World Neurosurgery: X 31 (2026) 100596

Contents lists available at ScienceDirect

World Neurosurgery: X

journal homepage: www.journals.elsevier.com/world-neurosurgery-x

The course of moderate-to-severe headaches in patients undergoing endovascular treatment for unruptured intracranial aneurysms: A retrospective cross-sectional study

Jin Young Choi [a,b], Yong Bae Kim [c], Joonho Chung [d], Keun Young Park [c], Jung-Jae Kim [c], Hyun Jin Han [c], Junhyung Kim [c], Sang Kyu Park [e,*]

[a] Graduate School, College of Nursing, Yonsei University, Republic of Korea
[b] Severance Hospital, Seoul, Republic of Korea
[c] Department of Neurosurgery, Severance Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea
[d] Department of Neurosurgery, Pohang Stroke and Spine Hospital, Pohang, Republic of Korea
[e] Department of Neurosurgery, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea

ARTICLE INFO

Keywords:
Endovascular treatment
Headache
Intracranial aneurysm

ABSTRACT

Background: This retrospective cross-sectional study aimed to investigate the course of newly onset moderate-to-severe headaches in patients who underwent endovascular treatment (EVT) for unruptured intracranial aneurysms (UIAs).

Methods: Between September 2009 and May 2022, 412 patients were included, and all met the following criteria: (1) presence of UIAs on computed tomography angiography or magnetic resonance angiography; (2) newly onset moderate-to-severe headache (Numeric Rating Scale, NRS $\geq$4) around the time of UIAs diagnosis; and (3) EVT of UIAs. We evaluated initial and follow-up NRS scores to determine the significance of NRS changes and identified predisposing factors for headache improvement at the 12-month follow-up.

Results: Compared to the NRS score (7.14) before EVT, the average NRS score (4.02) significantly decreased at discharge ($p < 0.05$). Subsequently, the follow-up NRS scores at 1-month (2.14), 6-month (1.65), and 12-month (1.27) were significantly decreased ($p < 0.01$). Follow-up NRS scores decreased continuously until the 12-month follow-up. A history of stroke (odds ratio [OR] = 0.539, 95% confidence interval [CI] 0.196 to 0.806; $p = 0.039$) and procedure-related complications (OR = 0.567, 95% CI 0.218 to 0.728; $p = 0.045$) were identified as independent predisposing factors of headache improvement on multivariate logistic regression analysis.

Conclusion: After EVT of UIAs, patients with newly onset moderate-to-severe headaches experienced significant headache improvement at discharge, with NRS continuously decreasing over the 12 months of follow-up. Headache improvement might be expected in patients who do not have a history of stroke and in those who have not experienced procedure-related complications.

Abbreviations

EVT	Endovascular treatment
UIA	Unruptured intracranial aneurysm
NRS	Numeric rating scale
mRS	Modified Rankin Scale
CT	Computed tomography
MRI	Magnetic resonance imaging

1. Introduction

Headache is one of the most frequent symptoms in patients with unruptured intracranial aneurysms (UIAs) and often prompts the work-up that leads to aneurysm detection.[1] About one-third of patients with UIAs report headache, yet many of these headaches have traditionally been regarded as incidental, despite formal diagnostic criteria for "headache attributed to unruptured saccular aneurysm".[2,3] Proposed mechanisms include local thrombosis and wall inflammation, stretching

* Corresponding author.Department of Neurosurgery, Gangnam Severance Hospital, Yonsei University College of Medicine, 211, Eonju-ro, Gangnam-gu, Seoul, 06273, Republic of Korea.

E-mail address: skparkns@yuhs.ac (S.K. Park).

https://doi.org/10.1016/j.wnsx.2026.100596
Received 12 December 2025; Accepted 1 May 2026
Available online 7 May 2026

or microbleeding of the aneurysm wall, activation of perivascular sensory nerve terminals, and psychological factors such as anxiety related to the perceived risk of rupture.[4–6].

Several clinical studies and meta-analyses have shown that treatment of UIAs can reduce headache severity. Kong et al reported improvement in nearly 90% of patients with chronic headache after clipping or coiling, and a recent meta-analysis demonstrated a significant overall reduction in headache intensity after surgical or endovascular treatment, although the included studies were small and heterogeneous.[7] A second systematic review limited to endovascular therapy found no clear difference in headache improvement between stent-assisted and simple coiling or between anterior and posterior circulation aneurysms, suggesting that aneurysm exclusion itself may be more important than the specific technique.[8] Conversely, other series have highlighted that 25–55% of patients develop new or worsened headache shortly after coil embolization, particularly in association with stent use, high packing density, and absence of hypertension, although these post-procedural headaches are usually transient.[7,9–12].

