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Association between Hearing Loss and Cognitive Disorder: A Nationwide Population-Based Study

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Purpose: To investigate the relationship between hearing loss and cognitive disorder with memory dysfunction in South Korea using data from the Korean Health Insurance claims database for 2009–2015.

Materials and Methods: We analyzed cross-sectional data of 66-year-old individuals who completed the Korea National Health and Nutrition Examination Surveys. Auditory function was evaluated using pure-tone audiometric testing. Cognitive disorder with memory dysfunction was assessed using standardized scores of the Prescreening Korean Dementia Screening Questionnaire.

Results: Among 1815835 participants at the age of 66 years, the prevalence of unilateral hearing loss was 5.84%, and that of bilateral hearing loss was 3.40%. The normal cognitive group comprised 86.35% of the participants, and the high-risk group for cognitive disorder with memory dysfunction totaled 13.65% of the participants. The bilateral hearing loss group had the highest percentage of subjects who responded "sometimes or frequently" to all five questions about cognitive disorder with memory dysfunction, compared to the normal hearing group or the unilateral hearing loss group. After adjusting for sex, smoking status, alcohol intake, exercise, income, diabetes, hypertension, dyslipidemia, and depression, the odds ratios for cognitive disorder with memory dysfunction was 1.183 [95% confidence interval (CI): 1.163–1.203] for bilateral hearing loss and 1.141 (95% CI: 1.126–1.156) for unilateral hearing loss, compared to the normal cognitive group.

Conclusion: Hearing loss has a significant effect on cognitive function in the Korean population. In our study, individuals with bilateral hearing loss showed poorer cognitive function than those with unilateral hearing loss.

Key Words: Hearing loss, cognitive dysfunction, epidemiology, Korea

INTRODUCTION

The prevalence of dementia among people aged 60 years and older is expected to be 5 to 7 percent, doubling every 20 years worldwide between 2010 and 2050.[1] Cognitive aging affects learning, memory, language, and high-order executive functioning, stemming from reduction in cognitive processing that occurs with increasing age.[2] Thus, identifying factors leading to cognitive decline and dementia in older people and understanding the mechanistic pathways are public-health priorities. Meanwhile, age-related hearing loss, arthritis, and high blood pressure are three leading chronic diseases in older people, with rapidly increasing incidence rates.[3] More than 35 percent of people in their 60s and 50 percent of those in their 70s have problems in their daily activities because of hearing loss.[3]

The negative relationship between sensory and cognitive measurements can be explained by common factors, for example, neurodegenerative processes. Thus, the correlation between sensory functions and cognitive abilities may increase in old age because both are affected by age-related physiological changes in brain function.[4] Some researchers have suggested that hearing loss could be linked to cognitive impairment by reducing provocative inputs and disrupting social interactions.[5,6] Cross-sectional and prospective studies have reported conflicting results that could be explained by differ-

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ences in the study population and various methods used for auditory and cognitive evaluations.[7,8] However, to the best of our knowledge, large population- based studies addressing the association between hearing loss and cognitive disorder with memory dysfunction have not been reported yet. Thus, we performed a population-based evaluation of the association between hearing loss and cognitive disorder with memory dysfunction in the Korean population.

MATERIALS AND METHODS

Ethical considerations

Prior to the investigation, we obtained written consent from all participants and received approval for this study from the Institutional Review Committee of The Catholic University of Korea (IRB No. XC20WIDI0045).

Study population

The Korean National Health Insurance Service (NHIS) is a public medical-insurance system managed by the Ministry of Health, Welfare, and Family Affairs.[9] Study subjects were older people who underwent life-transition health screening for 66-year-olds between 2009 and 2015 out of those registered in the NHIS-National Sample Cohort Database. We enrolled a total of 1815835 individuals in this study.

Life-transition health screening

Life-transition health screening is a national health-examination program managed by the Korea National Health Insurance Corporation for individuals who turn 66 in the year of their checkup. Health checkups use questionnaires to examine each individual's disease history, hearing loss, family history, health behaviors, cognitive disabilities, and depression. It also carries out anthropometric and physical examinations (height, weight, waist circumference, vision, hearing, blood pressure), blood tests, urine tests, chest radiography, and bone-density tests (for women).

