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Risk of ischemic and hemorrhagic stroke following migraine: A nationwide retrospective cohort study in South Korea

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Abstract

Objective: This study examined the association between migraine and the risk of ischemic stroke (IS) and hemorrhagic stroke (HS). *Methods:* This retrospective cohort study used data from the Korean National Health Insurance Service (NHIS) and included 13,379 individuals with migraine and 66,895 propensity score–matched controls. The primary outcome was the incidence of IS, and the secondary outcome was HS. Time-stratified Cox proportional hazards models were employed for analysis. *Results:* Migraine was associated with an increased risk of IS (incidence rate ratio [IRR], 1.78; 95% confidence interval [CI], 1.62–1.95) and HS (adjusted hazard ratio [aHR], 1.71; 95% CI, 1.35–2.18). The risk of IS peaked within the first two years following migraine diagnosis and remained elevated for up to eight years.
Conclusion: Migraine is independently associated with an increased long-term risk of both IS and HS, particularly among younger individuals and males, underscoring the need for targeted cerebrovascular surveillance.

Keywords: Migraine disorders, ischemic stroke, hemorrhagic stroke, cohort studies, South Korea

INTRODUCTION

Migraine, a primary episodic headache disorder involving neurological, gastrointestinal, and autonomic changes[1], is commonly classified based on the presence or absence of aura, and may manifest as unilateral pain, nausea, photophobia, and phonophobia.[2] Migraine is the second leading cause of disability globally, affecting up to 20% of the population.[1,3] It is now well established that migraine is not merely a headache disorder; it is also associated with an increased risk of cerebrovascular disease, particularly stroke. Migraine has been identified as being independently associated with ischemic stroke (IS) in several studies. Individuals experiencing migraine with aura exhibit approximately a twofold increased risk of IS compared to those without migraine.[4] This elevated risk is likely mediated by transient vasoconstriction, neurovascular inflammation, and a prothrombotic state, particularly in cases of migraine with aura.[5,6] In contrast, the association between migraine and hemorrhagic stroke (HS) remains inconclusive. Although an increased HS risk has been reported among young women[7], studies using data from the Korean

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National Health Insurance Service (NHIS) have demonstrated a significant association between migraine and IS, while findings regarding HS have been inconsistent.[8,9] However, these studies had several methodological limitations, including the absence of a washout period and inadequate control for confounding variables such as smoking and alcohol consumption. Moreover, previous studies have been based on Western populations, whereas research involving Asian cohorts remains limited.[10] Therefore, the purpose of the present study was to evaluate the risk of IS and HS among patients with migraine using the Korean NHIS data.

METHODS

Data source

The retrospective cohort study was conducted using data from the NHIS–National Sample Cohort (NHIS-NSC), a nationally representative claims database comprising approximately 1 million Koreans—equivalent to 2% of the 2002 population—sampled based on sex, age, and income strata.[11] In this context, a "claim" refers to medical records submitted by healthcare institutions to the Health Insurance Review and Assessment Service for reimbursement. Diagnoses in the Korean NHIS claims database were recorded using the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) codes. As these codes were designed for insurance reimbursement, they include diagnoses from both outpatient and inpatient care across all healthcare settings, from primary clinics to tertiary hospitals.

The study period spanned from January 2002 to December 2013, with 2002–2003 designated as the washout period and 2004–2013 as the observation period. Follow-up continued until the earliest occurrence of IS, death, or the end of the study period (December 31, 2013).

Ethics

Ethical approval and informed consent were waived by the Institutional Review Board (IRB) of Sungshin Women's University (SSWUIRB-2025-037) due to the use of anonymized NHIS data.

Study population

The migraine cohort comprised individuals aged 20–79 who had at least two claims for ICD-10 code G43, the diagnostic code for migraine, during the observation period. To enhance diagnostic reliability, the index date was defined as the second migraine diagnosis, as initial diagnoses may be transient or erroneous. This approach has been adopted in numerous domestic and international claims-based studies. Exclusion criteria were as follows: (1) diagnosis of underlying diseases associated with migraine or stroke during 2002–2003 (Table S1), (2) no health screening record within 2 years before the index date, (3) age <20 or >79 years at index date, and (4) diagnosis of IS within 2 years prior to the index date.

Controls were selected from NHSP participants between 2002 and 2013 who had no history of migraine or related conditions and met the same exclusion criteria as the migraine group (Table S1). Participants were matched to migraine cases at a 1:5 ratio based on age, sex, and year of health examination using propensity score matching (see Supplementary Materials for details). The participant selection process is illustrated in Figure 1.

Primary outcome

The primary outcome was defined as the first recorded diagnosis of ischemic stroke (ICD-10 code I63). A secondary analysis evaluated hemorrhagic stroke, defined by the first recorded diagnosis of ICD-10 code I60, I61, or I62.