However, prior work has seldom focused specifically on patients with "new-onset moderate-to-severe headaches" around the time of UIA diagnosis and has rarely examined vascular comorbidities, prior stroke, or procedural complications as modifiers of the long-term headache course. Because moderate-to-severe headache (for example, NRS ≥4) substantially impairs daily functioning, understanding its trajectory after endovascular treatment is clinically important.[13] We therefore analyzed a large cohort of patients with UIAs and new-onset moderate-to-severe headache to characterize changes in headache intensity over 12 months after EVT and to identify clinical, radiographic, and procedural factors associated with headache improvement or persistence.

2. Methods

2.1. Study design

This retrospective cross-sectional study, which utilized prospectively collected data, received approval from our institutional review board, and informed consent was waived.

2.2. Setting and participants

Since September 2009, we prospectively assessed patient headaches using a numeric rating scale (NRS). Out of 4439 patients with unruptured aneurysms treated with EVT between September 2009 and May 2022, we included 412 patients (male/female ratio 118:294, mean age [±SD] 56.7 ± 13.1 years, range 21-78 years). All included patients met the following criteria: (1) presence of UIAs as confirmed by computed tomography angiography or magnetic resonance angiography; (2) new-onset moderate-to-severe headache (NRS ≥4) occurring within four weeks before and after the diagnosis of UIAs; and (3) EVT of UIAs. The patients' headache could be daily or episodic. The remaining 4027 cases from the database were excluded for the following reasons: (1) incomplete NRS score data; (2) mild headache (NRS ≤3); (3) initial modified Rankin Scale ≥3 on admission; (4) history of neurosurgery (craniotomy due to any cause); and (5) loss to follow-up. A flow diagram of patient selection was shown in Fig. 1.

The intensity of headaches was assessed using the NRS, which is an 11-point numeric scale for rating pain intensity. It ranges from 0 (indicating "no headache at all") to 10 (indicating "the worst possible headache").[14,15] We categorized NRS scores of 1 to 3 as mild headaches, 4 to 6 as moderate, and 7 to 10 as severe. Mild headaches were described as nagging, annoying, or having little interference with daily activities. Moderate headaches interfered significantly with daily activities, and severe headaches were disabling, preventing patients from performing daily activities. An NRS score ≥4 was considered significant. NRS scores were recorded every 8 h during hospitalization (3 times per day) and twice during outpatient visits. Analgesics were prescribed to patients with headaches. Patients were instructed to report their headache intensity using the NRS based on the most severe pain they experienced prior to taking analgesic medication. Patient NRS scores were collected and averaged upon admission (pre-EVT), upon discharge (post-EVT), and at 1-month, 6-month, and 12-month intervals after discharge.

Clinical data, aneurysm characteristics, and radiographic images of the included patients were retrospectively reviewed. We assessed various variables related to NRS changes, including age, gender, hypertension, diabetes, dyslipidemia, smoking, alcohol consumption, previous stroke, small vessel disease, any history of headache treated with medication, procedure-related complications, clinical outcomes, aneurysm location, aneurysm size, and neck diameter. Aneurysm size was determined using digital subtraction angiography with three-