Audiometric measurements

A trained audiometric technician performed a pure-tone audiometric test at each screening visit at a dedicated acoustic detection booth. Pure-tone air conduction thresholds were measured in dB hearing levels for both ears at 0.5, 1.0, and 2.0 kHz. The average value for each ear was obtained. Hearing loss was defined as a pure-tone average of thresholds at 0.5, 1.0, and 2.0 kHz > 40 dB in each ear.

Assessment of cognitive function

Cognitive function during the medical examination was evaluated using responses from caregivers who participated in the screening according to five questions about cognitive disability in the subject (Prescreening Korean Dementia Screening Questionnaire, KDSQ-P). These five KDSQ-P questions were

- KDSQ-P 1, "Do you think your memory is worse than that of your friends and colleagues?",
- KDSQ-P 2, "Do you think your memory is worse than it was a year ago?",
- KDSQ-P 3, "Did you have a memory problem when you were doing something important?",
- KDSQ-P 4, "Do others notice that your memory has deteriorated?", and
- KDSQ-P 5, "Do you find that you don't do your daily activities as before?".

For each question, participants chose one of three responses: "no," "sometimes," and "frequently," to which scores of 0, 1, and 2 were assigned, respectively. Patients with four or more total points were classified as high-risk groups for cognitive disorder with memory dysfunction.[10,11]

Statistical analysis

We conducted statistical analyses using SAS software (version 9.2; SAS Institute, Cary, NC, USA). Values were compared using an independent t-test for continuous variables and a chi-squared test for categorical variables. We performed multiple logistic regression analyses to evaluate the association between hearing loss and cognitive disorder with memory dysfunction and calculated odds ratios (OR) and 95% confidence intervals (CIs). We considered a $p<0.05$ to be statistically significant.

RESULTS

Basic characteristics

The baseline characteristics of the study population are summarized in Table 1. Among 1815835 participants at the age of 66 years, the prevalence of unilateral hearing loss was 5.84%, and that of bilateral hearing loss was 3.40%. Unilateral hearing loss was high in female (51.29%), and bilateral hearing loss was high in male (54.92%). One-way ANOVA was performed to confirm if there were any significant differences for each item among the three groups. There were significant differences in all items (Table 1). Thus, we performed a post-hoc test using Bonferroni correction, the results of which are presented in Table 2. Compared to those with hearing loss, participants with normal hearing had significantly higher percentages of those who never smoked, who were non-drinkers, who exercised regularly, and who had hypertension (all $p<0.001$). Study participants with hearing loss had significantly higher percentages of individuals with diabetes and depression (both $p<0.001$).

Association between hearing loss and cognitive disorder with memory dysfunction

Table 3 summarizes the noted associations between cognitive disorder with memory dysfunction and hearing loss among

the study participants. During the health screening, we classified 1568007 (86.35%) subjects into a normal group (KDSQ-P<4) and 247828 (13.65%) into a high-risk group for cognitive disorder with memory dysfunction (KDSQ-P≥4). The proportion of participants at high risk for cognitive disorder with memory dysfunction was significantly greater in the hearing loss group (bilateral: 19.01%; unilateral: 16.29%) than in the normal hearing group (13.28%) (Fig. 1). We examined the ef-

Table 1. Clinical Characteristics of the Study Subjects according to Hearing Loss (n=1815835)

Parameter	Normal hearing (n=1648091)	Unilateral hearing loss (n=106065)	Bilateral hearing loss (n=61679)	*p* value
Age	66±0	66±0	66±0	
Sex				<0.0001*
Male	756030 (45.87)	51660 (48.71)	33873 (54.92)	
Female	892061 (54.13)	54405 (51.29)	27806 (45.08)	
Smoking status				<0.0001*
Never smoker	1145704 (69.59)	70843 (66.87)	38806 (62.98)	
Ex-smoker	296924 (18.03)	20821 (19.65)	12987 (21.08)	
Current smoker	203846 (12.38)	14278 (13.48)	9821 (15.94)	
Drinking level				<0.0001*
None	1176731 (71.66)	74481 (70.51)	42047 (68.5)	
Mild	402027 (24.48)	26493 (25.08)	16165 (26.34)	
Heavy	63436 (3.86)	4663 (4.41)	3169 (5.16)	
Routine exercise	784244 (47.66)	48644 (45.95)	27693 (44.99)	<0.0001*
Income (Q1)	399822 (24.26)	26062 (24.57)	15548 (25.21)	<0.0001*
Diabetes	338723 (20.56)	22740 (21.45)	13693 (22.22)	<0.0001*
Hypertension	883102 (53.62)	55950 (52.79)	31983 (51.9)	<0.0001*
Dyslipidemia	644220 (39.11)	40953 (38.64)	22524 (36.55)	<0.0001*
Depression	240313 (14.61)	19413 (18.33)	12489 (20.29)	<0.0001*