Covariates

Covariates included age, sex, smoking status, alcohol consumption, height, weight, body mass index (BMI), total cholesterol, systolic and diastolic blood pressure, fasting blood glucose (FBS), and income. Height and weight were treated as continuous variables, whereas all other covariates were considered categorical.

Statistical analysis

Baseline characteristics were compared using standardized differences, with values <0.1 indicating negligible imbalance. Incidence rates (IRs) and incidence rate ratios (IRRs) per 1,000 person-years were calculated to compare the incidence of IS. Kaplan–Meier curves and log-rank tests were used to assess cumulative IS incidence. Multivariable Cox models were employed to evaluate the association between migraine and IS. Due to violations of proportional hazards assumptions, as indicated by Schoenfeld residuals, time-stratified Cox models were

applied in 2-year intervals over a 10-year follow-up. Subgroup analyses were conducted by age and sex. All analyses were performed using R (v4.4.1), with two-sided tests, and significance threshold of $p < 0.05$.

RESULTS

The migraine and control groups comprised 13,379 and 66,895 individuals, respectively, with mean follow-up durations of 3.79 (2.59) and 3.86 (2.58) years (Figure 1). Baseline characteristics were well balanced, with all standardized differences <0.1 (Table 1).

During the 10-year follow-up period, 584 (4.37%) patients in the migraine group and 1,867 (2.50%) in the control group were diagnosed with IS. The crude IR per 1,000 person-years was significantly higher in the migraine group (11.51 [95% CI, 10.58–12.45]) compared to the control group (6.47 [95% CI, 6.16–6.78]). The IRR was 1.78 (95% CI, 1.62–1.95), indicating a significantly elevated IS risk in patients with migraine (Table 2). HS occurred in 94 (0.70%) migraine patients and 279 (0.42%) controls, with a crude IRR of 1.69 (95% CI, 1.34–2.13) (Table S2).

Age- and sex-stratified analyses revealed higher IRRs for IS among individuals aged <60 years (2.29 [95% CI, 1.93–2.7]) and males (1.92 [95% CI, 1.64–2.27]). Furthermore, the highest IRR was observed in males aged <60 years (3.17 [95% CI, 2.39–4.20]).

Lifestyle and metabolic stratifications showed significantly elevated IRRs across all subgroups except for individuals with BMI <18.5 kg/m^2 (0.88 [95% CI, 0.42–1.87]). In the smoking status-stratified analysis, the IRR for IS was highest among former smokers (2.50 [95% CI, 1.70–3.68]), followed by current smokers (1.85 [95% CI, 1.42–2.42]) and non-smokers (1.73 [95% CI, 1.55–1.93]). Analysis by alcohol consumption showed that non-drinkers,

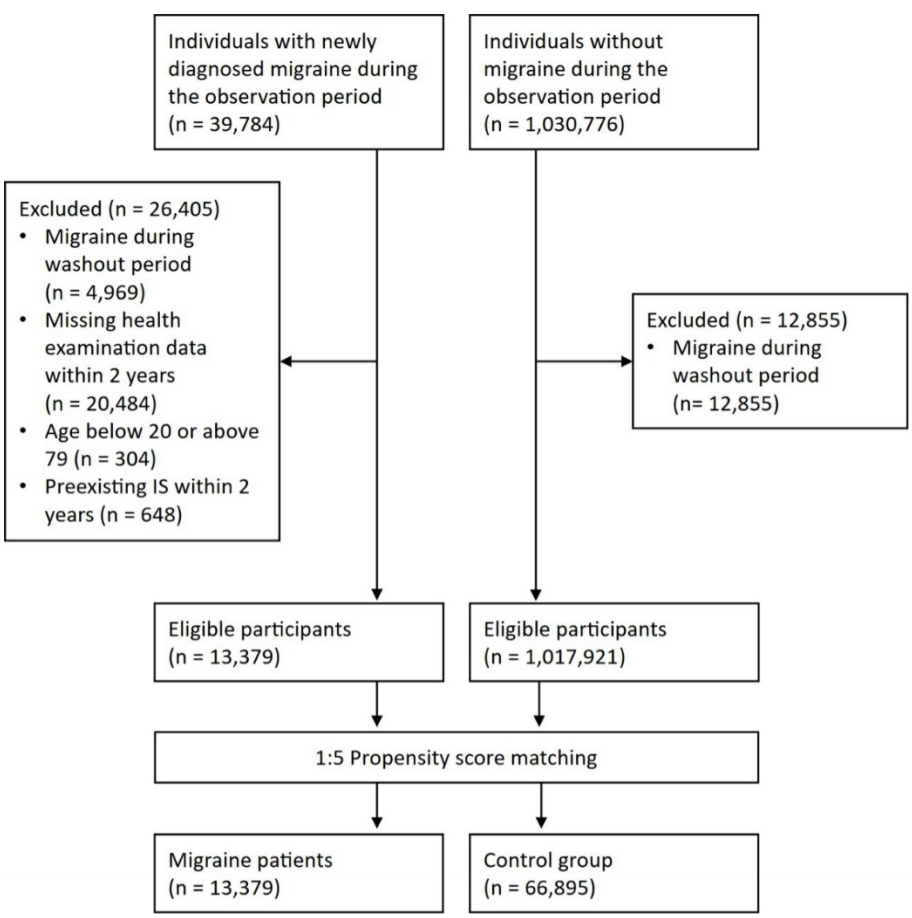

Figure 1. Flowchart of the selection of patients with migraine and propensity score–matched controls.

Table 1: Baseline demographic characteristics of migraine patients and control group

		Case group (n = 13,379) (%)	Control group (n = 66,895) (%)	Standardized difference
Age (years)	20–29	828 (0.06)	4140 (0.06)	0.00
	30–39	1545 (0.12)	7725 (0.12)	
	40–49	3324 (0.25)	16620 (0.25)	
	50–59	3591 (0.27)	17955 (0.27)	
	60–69	2431 (0.18)	12155 (0.18)	
	≥70	1660 (0.12)	8300 (0.12)	
Sex	Male	9395 (0.70)	46975 (0.70)	0.00
	Female	3984 (0.30)	19920 (0.30)	
Smoking status	Yes	1686 (0.13)	8703 (0.13)	0.02
	No	10312 (0.77)	51066 (0.76)	
	Ex-smoking	947 (0.07)	4844 (0.07)	
	Missing	434 (0.03)	2282 (0.03)	
Frequency of alcohol consumption (per week)	0	8874 (0.68)	44268 (0.67)	0.01
	1–2	3237 (0.25)	16175 (0.25)	
	≥3	1009 (0.08)	5165 (0.08)	
Weight (kg, mean ± SD)		60.63 ± 10.63	60.50 ± 10.55	0.01
Height (cm, mean ± SD)		159.75 ± 8.61	159.74 ±8.62	0.00
BMI (kg/m^2)	<18.5	514 (0.04)	2497 (0.04)	0.02
	18.5 to <25	8650 (0.65)	43684 (0.65)	
	≥25	4215 (0.32)	20697 (0.31)	
Total cholesterol (mg/dL)	<200	7429 (0.56)	37464 (0.56)	0.01
	≥200	5937 (0.44)	29384 (0.44)	
Systolic Blood Pressure (mmHg)	<120	5279 (0.39)	26580 (0.40)	0.01
	120 to <140	6223 (0.47)	31031 (0.46)	
	≥140	1875 (0.14)	9270 (0.14)	
Diastolic Blood Pressure (mmHg)	<80	7241 (0.54)	36323 (0.54)	0.01
	80 to <90	4557 (0.34)	22799 (0.34)	
	≥90	1580 (0.12)	7758 (0.12)	
FBS (mg/dL)	<100	9598 (0.72)	48161 (0.72)	0.01
	100 to <126	3064 (0.23)	15276 (0.23)	
	≥126	713 (0.05)	3427 (0.05)	
Income	Low	5465 (0.41)	27210 (0.41)	0.00
	High	7914 (0.59)	39685 (0.59)	

BMI, body mass index; FBS, fasting blood glucose.

Table 2: Crude incidence rates and risk ratios for ischemic stroke among migraine patients and matched controls

		Case cohort (n = 13,379)			Reference cohort (n = 66,895)			IRR (95% CI)
		Cases	Person-years)	IR per 1000 person-years (95% CI)	Cases	Person-years)	IR per 1000 person-years (95% CI)	
All		584	50757.83	11.51 (10.58–12.45)	1671	258278.73	6.47 (6.16–6.78)	1.78 (1.62–1.95)
Age (years)	<60	183	36336.03	5.04 (4.32–5.78)	403	183517.61	2.20 (1.98–2.41)	2.29 (1.93–2.73)
	≥60	401	14421.80	27.81 (25.10–30.58)	1268	74761.11	16.96 (16.04–17.90)	1.64 (1.47–1.83)
Sex	Male	199	15017.13	13.25 (11.45–15.12)	529	76836.51	6.88 (6.30–7.48)	1.92 (1.64–2.27)
	Female	385	35740.70	10.77 (9.71–11.86)	1142	181442.21	6.29 (5.93–6.66)	1.71 (1.52–1.92)
Sex & Age (years)	Male, <60	79	10921.70	7.23 (5.68–8.88)	127	55680.42	2.28 (1.89–2.69)	3.17 (2.39–4.20)
	Male, ≥60	120	4095.43	29.30 (24.17–34.67)	402	21156.10	19.00 (17.16–20.89)	1.54 (1.26–1.89)
	Female, <60	104	25414.33	4.09 (3.34–4.88)	276	127837.20	2.16 (1.91–2.42)	1.90 (1.51–2.37)
	Female, ≥60	281	10326.37	27.21 (24.11–30.41)	866	53605.02	16.16 (15.09–17.24)	1.68 (1.47–1.93)
Smoking status	Yes	72	6134.95	11.74 (9.13–14.51)	212	33490.07	6.33 (5.49–7.20)	1.85 (1.42–2.42)
	No	440	39512.93	11.14 (10.10–12.20)	1272	197696.04	6.43 (6.09–6.79)	1.73 (1.55–1.93)
	Ex-Smoking	38	2537.62	14.97 (10.25–20.10)	80	13352.11	5.99 (4.72–7.34)	2.50 (1.70–3.68)
Frequency of alcohol consumption (per week)	0	426	33341.92	12.78 (11.58–14.01)	1253	169996.92	7.37 (6.96–7.78)	1.73 (1.55–1.93)
	1–2	96	12813.41	7.49 (6.01–9.05)	225	64318.09	3.50 (3.05–3.96)	2.14 (1.69–2.72)
	≥3	43	3249.24	13.23 (9.54–17.23)	138	17016.83	8.11 (6.76–9.46)	1.63 (1.16–2.30)
BMI (kg/m^2)	<18.5	8	2009.18	3.98 (1.49–6.97)	44	9743.15	4.52 (3.18–5.85)	0.88 (0.42–1.87)
	18.5 to <25	352	32910.22	10.70 (9.60–11.82)	966	169472.87	5.70 (5.35–6.06)	1.88 (1.66–2.12)
	≥25	224	15838.43	14.14 (12.31–16.04)	661	78985.78	8.37 (7.74–9.01)	1.69 (1.45–1.97)
Total cholesterol (mg/dL)	<200	281	28432.90	9.88 (8.76–11.04)	802	145382.45	5.52 (5.14–5.90)	1.79 (1.56–2.05)
	≥200	303	22246.25	13.62 (12.09–15.19)	862	112640.57	7.65 (7.15–8.17)	1.78 (1.56–2.03)
Income	Low	226	20731.90	10.90 (9.50–12.35)	668	105066.13	6.36 (5.88–6.84)	1.71 (1.47–1.99)
	High	358	30025.93	11.92 (10.69–13.19)	1003	153212.60	6.55 (6.14–6.96)	1.82 (1.61–2.05)

IR, incidence rate; IRR, incidence rate ratio.

moderate drinkers (1–2 times/week), and heavy drinkers (≥3 times/week) exhibited IRRs of 1.73 (95% CI, 1.55–1.93), 2.14 (95% CI, 1.69–2.72), and 1.63 (95% CI, 1.16–2.30), respectively. Furthermore, the IRR for IS was higher in the normal-weight group (1.88 [95% CI, 1.66–2.12]) than in the overweight group (1.69 [95% CI, 1.45–1.97]). IRRs were similar between the low-cholesterol group (<200 mg/dL; 1.79 [95% CI, 1.56–2.05]) and the high-cholesterol group (≥200 mg/dL; 1.78 [95% CI, 1.56–2.03]). In the income-stratified analysis, the high-income group had a higher IRR (1.82 [95% CI, 1.61–2.05]) compared to the low-income group (1.71 [95% CI, 1.47–1.99]).

Kaplan–Meier curves showed a steeper decline in both IS-free and HS-free survival among patients with migraine compared to controls, indicating an elevated risk of both ischemic and hemorrhagic stroke (Figure S1, S2).

Extended Cox proportional hazards models, which divided the 10-year period into 2-year intervals, indicated that the adjusted hazard ratio (aHR) for IS remained elevated for up to eight years post-diagnosis. According to Figure 2A, the aHR peaked in years 0–2 at 2.14 (95% CI, 1.88–2.45), decreased to 1.35 (95% CI, 1.02–1.78) in years 4–6, and increased again to 1.87 (95% CI, 0.96–3.62) in years 8–10 (Figure 2A).

Among individuals aged <60 years, the aHR declined from 2.68 (95% CI, 2.07–3.46) in years 0–2 to 1.44 (95% CI, 0.86–2.40) in years 4–6, then increased to 3.36 (95% CI, 1.30–8.69) in years 8–10 (Figure 2B, 2C). In contrast, individuals aged ≥60 years exhibited the highest aHR of 1.95 (95% CI, 1.66–2.28) in years 0–2, with risk decreasing thereafter and becoming non-significant after four years. According to sex, the highest aHR was recorded in years 8–10 (3.10 [95% CI, 1.19–8.04]) and in years 0–2 (2.01 [95% CI, 1.71–2.37]) among men and women, respectively (Figure 2D, 2E). For HS, the overall aHR during the 10 years was 1.71 (95% CI, 1.35–2.18) (Figure S3).

DISCUSSION

In this nationwide cohort study, migraine was independently associated with an increased risk of both IS and HS, with IRRs of 1.78 (95% CI, 1.62–1.95) and 1.69 (95% CI, 1.34–2.13), respectively. However, previous studies using the same Korean NHIS National Sample Cohort have reported inconsistent results regarding the same.[8,9] For example, Lee *et al*. (2019) reported an increased risk of IS (aHR 1.17; 95% CI 1.08–1.25) in patients with migraine, but no significant association with HS (aHR 1.10; 95% CI 0.96–1.25).[8] Conversely, Lee et al. (2022) reported significantly increased risk of both IS (aHR 2.91 [95% CI, 2.67–3.16]) and HS (aHR 2.46 [95% CI, 2.23–2.71]) in patients with migraine.[9]

These discrepancies may be attributable to methodological differences among the three studies. Lee *et al*. (2019) employed exact matching on age, sex, income, and region and adjusted for comorbidities such as hypertension and diabetes.[8] Conversely, the present study defined new migraine cases using a two-year washout period without prior migraine diagnoses and applied 1:5 propensity score matching based on smoking status, alcohol use, body mass index, total cholesterol, blood pressure, fasting glucose, and income, following exact matching on age, sex, and examination year.

Conversely, Lee *et al*. (2022) employed a one-year washout period and 1:1 propensity score matching based on age, sex, income level, residential region, and comorbidities, but restricted their cohort to participants aged 20–49 years.[9] The present study expanded the cohort to include older participants (aged 20–79) to enable age-stratified analyses. To account for potential confounders introduced by including older participants, stricter exclusion criteria were implemented. To preserve statistical power and minimize selection bias, a 1:5 propensity score matching was adopted. Furthermore, time-stratified Cox models were applied to address violations of the proportional hazards assumption, thereby facilitating comparison of changes in risk over the follow-up period.

Numerous previous studies have highlighted the association between migraine and IS.[12] Proposed mechanistic pathways linking migraine to IS include cortical spreading depression, which induces transient hyperemia followed by prolonged cerebral oligemia,[13] and endothelial dysfunction which promotes thrombosis and atherosclerosis.[5,6] Additionally, genetic factors may contribute to the shared risk of migraine and IS.[14]

The pathophysiological mechanisms linking migraine and HS are not well established but likely involve endothelial dysfunction, vascular wall remodeling, and coagulopathy.[15] The risk appears to be particularly elevated in women under 45 years of age and in those with migraine with aura.[16] However, owing to the low incidence of HS, large epidemiological datasets are scarce.[17]

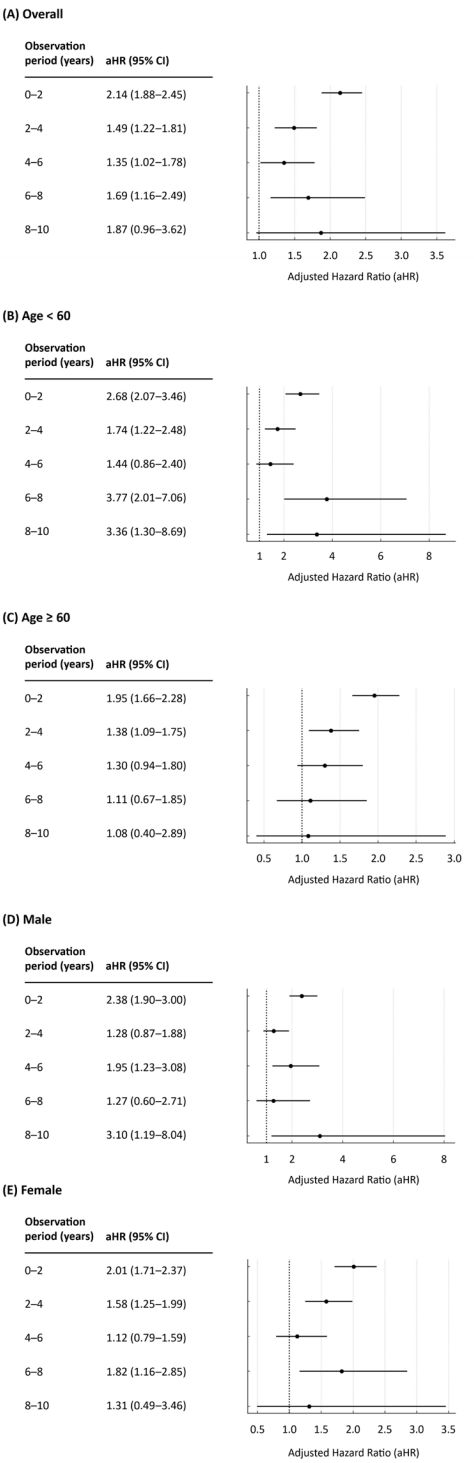

Figure 2. Forest plots illustrating the risk of ischemic stroke among all patients (A), stratified by age (<60 and ≥60 years; (B) and (C)), and by sex (male and female; (D) and (E)) using an extended time-stratified Cox proportional hazards model.

Note. Adjusted for age, sex, smoking status, alcohol consumption, body mass index (BMI), total cholesterol, and income.

This study found a higher risk of IS in males and individuals under 60 years of age. In younger individuals, fewer traditional vascular risk factors may allow migraine-specific mechanisms to have a greater impact[18], whereas in older adults, comorbidities may attenuate this effect.[19] Despite being less common in men, migraine has been associated with increased IS risk in this group.[20] These findings suggest that the risk of IS in younger and male migraine patients warrants further investigation.

Among lifestyle and metabolic subgroups, former smokers exhibited the highest risk of IS, consistent with prior studies.[21] This may be attributable to the "sick quitter effect" or the cumulative vascular damage caused by long-term smoking. Nevertheless, this study does not undermine the importance of quitting smoking; rather, it emphasizes the importance of early cessation.

Interestingly, the hazard ratio was higher in those consuming alcohol 1–2 times per week than in those drinking ≥3 times. This paradox may reflect differences in baseline risk among controls and the small number of heavy drinkers, which produced wide confidence intervals. Importantly, absolute incidence rates were still highest in heavy drinkers, indicating that frequent alcohol use remains harmful despite the attenuated relative risk. Obesity and increased total cholesterol levels were associated with an increased incidence of IS, consistent with previous studies.[22,23] These associations may be mediated by systemic inflammation, a prothrombotic state, and atherosclerosis.[24,25] These findings underscore the importance of lifestyle modification and lipid management for stroke prevention in individuals with migraine.

In patients with migraine, the risk of IS was highest during the early period (0–2 years), declined in the mid-term, and increased again in the late period (8–10 years). The early peak may reflect vasospasm, a prothrombotic state, and altered cerebral blood flow; the mid-term decline may result from risk attrition or treatment effects. Although the late-period increase could be related to persistent endothelial dysfunction, the confidence interval was wide and crossed unity, indicating statistical uncertainty. Therefore, this finding should be considered exploratory and requires confirmation in future studies with longer follow-up. The late increase may be associated with persistent endothelial dysfunction.[26] These results suggest that migraine is independently associated with both short- and long-term

cerebrovascular risks, highlighting the need for sustained management.

The major strengths of this study include the use of a large-scale national dataset, robust propensity score matching, and time-stratified survival analysis. Nonetheless, certain limitations should be noted. First, migraine subtypes (with or without aura) and disease severity were not captured, even though aura is considered an important determinant of stroke risk. Second, data on medication use and treatment duration were unavailable. Specifically, information on the use of oral contraceptives, a known risk factor for stroke especially in younger women, was not captured in the dataset. Third, diagnoses were based on administrative claims, which may have introduced misclassification. Fourth, although our analysis demonstrated an elevated risk up to 8 years after diagnosis, the mean follow-up was only about 3.8 years, and thus the long-term risk estimates should be interpreted with caution. Fifth, certain vascular comorbidities, such as atrial fibrillation, which are significant independent risk factors for stroke, were not explicitly controlled for in the analysis. This lack of control for potential confounders may have influenced the observed associations. Future research should investigate post-migraine stroke mechanisms using datasets with more comprehensive clinical detail. Using a nationwide cohort, this study identified that migraine is independently associated with an increased risk of IS and HS. The risk of IS was higher in individuals under 60 years of age and males, with elevated risk persisting for up to 8 years post-diagnosis. These results underscore the need to recognize migraine's independent association with cerebrovascular risk and emphasize the importance of early detection and long-term management to mitigate stroke risk in vulnerable groups.

DISCLOSURE

Contribution by authors: CY Kang, YJ Lee, HR Cho, SW Lee, SY Kim, HY Jung made equal contributions to this work

Data availability: The data that support the findings of this study are not publicly available due to legal and privacy restrictions imposed by the NHIS. The data are licensed for use only by authorized researchers and are not publicly available. Further inquiries can be directed to the corresponding author.

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Conflicts of interest: None

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Supplementary materials

Study Population Details

Covariates included in the propensity score model were smoking status, alcohol consumption, body mass index (BMI), total cholesterol, systolic and diastolic blood pressure, fasting blood glucose (FBS), and income level. Single imputation via predictive mean matching was used to address missing covariate data. The index date for each control was assigned to match that of the corresponding case.

Supplementary Table 1: International Classification of Diseases, 10th Revision (ICD-10) codes for stroke-related conditions excluded during the washout period.

Disease	ICD-10 Code
Stroke	
Cerebral infarction	I63.x
Intracerebral hemorrhage	I61.x
Subarachnoid hemorrhage	I60.x
Stroke, not specified as hemorrhage or infarction	I64
Severe cardiovascular disease	
Acute myocardial infarction	I21.x
Subsequent myocardial infarction	I22.x
Congestive heart failure	I50.x
Paroxysmal tachycardia	I47.x
Atrial fibrillation and flutter	I48.x
Other cardiac arrhythmias	I49.x
Presence of electronic cardiac devices	Z95.1–Z95.5
Bleeding disorder	
Hereditary factor VIII deficiency	D66
Hereditary factor IX deficiency	D67
Other coagulation defects	D68.x
Severe neurological disorder	
Malignant neoplasm of meninges, brain, spinal cord, cranial nerves and other parts of central nervous system	C70.x–C72.x
Epilepsy	G40.x
Dementia (dementia in Alzheimer disease, vascular dementia, dementia in other diseases classified elsewhere, unspecified dementia)	F00.x–F03.x
Malignant neoplasms	
Malignant neoplasms	C00–C97
Malignant neoplasms of ill-defined, secondary, and unspecified sites	C77–C79
Patients on chronic dialysis	
Chronic kidney disease, stage 5	N18.5
Dependence on renal dialysis	Z99.2
Severe liver disease	
Hepatic failure, not elsewhere classified	K72.x
Fibrosis and cirrhosis of liver	K74.x
Congenital malformations of cardiac chambers and connections	
Congenital malformations of cardiac chambers and connections	Q20

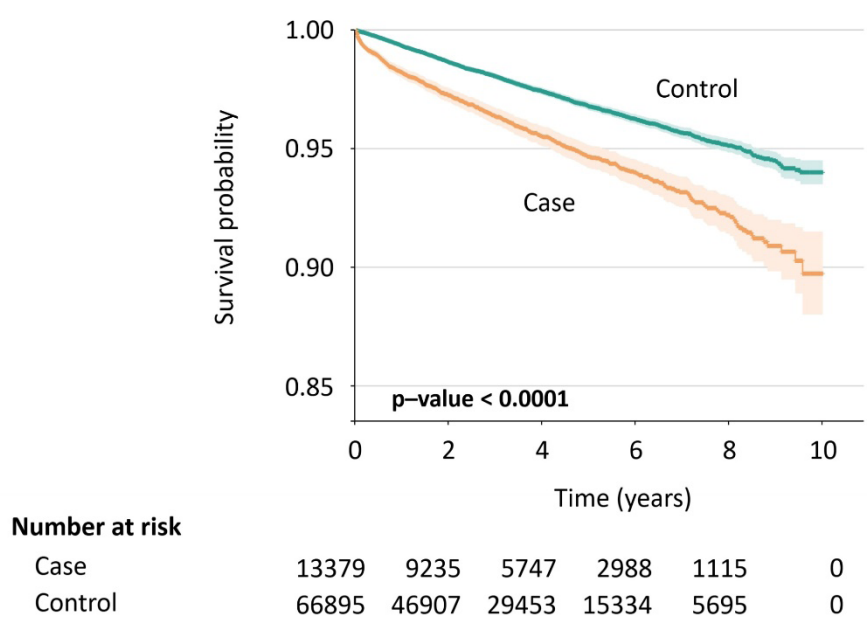
Supplementary Table 2. Crude incidence rates and risk ratios for hemorrhagic stroke among patients with migraine and matched controls.

		Case cohort (n = 13,379)			Reference cohort (n = 66,895)			IRR (95% CI)
		Cases	Person-years	IR per 1000 person-years (95% CI)	Cases	Person-years	IR per 1000 person-years (95% CI)	
All		94	52405.31	1.79 (1.43–2.16)	279	262385.44	1.06 (0.94–1.19)	1.69 (1.34–2.13)
Age (years)	<60	40	36830.26	1.09 (0.76–1.44)	106	184530.83	0.57 (0.47–0.69)	1.89 (1.31–2.72)
	≥60	54	15575.05	3.47 (2.57–4.43)	173	77854.61	2.22 (1.90–2.56)	1.56 (1.15–2.12)
Sex	Male	40	15500.79	2.58 (1.81–3.42)	91	78005.48	1.17 (0.94–1.41)	2.21 (1.53–3.21)
	Female	54	36904.52	1.46 (1.08–1.87)	188	184379.96	1.02 (0.88–1.17)	1.44 (1.06–1.94)
Sex & Age (years)	Male, <60	17	11133.09	1.53 (0.81–2.34)	26	56004.47	0.46 (0.30–0.64)	3.29 (1.78–6.06)
	Male, ≥60	23	4367.70	5.27 (3.21–7.56)	65	22001.01	2.95 (2.27–3.68)	1.78 (1.11–2.87)
	Female, <60	23	25697.17	0.90 (0.54–1.28)	80	128526.36	0.62 (0.49–0.76)	1.44 (0.90–2.29)
	Female, ≥60	31	11207.35	2.77 (1.87–3.75)	108	55853.60	1.93 (1.58–2.31)	1.43 (0.96–2.13)
Smoking status	Yes	15	6317.22	2.37 (1.27–3.64)	37	33931.90	1.09 (0.77–1.44)	2.18 (1.20–3.97)
	No	69	40811.28	1.69 (1.30–2.11)	217	200885.51	1.08 (0.94–1.22)	1.57 (1.19–2.05)
	Ex-Smoking	6	2584.26	2.32 (0.77–4.26)	13	13481.62	0.96 (0.45–1.56)	2.41 (0.92–6.33)
Frequency of alcohol consumption (per week)	0	65	34600.54	1.88 (1.45–2.34)	198	173173.04	1.14 (0.99–1.31)	1.64 (1.24–2.17)
	1–2	19	13045.45	1.46 (0.84–2.15)	52	64800.88	0.80 (0.59–1.03)	1.81 (1.07–3.07)
	≥3	9	3347.54	2.69 (1.19–4.48)	22	17302.87	1.27 (0.75–1.85)	2.11 (0.97–4.59)

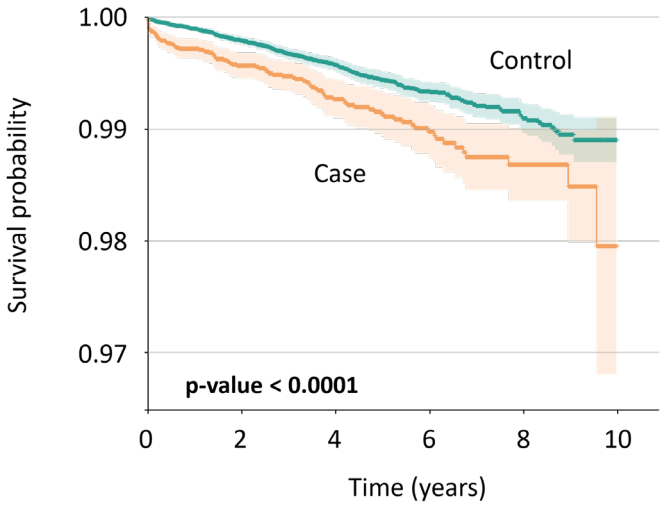
BMI (kg/m^2)	<18.5	2	2028.67	0.99 (0–2.46)	11	9839.97	1.12 (0.51–1.83)	0.88 (0.20–3.98)
	18.5 to <25	68	33892.66	2.01 (1.53–2.51)	155	171884.63	0.90 (0.76–1.05)	2.22 (1.67–2.96)
	≥25	24	16483.99	1.46 (0.91–2.06)	113	80583.91	1.40 (1.15–1.66)	1.04 (0.67–1.61)
Total cholesterol (mg/dL)	<200	46	29242.49	1.57 (1.13–2.05)	151	147290.27	1.03 (0.86–1.19)	1.53 (1.10–2.13)
	≥200	48	23084.15	2.08 (1.52–2.69)	126	114820.79	1.10 (0.91–1.29)	1.89 (1.36–2.64)
Income	Low	33	21411.42	1.54 (1.03–2.10)	130	106612.54	1.22 (1.01–1.44)	1.26 (0.86–1.85)
	High	61	30993.90	1.97 (1.48–2.48)	149	155772.90	0.96 (0.81–1.11)	2.06 (1.53–2.77)

IR, incidence rate; IRR, incidence rate ratio.

Supplementary Figure 1. Kaplan–Meier curves of ischemic stroke-free survival in migraine patients and matched controls.



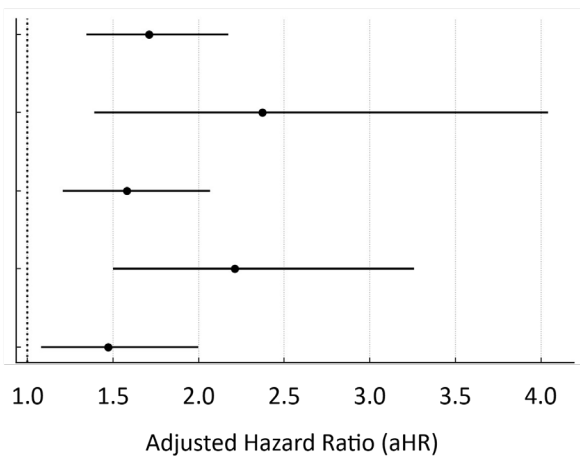
Supplementary Figure 2. Kaplan-Meier curve of hemorrhagic stroke-free survival in patients with migraine and matched controls.



Number at risk						
Case	13379	9466	5997	3178	1208	0
Control	66895	47453	30114	15829	5957	0

Supplementary Figure 3. Forest plot of adjusted hazard ratios for hemorrhagic stroke in patients with migraine compared with matched controls, using a multivariable Cox proportional hazards model.

Subgroup	aHR (95% CI)
Overall	1.71 (1.35–2.18)
Age < 60	2.37 (1.39–4.04)
Age ≥ 60	1.58 (1.21–2.07)
Male	2.21 (1.50–3.26)
Female	1.47 (1.08–2.00)



Note. Adjusted for age, sex, smoking status, alcohol consumption, body mass index (BMI), total cholesterol, and income.