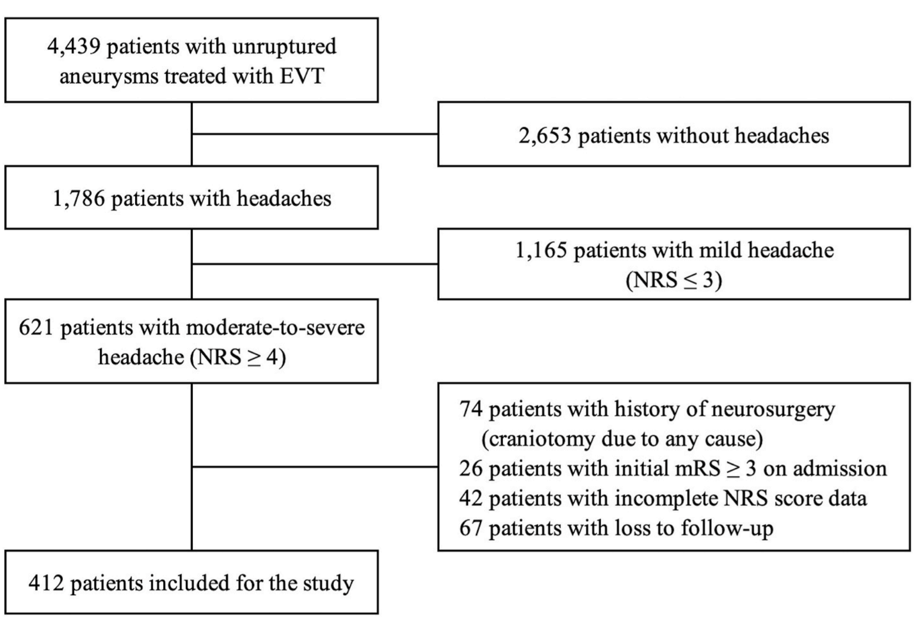

Fig. 1. Flow diagram of patient selection. EVT, endovascular treatment; mRS, modified Rankin Scale; NRS, numeric rating scale.

dimensional rotational imaging, and it was defined as the maximum perpendicular height of the dome from the neck plane. Radiographic data were evaluated and collected by two independent investigators. Previous stroke was defined as encephalomalatic changes or old lacunar infarction observed in radiographic images, regardless of clinical stroke history. Small vessel disease was defined as Fazekas grade 3 on radiographic images. Procedure-related complications included symptomatic ischemic (thromboembolic or venous infarct) or hemorrhagic (intraparenchymal, subdural, epidural, or intraventricular) complications secondary to EVT.[14] Improvement in headache was defined as a follow-up NRS score ≤3, indicating mild headache or no headache. Most of the variables represent baseline characteristics assessed at the time of endovascular treatment. Specifically, demographic and clinical characteristics were evaluated at baseline. Aneurysm characteristics and treatment modality were recorded at the time of the index procedure. Procedure-related complications were assessed at the time of occurrence during or immediately after the procedure.

2.3. Endovascular treatment

EVT encompassed various procedures, including simple coiling ($n = 87$), balloon-assisted coiling ($n = 46$), stent-assisted coiling ($n = 187$), multiple stenting ($n = 22$), flow diverter ($n = 55$), and flow disruptor ($n = 15$). For statistical analysis, treatment modalities were reclassified into three broader categories to minimize potential bias from small subgroup sizes: (1) coiling without stent (simple coiling and balloon-assisted coiling), (2) stent-assisted coiling, and (3) other techniques (multiple stenting, flow diverter, and flow disruptor).

Treatment decisions were made in consensus among neurosurgeons and neurointerventionists. All procedures were performed under general anesthesia. Patients were administered preprocedural dual antiplatelet agents (daily dose of aspirin 100 mg and clopidogrel 75 mg) for at least 5 days. Systemic heparinization (50 IU/kg) was routinely conducted after the placement of the femoral sheath. Additional heparin (1000 IU) was administered intravenously if the procedure was prolonged, based on the activated clotting time, which was maintained at twice the baseline level. For patients treated with stents in the parent arteries, dual antiplatelet agents were maintained for 6 months post-stent placement and switched to aspirin monotherapy for at least 12 months. Otherwise, antiplatelet agents were not prescribed.

2.4. Statistical analysis

All statistical analyses were conducted in consultation with a biostatistician and using R language version 4.1.0 (R Foundation for Statistical Computing, Vienna, Austria). Paired *t*-tests or Wilcoxon signed rank tests were used to evaluate NRS score changes between baseline and follow-up. Mann–Whitney *U*-tests were applied to numeric variables, and chi-square tests or Fisher's exact tests were used for nominal variables. Univariate analysis was performed to determine independent predictors of headache improvement in relation to NRS score changes at the 12-month follow-up. Binary logistic regression analysis was performed on variables with an unadjusted effect and a *p*-value of <0.10 from univariate analysis. Linear regression analysis was conducted to identify factors associated with the NRS score decrease throughout the follow-up periods. Statistical significance was defined by $p < 0.05$, with a 95% confidence interval (CI).

3. Results

3.1. Baseline characteristics

Baseline clinical characteristics of the patients were shown in Table 1. Out of the 412 patients, 208 (50.5%) had hypertension, 54 (13.1%) had a history of previous strokes, 36 (8.7%) had small vessel disease, and 44 (10.7%) had a history of headaches treated with

Table 1
Baseline characteristics of the patients and redisposing factors for improvement of moderate-to-severe headache at the 12-month follow-up.

	Baseline characteristics (n = 412)	12-month follow-up			
		Headache improved (n = 358)	Headache not improved (n = 54)	p value	
				Univariate analysis	Multivariate logistic regression (OR, 95%CI)
Age (mean ± SD, year)	56.7 ± 13.1	55.8 ± 12.5	59.6 ± 13.2	0.254[a]	
Female (n, %)	294 (71.4)	258 (72.1)	36 (66.7)	0.536	
Hypertension (n, %)	208 (50.5)	175 (48.9)	33 (61.1)	0.041	0.092 (0.520, 0.313-2.364)
Diabetes (n, %)	87 (21.1)	79 (22.1)	8 (14.8)	0.489	
Dyslipidemia (n, %)	139 (33.7)	124 (34.6)	15 (27.8)	0.128	
Smoking (n, %)	128 (31.1)	110 (30.7)	18 (33.3)	0.656	
Alcohol (n, %)	99 (24.0)	88 (24.6)	11 (20.4)	0.561	
Previous stroke	54 (13.1)	39 (10.9)	15 (27.8)	0.034	0.039 (0.539, 0.196-0.806)
Small vessel disease	36 (8.7)	28 (7.8)	8 (14.8)	0.076	0.065 (0.614, 0.297-1.035)
Previous headache treated with medication	44 (10.7)	37 (10.3)	7 (13.0)	0.885	
Aneurysm location (n, %)				0.928	
Anterior circulation	303 (73.5)	263 (73.5)	40 (74.1)		
Posterior circulation	109 (26.5)	95 (26.5)	14 (25.9)		
Aneurysm size (mean ± SD, mm)	5.8 ± 1.9	5.7 ± 2.1	6.3 ± 1.8	0.353[a]	
Aneurysm neck (mean ± SD, mm)	3.7 ± 1.2	3.6 ± 1.4	3.9 ± 1.6	0.418[a]	
Aneurysm characteristic (n, %)				0.602	
Saccular	325 (78.9)	284 (79.3)	41 (75.9)		
Fusiform	28 (6.8)	24 (6.7)	4 (7.4)		
Dissecting	59 (14.3)	50 (14.0)	9 (16.7)		
Endovascular treatment (n, %)				0.374	
Coiling without stent	133 (32.2)	120 (33.5)	13 (24.1)		
Stent assisted coiling	187 (45.4)	160 (44.7)	27 (50.0)		
Other technique	92 (22.2)	78 (21.7)	14 (25.9)		
Antiplatelet agents (n, %)	264 (64.1)	233 (65.1)	31 (57.4)	0.121	
Anticoagulant (n, %)	33 (8.0)	29 (8.1)	4 (7.4)	0.902	
Procedure-related complications (n, %)	19 (4.6)	13 (3.6)	6 (11.1)	0.055	0.045 (0.567, 0.218-0.728)

[a] According to the Mann–Whitney *U*-test.

medication. The majority of patients in this study had anterior circulation aneurysms (303 patients, 73.5%). The mean size of the aneurysm dome and neck were 5.8 mm and 3.7 mm, respectively. The cohort consisted of 325 patients with saccular aneurysms (78.9%), 28 patients with fusiform aneurysms (6.8%), and 59 patients with dissecting aneurysms (14.3%). Procedure-related complications occurred in 19 patients (4.6%): 9 patients were classified as modified Rankin Scale (mRS) 1, and 10 were classified as mRS 2 at the 12-month clinical follow-up.

3.2. Longitudinal course of headache

Of the 412 patients with moderate-to-severe headaches before EVT, 213 patients (51.7%) experienced headache improvement (NRS score $\leq$3) upon discharge, 287 (69.7%) after 1 month, 311 (75.5%) after 6 months, and 358 (86.9%) after 12 months of follow-up. Additionally, 148 patients (35.9%) became headache-free upon discharge, 223 (54.1%) after 1 month, 249 (60.4%) after 6 months, and 304 (73.8%) after 12 months of follow-up. The average NRS scores, chronologically, were 7.14, 4.02, 2.14, 1.65, and 1.27 at pre-EVT, discharge, 1-month, 6-month, and 12-month follow-up, respectively (Fig. 2). The NRS scores were significantly decreased at discharge ($p < 0.05$). Subsequently, the follow-up NRS scores at 1 month, 6 months, and 12 months were significantly lower than those at pre-EVT ($p < 0.01$). Furthermore, there was a significant decrease in the NRS score between discharge and the 12-month follow-up ($p < 0.05$). Follow-up NRS scores continuously decreased up to the 12-month follow-up.

3.3. Factors associated with headache improvement

Hypertension, a history of previous strokes, and small vessel disease, with a p value < 0.10 on univariate analysis ($p = 0.041$, 0.034, and 0.076, respectively), were included in multivariate logistic regression analysis to determine independent predictors of headache improvement at the 12-month follow-up. Among them, a history of stroke (odds ratio [OR] = 0.539, 95% confidence interval [CI] 0.196 to 0.806; $p = 0.039$) and procedure-related complications (OR = 0.567, 95% CI 0.218 to 0.728; $p = 0.045$) were identified as independent predictors of headache improvement (Table 1).

3.4. Worsening headache subgroup

Among the 54 patients in the group with no improvement in headaches at the 12-month follow-up, 12 experienced worsening headaches, while the remaining 42 reported persistent headache without improvement. Compared to the improvement group, baseline demographic and aneurysm characteristics were not significantly different. Procedural complications were observed in 2 patients within the worsening group. Importantly, no hemorrhagic complications occurred in the 12 patients with worsening headache during the follow-up period.

4. Discussion

In this retrospective study of 412 patients with UIAs and new-onset moderate-to-severe headache, we observed a marked and sustained reduction in headache intensity after endovascular treatment. Mean NRS scores fell from 7.14 at baseline to 4.02 at discharge and continued to decrease to 2.14, 1.65, and 1.27 at 1, 6, and 12 months, respectively, with each time point showing a statistically significant improvement compared with pretreatment and with discharge. By 12 months, 86.9% of patients had at least partial improvement (NRS $\leq$3), and 73.8% were completely headache-free. These findings are concordant with earlier reports that treatment of UIAs frequently leads to clinically meaningful headache relief, including the prior meta-analytic data demonstrating a moderate pooled reduction in headache severity after UIA treatment.[10] Our study extends this literature by restricting the cohort to patients with new-onset moderate-to-severe headaches and by providing detailed longitudinal NRS data over a 12-month period.

The trajectory we observed—rapid improvement by discharge followed by gradual, continued decline over 1 year—suggests that both early and late mechanisms contribute to headache relief. In the acute phase, aneurysm exclusion may attenuate pulsatile expansion of the sac and reduce mechanical stimulation of perivascular sensory afferents, while early thrombus formation within the coil mass and aneurysm

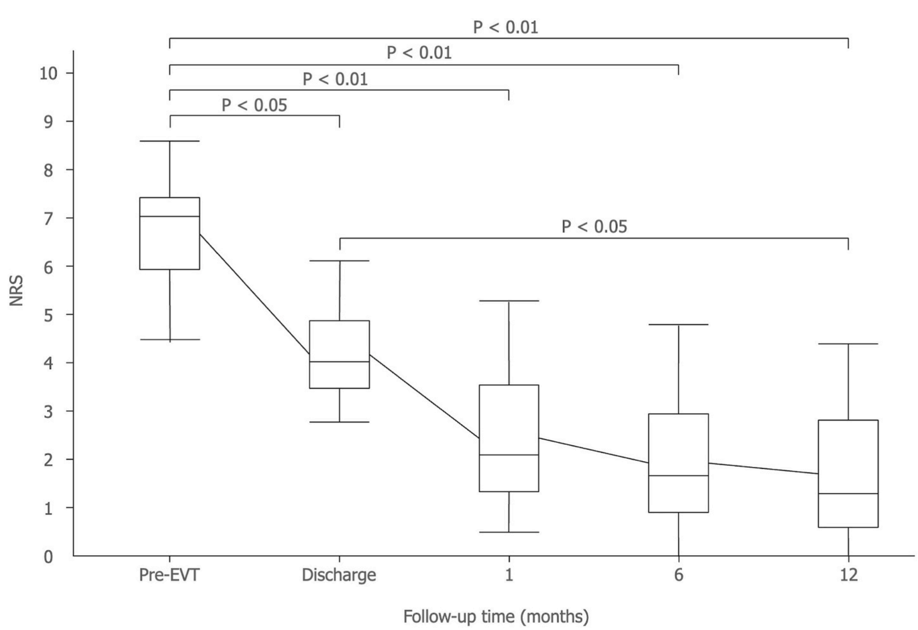

Fig. 2. Changes in the numeric rating scale (NRS) scores representing the course of headache in patients with moderate-to-severe headache before endovascular treatment of unruptured intracranial aneurysms over a 12-month follow-up period. Compared to NRS scores at pretreatment, those at discharge were significantly decreased ($p < 0.05$). Subsequently, the follow-up NRS scores at 1-month, 6-month, and 12-month were significantly lower than those at pretreatment ($p < 0.01$). Additionally, there was a significant decrease between the NRS score at discharge and the 12-month follow-up ($p < 0.05$). Follow-up NRS scores showed a continuous decrease over the 12-month follow-up period.

dome may initially provoke, but then ultimately dampen, local inflammatory activity.[4–6,16] Over the longer term, progressive endothelialization across the aneurysm neck and remodeling of the aneurysm wall may further reduce nociceptive input. At the same time, several authors have emphasized psychological mechanisms: successful treatment may alleviate catastrophic fears of rupture and modify central pain processing, a hypothesis supported by data linking anxiety to increased pain responses on functional neuroimaging.[3,12,17–19] The continuous decline in NRS scores between discharge and 12 months in our cohort fits well with a model in which biological stabilization of the treated aneurysm and gradual psychological adaptation jointly promote sustained headache improvement.

A key contribution of our study is the identification of clinical factors associated with persistent moderate-to-severe headache. In univariate analyses, hypertension, previous stroke, small vessel disease, and procedure-related complications differed between patients with and without 12-month headache improvement, and in multivariable models, previous stroke and procedural complications emerged as independent predictors. Some previous studies reported that "no history of hypertension" and high packing density were associated with the development of early headache after coiling (Table 2).[9,11,20,21] One proposed explanation is that normotensive vessels and aneurysm walls are more elastic and thus more susceptible to distension and inflammatory changes after dense coil packing, triggering pain.[11,22–24] Our data instead suggest that, once moderate-to-severe headache is present at baseline, chronic cerebrovascular disease—including prior stroke and advanced small vessel disease—may predispose to persistence rather than resolution of headache. Structural white matter changes and impaired autoregulation in these patients might promote central sensitization of pain pathways and reduce the capacity for symptom improvement even after aneurysm occlusion.

The association between procedure-related complications and reduced likelihood of headache improvement merits particular caution and discussion. Intuitively, ischemic or hemorrhagic complications might be expected to worsen or prolong headache by introducing additional parenchymal injury, meningeal irritation, or hydrocephalus. However, taken together with meta-analytic data showing no robust effect of treatment modality or aneurysm location on pooled headache improvement rates, we interpret our complication-related findings as hypothesis-generating rather than definitive.

Regarding endovascular technique and aneurysm location, our overall pattern of sustained improvement across a spectrum of approaches—including simple coiling, balloon-assisted coiling, stent-assisted coiling, multiple stenting, flow diversion, and flow disruption—and predominantly anterior circulation aneurysms aligns with prior pooled analyses. Dibas et al found no statistically significant difference in headache improvement between stent-assisted coiling and coiling alone or between posterior and anterior circulation aneurysms, although there was a trend toward better outcomes with simple coiling. Dandurand et al were likewise unable to demonstrate a consistent effect of size, location, or modality, largely because individual studies did not stratify headache outcomes by these variables. Our results suggest that, in the specific context of new-onset moderate-to-severe headache, the fact of aneurysm exclusion and subsequent vascular remodeling may be more important for long-term headache relief than the precise endovascular strategy, though adequately powered, stratified analyses will

Table 2
Headache outcomes after endovascular treatment for unruptured intracranial aneurysms.

Studies	Year of publication	Study Design	Total patients number (n)	Headache after EVT				Assessment	Risk factor[a]	Predisposing factor[b]
				Improvement (%)	No change (%)	Deteriorate (%)	New onset (%)			
Hwang et al. 6	2012	Prospective cohort	90	—	—	—	55.6	VAS	No hypertension, packing density >25%	—
Gu et al. 5	2013	Retrospective cohort	72	77	19.2	3.8	10	VAS	Pretreatment headache, greater headache score	—
Choi et al. 2	2014	Retrospective cohort	130	85	0	15	29	The quality, severity, and frequency	No history of hypertension, stent-assisted coiling	—
Ji et al. 8	2017	Retrospective cohort	123	56.1	43.9	—	—	VAS	—	Headache ipsilateral to the side of the aneurysm, aneurysm size >10 mm
Zhang et al. 23	2017	Prospective cohort	73	83	—	17	24	VAS	—	—
Park et al. 16	2018	Prospective cohort	82	71.2	28.8	0	13	VAS, HIT-6, DASS-D	None	None
Maragkos et al. 13	2020	Prospective cohort	38	40	33.3	26.7	23.7	VAS, MIDAS, HIT-6, PHQ-2	—	—
Dibas et al. 4	2020	Meta-analysis	383	65.3	34.7	—	—	—	None	None
Marquez-Romero et al. 14	2024	Prospective cohort	42	90.5	0	9.5	—	Self-reported headache (yes or no)	None	None
Current study	present	Retrospective cohort	412	86.9	10.2	2.9	—	VAS (NRS)	—	History of stroke, procedure-related complication

DASS-D = Depression Anxiety and Stress Scale; EVT = endovascular treatment; HIT-6 = Headache Impact Test-6; MIDAS = Migraine Disability Assessment; NRS = Numeric Rating Scale; PHQ-2 = Patient Health Questionnaire-2; VAS = Visual Analogue Scale.
[a] Risk factor for a lack of improvement, new onset, or headache deteriorate.
[b] Predisposing factor for headache improvement.

be needed to confirm this.

Several limitations of our study should be emphasized. The retrospective cross-sectional design, derived from a prospectively collected registry, leaves room for selection bias, particularly because patients with incomplete NRS data or loss to follow-up were excluded. We did not systematically capture detailed analgesic regimens (type, dose, timing), headache-specific preventive medications, or rescue therapies, which could influence the trajectory of pain intensity. Information on psychiatric comorbidities, stress, and anxiety—which are known to affect both headache and quality of life in UIA patients—was also lacking, limiting our ability to disentangle biological from psychological determinants of outcome. Furthermore, we focused on headache intensity rather than specific headache diagnoses; we did not subclassify patients into migraine, tension-type, or other headache disorders, in contrast to some prior headache-focused studies. This pragmatic approach enhances generalizability to everyday clinical practice but may obscure phenotype-specific responses to EVT. Finally, as in earlier observational work, our reliance on patient-reported NRS scores introduces the possibility of recall bias and expectancy effects, particularly in patients who strongly believed that aneurysm treatment would resolve their headaches.

Despite these caveats, the present study has several practical implications for clinicians managing patients with UIAs and moderate-to-severe headache. First, our data allow physicians to counsel patients that, in the majority of cases with new-onset significant headache, EVT is associated with substantial and sustained improvement in pain over at least 12 months, often culminating in complete headache resolution. Second, the identification of previous stroke and procedure-related complications as negative prognostic factors suggests that expectations should be tempered in patients with advanced cerebrovascular disease or periprocedural events; for these individuals, persistent headache may reflect underlying brain vulnerability rather than failure of aneurysm treatment per se. Finally, our findings underscore the need for future prospective studies that integrate standardized headache classifications, validated quality-of-life instruments, detailed medication and psychiatric assessments, and stratification by aneurysm characteristics and endovascular technique. Such work will be essential to refine prognostic models, to clarify causal mechanisms, and ultimately to tailor both interventional and supportive strategies for patients with UIAs and debilitating headaches.

5. Conclusion

Following EVT of UIAs, patients with new-onset moderate-to-severe headaches experienced significant improvements in their headaches upon discharge, with NRS scores continuously decreasing over 12 months of follow-up. Moreover, NRS scores at the 12-month follow-up were significantly lower than those recorded before EVT and upon discharge. Patients without a history of stroke and those who did not experience procedure-related complications were more likely to experience headache improvement. These findings provide valuable insights for healthcare providers to educate patients about the expected course of their headaches after EVT of UIAs.

CRediT authorship contribution statement

Jin Young Choi: Writing – original draft, Data curation, Conceptualization. **Yong Bae Kim:** Supervision, Resources, Formal analysis. **Joonho Chung:** Validation, Supervision, Conceptualization. **Keun Young Park:** Project administration, Formal analysis, Data curation. **Jung-Jae Kim:** Visualization, Software, Investigation. **Hyun Jin Han:** Resources, Methodology, Data curation. **Junhyung Kim:** Project administration, Methodology, Investigation. **Sang Kyu Park:** Writing – review & editing, Validation, Supervision.

Patient consent

For this type of retrospective study formal consent is not required.

Ethics approval and consent to participate

The study received ethics approval by the Yonsei University of Medical Science Ethics Committee. Given the retrospective nature of the study, the institutional review board granted approval and waived the requirement for informed consent. All methods were carried out in accordance with relevant guidelines and regulations. The patient's data included in this manuscript has not been previously reported.

Consent for publication

Not applicable.

Ethical approval

All procedures performed in the studies involving human participants were in accordance with the ethical standards of our Institutional Review Board with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Funding

There was no external source of funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due them containing information that could compromise research participant privacy/consent but are available from the corresponding author on reasonable request.

References

1. Unruptured intracranial aneurysms–risk of rupture and risks of surgical intervention. *N Engl J Med*. 1998;339(24):1725–1733. https://doi.org/10.1056/nejm199812103392401.
2. Headache Classification Committee of the International Headache Society (IHS). The international classification of headache disorders, 3rd edition *Cephalalgia*. 2018;38 (1):1–211. https://doi.org/10.1177/0333102417738202.
3. Autret A, Valade D, Debiais S. Placebo and other psychological interactions in headache treatment. *J Headache Pain*. 2012;13(3):191–198. https://doi.org/10.1007/s10194-012-0422-0.
4. Aoki N. Partially thrombosed aneurysm presenting as the sudden onset of bitemporal hemianopsia. *Neurosurgery*. 1988;22(3):564–566. https://doi.org/10.1227/00006123-198803000-00021.
5. Nichols 3rd FT, Mawad M, Mohr JP, Stein B, Hilal S, Michelsen WJ. Focal headache during balloon inflation in the internal carotid and middle cerebral arteries. *Stroke*. 1990;21(4):555–559. https://doi.org/10.1161/01.str.21.4.555.
6. Schubiger O, Valavanis A, Wichmann W. Growth-mechanism of giant intracranial aneurysms; demonstration by CT and MR imaging. *Neuroradiology*. 1987;29(3): 266–271. https://doi.org/10.1007/bf00451765.
7. Kong DS, Hong SC, Jung YJ, Kim JS. Improvement of chronic headache after treatment of unruptured intracranial aneurysms. *Headache*. 2007;47(5):693–697. https://doi.org/10.1111/j.1526-4610.2006.00630.x.
8. Dibas M, Ghozy S, El-Qushayri AE, Griessenauer CJ. Impact of aneurysm location and endovascular treatment modality on the improvement of headache in patients with unruptured intracranial aneurysms. *J Neurosurg Sci*. 2020;64(5):464–467. https://doi.org/10.23736/s0390-5616.20.05045-6.
9. Choi KS, Lee JH, Yi HJ, Chun HJ, Lee YJ, Kim DW. Incidence and risk factors of postoperative headache after endovascular coil embolization of unruptured intracranial aneurysms. *Acta Neurochir*. 2014;156(7):1281–1287. https://doi.org/10.1007/s00701-014-2095-8.

10. Dandurand C, Parhar HS, Naji F, et al. Headache outcomes after treatment of unruptured intracranial aneurysm: a systematic review and meta-analysis. *Stroke*. 2019;50(12):3628–3631. https://doi.org/10.1161/strokeaha.119.026864.
11. Hwang G, Jeong EA, Sohn JH, et al. The characteristics and risk factors of headache development after the coil embolization of an unruptured aneurysm. *AJNR Am J Neuroradiol*. 2012;33(9):1676–1678. https://doi.org/10.3174/ajnr.A3018.
12. Choxi AA, Durrani AK, Mericle RA. Both surgical clipping and endovascular embolization of unruptured intracranial aneurysms are associated with long-term improvement in self-reported quantitative headache scores. *Neurosurgery*. 2011;69 (1):128–133. https://doi.org/10.1227/NEU.0b013e318213437d. discussion 133-124.
13. The international classification of headache disorders: 2Nd edition. *Cephalalgia*. 2004;24(Suppl 1):9–160. https://doi.org/10.1111/j.1468-2982.2003.00824.x.
14. Kwong WJ, Pathak DS. Validation of the eleven-point pain scale in the measurement of migraine headache pain. *Cephalalgia*. 2007;27(4):336–342. https://doi.org/10.1111/j.1468-2982.2007.01283.x.
15. Lebedeva ER, Gurary NM, Sakovich VP, Olesen J. Migraine before rupture of intracranial aneurysms. *J Headache Pain*. 2013;14(1):15. https://doi.org/10.1186/1129-2377-14-15.
16. Murayama Y, Viñuela F, Tateshima S, Song JK, