (26.9%)
Dementia	478	2 (0.4%)	26 (5.4%)	13 (2.7%)	437 (91.4%)	162 (33.9%)
Chronic pulmonary disease	41,750	51 (0.1%)	1,235 (3.0%)	375 (0.9%)	40,089 (96.0%)	8,964 (21.5%)

Rheumatologic disease	15,382	16 (0.1%)	353 (2.3%)	105 (0.7%)	14,908 (96.9%)	4,207 (27.4%)
Peptic ulcer disease	64,999	61 (0.1%)	1,691 (2.6%)	563 (0.9%)	62,684 (96.4%)	15,531 (23.9%)
Liver disease	85,030	84 (0.1%)	1,893 (2.2%)	757 (0.9%)	82,296 (96.8%)	17,885 (21.0%)
Diabetes	97,727	78 (0.1%)	2,143 (2.2%)	839 (0.9%)	94,667 (96.9%)	22,490 (23.0%)
Hemiplegia or Paraplegia	3,474	2 (0.1%)	42 (1.2%)	141 (4.1%)	3,289 (94.7%)	1,022 (29.4%)
Renal disease	3,692	6 (0.2%)	103 (2.8%)	33 (0.9%)	3,550 (96.2%)	912 (24.7%)
Any malignancy	9,902	9 (0.1%)	242 (2.4%)	122 (1.2%)	9,529 (96.2%)	2,179 (22.0%)
Metastatic solid tumor	2,347	0 (0%)	68 (2.9%)	34 (1.5%)	2,245 (95.7%)	464 (19.8%)
AIDS/HIV	88	0 (0%)	4 (4.6%)	3 (3.4%)	81 (92.1%)	11 (12.5%)

CCI = Charlson comorbidity index
AIDS/HIV = Acquired Immune Deficiency Syndrome/Human Immunodeficiency Virus

Table 2. Incidence rates and incidence rate ratios of depression compared to the control group

		Depression
Without Hearing Loss	Control (N=809,403)	
	Number of patients	129,044
	Person years	9,717,665
	IR (/100,000 person year)	1,327.93
With Hearing Loss	Cochlear Implant (N=661)	
	Number of patients	90
	Person years	6,728
	IR (/100,000 person year)	1,337.62
	IRR (95% CI)	1.01 (0.82-1.24)
	Hearing Aids (N=15,939)	
	Number of patients	2,908
	Person years	159,583.33
	IR (/100,000 person year)	1,822.25
	IRR (95% CI)	1.37 (1.32-1.42)
	No Rehabilitation (N=5,039)	
	Number of patients	1,103
	Person years	47,723
	IR (/100,000 person year)	2,311.24
	IRR (95% CI)	1.74 (1.64-1.85)

IR = Incidence rate; IRR = Incidence rate ratio; CI = Confidence interval

Table 3. Risks of depression according to auditory rehabilitation compared to the control group

	HR (95% CI)			
	Before IPTW			After IPTW
	Model 1	Model 2	Model 3	
Depression				
Control	1.000	1.000	1.000	1.000
Cochlear Implant	1.030 (0.837-1.266)	1.267 (1.030-1.558)	1.242 (1.010-1.527)	1.250 (1.033-1.512)
Hearing Aids	1.405 (1.354-1.457)	1.337 (1.289-1.387)	1.323 (1.275-1.373)	1.352 (1.302-1.403)
No Rehabilitation	1.795 (1.691-1.904)	1.648 (1.553-1.749)	1.617 (1.524-1.716)	1.510 (1.418-1.608)

Model 1: Unadjusted

Model 2: Adjusted for age, gender, income level, urbanization level, and Charlson comorbidity index

Model 3: Adjusted for age, gender, income level, urbanization level, Charlson comorbidity index, and comorbidities (Hypertension, Ischemic heart disease, Congestive heart failure, Peripheral vascular disease, Cerebrovascular disease, Dementia, Chronic pulmonary disease, Rheumatologic disease, Peptic ulcer disease, Liver disease, Diabetes, Hemiplegia or Paraplegia, Renal disease, Any malignancy, Metastatic solid tumor, Acquired Immune Deficiency Syndrome/Human Immunodeficiency Virus)

HR = Hazard ratio; CI = Confidence Interval; IPTW = Inverse probability of treatment weighting

Table 4. Risks of depression according to auditory rehabilitation compared to the cochlear implant group

	HR (95% CI)			
	Before IPTW			After IPTW
	Model 1	Model 2	Model 3	
Depression				
Cochlear Implant	1.000	1.000	1.000	1.000
Hearing Aids	1.365 (1.106-1.683)	1.055 (0.856-1.302)	1.066 (0.864-1.314)	1.082 (0.891-1.313)
No Rehabilitation	1.743 (1.406-2.161)	1.301 (1.050-1.613)	1.303 (1.051-1.615)	1.308 (1.089-1.577)
Control	0.971 (0.790-1.194)	0.789 (0.642-0.971)	0.805 (0.655-0.990)	0.800 (0.661-0.968)

Model 1: Unadjusted

Model 2: Adjusted for age, gender, income level, urbanization level, and Charlson comorbidity index

Model 3: Adjusted for age, gender, income level, urbanization level, Charlson comorbidity index, and comorbidities (Hypertension, Ischemic heart disease, Congestive heart failure, Peripheral vascular disease, Cerebrovascular disease, Dementia, Chronic pulmonary disease, Rheumatologic disease, Peptic ulcer disease, Liver disease, Diabetes, Hemiplegia or Paraplegia, Renal disease, Any malignancy, Metastatic solid tumor, Acquired Immune Deficiency Syndrome/Human Immunodeficiency Virus)

HR = Hazard ratio; CI = Confidence Interval; IPTW = Inverse probability of treatment weighting