Data are presented as n (%). Statistical analysis was performed using one-way ANOVA.
*p<0.001.

Table 2. Post-hoc Analysis for Three Groups

Parameter	Normal hearing (n=1648091)	Unilateral hearing loss (n=106065)	*p* value	Normal hearing (n=1648091)	Bilateral hearing loss (n=61679)	*p* value	Unilateral hearing loss (n=106065)	Bilateral hearing loss (n=61679)	*p* value
Age	66±0	66±0		66±0	66±0		66±0	66±0	
Sex			<0.0001*			<0.0001*			<0.0001*
Male	756030 (45.87)	51660 (48.71)		756030 (45.87)	33873 (54.92)		51660 (48.71)	33873 (54.92)	
Female	892061 (54.13)	54405 (51.29)		892061 (54.13)	27806 (45.08)		54405 (51.29)	27806 (45.08)	
Smoking status			<0.0001*			<0.0001*			<0.0001*
Never smoker	1145704 (69.59)	70843 (66.87)		1145704 (69.59)	38806 (62.98)		70843 (66.87)	38806 (62.98)	
Ex-smoker	296924 (18.03)	20821 (19.65)		296924 (18.03)	12987 (21.08)		20821 (19.65)	12987 (21.08)	
Current smoker	203846 (12.38)	14278 (13.48)		203846 (12.38)	9821 (15.94)		14278 (13.48)	9821 (15.94)	
Drinking level			<0.0001*			<0.0001*			<0.0001*
None	1176731 (71.66)	74481 (70.51)		1176731 (71.66)	42047 (68.5)		74481 (70.51)	42047 (68.5)	
Mild	402027 (24.48)	26493 (25.08)		402027 (24.48)	16165 (26.34)		26493 (25.08)	16165 (26.34)	
Heavy	63436 (3.86)	4663 (4.41)		63436 (3.86)	3169 (5.16)		4663 (4.41)	3169 (5.16)	
Routine exercise	784244 (47.66)	48644 (45.95)	<0.0001*	784244 (47.66)	27693 (44.99)	<0.0001*	48644 (45.95)	27693 (44.99)	0.0006
Income (Q1)	399822 (24.26)	26062 (24.57)	0.0648	399822 (24.26)	15548 (25.21)	<0.0001*	26062 (24.57)	15548 (25.21)	0.0108
Diabetes	338723 (20.56)	22740 (21.45)	<0.0001*	338723 (20.56)	13693 (22.22)	<0.0001*	22740 (21.45)	13693 (22.22)	0.0006
Hypertension	883102 (53.62)	55950 (52.79)	<0.0001*	883102 (53.62)	31983 (51.9)	<0.0001*	55950 (52.79)	31983 (51.9)	0.0015
Dyslipidemia	644220 (39.11)	40953 (38.64)	0.0063	644220 (39.11)	22524 (36.55)	<0.0001*	40953 (38.64)	22524 (36.55)	<0.0001*
Depression	240313 (14.61)	19413 (18.33)	<0.0001*	240313 (14.61)	12489 (20.29)	<0.0001*	19413 (18.33)	12489 (20.29)	<0.0001*

Data are presented as n (%). Post-hoc test was performed using Bonferroni correction.
*p<0.001.

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Table 3. Analysis of the Association between Cognitive Disorder with Memory Dysfunction and Hearing Loss (n=1815835)

Parameter	Normal hearing (n=1648091)	Unilateral hearing loss (n=106065)	Bilateral hearing loss (n=61679)	*p* value
Total score of KDSQ-P				<0.0001*
<4	1429263 (86.72)	88787 (83.71)	49957 (80.99)*	
≥4	218828 (13.28)	17278 (16.29)	11722 (19.01)*	
KDSQ-P 1				<0.0001*
Not at all	1223747 (74.25)	74426 (70.17)	41902 (67.94)	
Sometimes	384806 (23.35)	28225 (26.61)	17130 (27.77)	
Frequently	39538 (2.40)	3414 (3.22)	2647 (4.29)	
KDSQ-P 2				<0.0001*
Not at all	1059647 (64.3)	64039 (60.38)	36376 (58.98)	
Sometimes	543982 (33.01)	38157 (35.98)	22479 (36.45)	
Frequently	44462 (2.70)	3869 (3.65)	2824 (4.58)	
KDSQ-P 3				<0.0001*
Not at all	1305419 (79.21)	80951 (76.32)	45702 (74.10)	
Sometimes	316806 (19.22)	22814 (21.51)	14141 (22.93)	
Frequently	25866 (1.57)	2300 (2.17)	1836 (2.98)	
KDSQ-P 4				<0.0001*
Not at all	1429103 (86.71)	89025 (83.93)	50298 (81.55)	
Sometimes	203471 (12.35)	15542 (14.65)	10153 (16.46)	
Frequently	15517 (0.94)	1498 (1.41)	1228 (1.99)	
KDSQ-P 5				
Not at all	1317957 (79.97)	81391 (76.74)	46019 (74.61)	<0.0001*
Sometimes	309313 (18.77)	22750 (21.45)	14099 (22.86)	
Frequently	20821 (1.26)	1924 (1.81)	1561 (2.53)	

KDSQ-P: Prescreening Korean Dementia Screening Questionnaire.
Data are presented as n (%).
*Significant at $p<0.05$.

fect of each of the five KDSQ-P components on the risk of cognitive disorder with memory dysfunction. The bilateral hearing loss group had the highest percentage of subjects who responded "sometimes or frequently" to all five KDSQ-P components ($p<0.0001$).

Table 4 shows results of logistic regression analyses after adjusting for sex, smoking status, alcohol intake, exercise, income, diabetes, hypertension, dyslipidemia, and depression. A high risk of cognitive disorder with memory dysfunction was significantly associated bilateral hearing loss (OR: 1.183; 95% CI: 1.163–1.203) or unilateral hearing loss (OR: 1.141; 95% CI: 1.126–1.156) after adjusting for confounders. Multivariate-adjusted ORs of having hearing loss for each individual question in the KDSQ-P are presented. The OR for the bilateral hearing loss group was significantly higher than that for the unilateral hearing group for all five dimensions of the KDSQ-P and the total score of KDSQ-P≥4 after adjusting for confounders ($p<0.001$, post-hoc analysis using Sidak test).

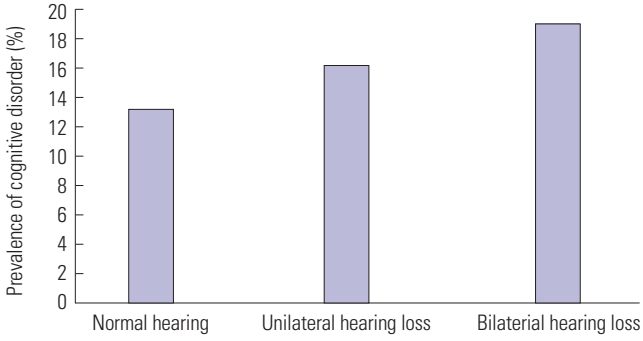

Fig. 1. The risk of cognitive disorder with memory dysfunction according to the presence of hearing loss.

DISCUSSION

To the best of our knowledge, this is the first large population-based study to investigate associations between hearing loss and cognitive disorder with memory dysfunction. The strength of the current study was that we used population-based cohorts of older people. We demonstrated that the prevalence of cognitive disorder with memory dysfunction among individuals with hearing loss was significantly higher than that among individuals with normal hearing independent of sex, smoking status, alcohol intake, exercise, income, diabetes, hypertension, or dyslipidemia. We observed strong associations of cognitive disorder with memory dysfunction with bilateral hear-

Table 4. Effect of Hearing Loss on the Risk of Cognitive Disorder with Memory Dysfunction

Hearing loss	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Total score of KDSQ-P ≥4			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.179 (1.164–1.194)	1.191 (1.177–1.206)	1.141 (1.126–1.156)
Bilateral	1.224 (1.205–1.244)	1.269 (1.248–1.290)	1.183 (1.163–1.203)
KDSQ-P 1			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.355 (1.307–1.404)	1.362 (1.314–1.412)	1.234 (1.190–1.280)
Bilateral	1.827 (1.755–1.902)	1.883 (1.808–1.961)	1.599 (1.533–1.667)
KDSQ-P 2			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.364 (1.319–1.411)	1.373 (1.327–1.420)	1.243 (1.201–1.287)
Bilateral	1.734 (1.667–1.803)	1.790 (1.721–1.862)	1.525 (1.464–1.588)
KDSQ-P 3			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.392 (1.333–1.454)	1.398 (1.338–1.459)	1.253 (1.199–1.310)
Bilateral	1.930 (1.840–2.026)	1.978 (1.885–2.076)	1.636 (1.556–1.719)
KDSQ-P 4			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.513 (1.434–1.596)	1.519 (1.439–1.602)	1.359 (1.286–1.435)
Bilateral	2.150 (2.027–2.280)	2.199 (2.074–2.333)	1.787 (1.682–1.900)
KDSQ-P 5			
No	1 (reference)	1 (reference)	1 (reference)
Unilateral	1.445 (1.378–1.515)	1.446 (1.379–1.516)	1.285 (1.224–1.349)
Bilateral	2.039 (1.935–2.148)	2.071 (1.966–2.183)	1.660 (1.572–1.753)

KDSQ-P: Prescreening Korean Dementia Screening Questionnaire; OR, odds ratio; CI, confidence interval.
Model 1: Unadjusted. Model 2: Adjusted for sex, smoking status, alcohol intake, exercise, and income. Model 3: Adjusted for sex, smoking status, alcohol intake, exercise, income, diabetes, hypertension, dyslipidemia, and depression.

ing loss (OR: 1.183; 95% CI: 1.163–1.203) and unilateral hearing loss (OR: 1.141; 95% CI: 1.126–1.156). Notably, cognitive abilities in the bilateral hearing-loss group were significantly lower than those of the normal and unilateral hearing-loss groups for all five dimensions of the KDSQ-P after adjusting for sociodemographic factors and comorbidities. The question about "Do others notice that your memory has deteriorated?" had the highest odds for cognitive disorder with memory dysfunction in participants with bilateral hearing loss (OR: 1.787; 95% CI: 1.682–1.900).

Previous studies have suggested that people with hearing loss are more likely to have a diagnosis of dementia and poorer cognitive function. Lin, et al.[12] have reported that hearing loss is independently associated with accelerated cognitive decline and incident cognitive impairment in 1984 older adults. They showed that the magnitude of this association was clinically significant because individuals with hearing impairments had accelerated cognitive reduction rates by 30–40% over 6 years, compared to individuals with normal hearing, and an increased risk for accident cognitive impairment by 24%. One meta-analysis has concluded that cognitive and hearing impairments are interrelated and that hearing loss affects multiple domains of cognition.[13]

There are three main explanatory hypotheses for the association between hearing loss and cognitive disorder with memory dysfunction. The first is that the association of cognitive and auditory variables reflects a "common cause" of age-related changes in the nervous system.[14,15] The second is the "cascade" hypothesis, in which long-term deprivation of auditory input can affect recognition and thus lead to social isolation and depression.[12,16] The third is the "cognitive load" hypothesis: hearing loss requires more cognitive efforts for the auditory perception. For hearing-impaired individuals, the cognitive load can divert cognitive resources away from working memory. This is a theory that cognitive decline progresses as this process is repeated.[17,18]

Cognitive decline can lead to hearing loss due to indirect effects of cognitive impairment on the accuracy of hearing assessment or due to direct effects of neuropathology that contributes to cognitive impairment (e.g., microvascular disease, accumulation of amyloid β and τ protein).[19] Poor verbal communication associated with hearing loss can confuse cognitive testing. Conversely, hearing loss might have been over-diagnosed in individuals with subclinical cognitive disabilities.

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In this study, we demonstrated that depression was associated with unilateral (18.33%) and bilateral (20.29%) hearing loss. Communication disorders caused by hearing loss can lead to social isolation in older people. Epidemiological and neurological studies have demonstrated a link between poor social networks and dementia.[20,21]

In this study, normal hearing participants had significantly higher percentages of individuals who never smoked, who were non-drinkers, who exercised regularly, and who had hypertension (all $p<0.001$). Adverse effects of smoking on hearing loss have been reported in a number of studies in the past.[22,23] Toluene, benzene, and carbon monoxide in cigarettes could be associated with hearing loss.[24] The effect of drinking on hearing loss is not yet clear. It has been reported that chronic drinking can affect hearing loss. However, one study has reported that drinking a small amount of alcohol could protect against hearing loss.[25,26] In our study, the ratio of non-drinkers was high in the normal hearing group. Therefore, it is better to avoid drinking as much as possible. Hearing loss is associated with declines in physical function, gait speed, and balance.[27] Therefore, it is important to maintain a healthy lifestyle with regular exercise. Most studies have reported that hypertension has an adverse effect on hearing. However, in one study, high blood pressure subjects comprised a high percentage of individuals in the normal hearing group.[27] Further research on detailed factors, such as high blood pressure level and drug treatment, is needed in the future.

The hearing loss groups had significantly higher percentages of participants with diabetes and depression ($p<0.001$). Diabetes causes neuropathy, microangiopathy, and mitochondrial damage, and it can damage the auditory nerve system. In the National Health and Nutrition Examination Study (NHANES) of a US population of people aged 40–69 years, hearing impairment was noted in 21.3% of individuals with diabetes.[28] Meanwhile, an association between depression and hearing loss has been reported in a number of studies. About 20% of patients with hearing impairment have depression that requires treatment.[29] Longitudinal studies have also shown an association between increased depression and hearing impairment.[30]

This study has several limitations. First, there might be an overdiagnosis of cognitive disorder with memory dysfunction in individuals affected by hearing loss. There might be some response bias when reporting cognitive functions. Since the assessment was performed using a self-administered questionnaire, there might be some bias against a few parameters, such as lifestyle habits and psychological stress. Second, this study was cross-sectional. In particular, hearing loss can contribute reasonably to an overall cycle of multimorbidity or create synergies with other known risk factors for cognitive impairment, and the causality of risk factors related to hearing loss or cognitive impairment is not conclusive. However, our results are reliable because this is a population-based study across Korea. The third limitation of this study was the absence of bone-conduction pure-tone testing. The audiometric assessment could not entirely exclude conductive hearing losses. Another limitation of this study was the absence of evaluation at a high frequency hearing level. The degree of hearing loss in the health examination of NIHS was measured at 0.5, 1, and 2 kHz. Therefore, we could not confirm 3 kHz or 4 kHz frequency hearing. In the future, national health checkups should screen for hearing loss in the high frequency region.

In conclusion, this study showed that hearing loss may be related to cognitive disorder with memory dysfunction in older adults. Subjects with bilateral hearing loss appeared to face a greater risk of deterioration of cognitive function than those with normal hearing or unilateral hearing loss. We expect this to be a very useful finding for the care and treatment of older adults. In the future, a large prospective cohort study should be conducted to examine changes in cognitive and auditory functions in older adults and to investigate causal relationships between these variables.

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AUTHOR CONTRIBUTIONS

Conceptualization: Kyoung-Ho Park and Young-Hoon Joo. Data curation: Kyung-do Han. Formal analysis: Kyung-do Han and Young-Hoon Joo. Investigation: Young-Hoon Joo and Hyun Jin Lee. Methodology: Young-Hoon Joo and Kyoung-Ho Park. Project administration: Young-Hoon Joo and Kyoung-Ho Park. Resources: Kyung-do Han. Software: Kyung-do Han. Supervision: Kyoung-Ho Park and Young-Hoon Joo. Validation: Kyoung-Ho Park and Young-Hoon Joo. Visualization: Kyung-do Han and Hyun Jin Lee. Writing—original draft: Young-Hoon Joo and Hyun Jin Lee. Writing—review & editing: Hyun Jin Lee and Young-Hoon Joo. Approval of final manuscript: all authors.

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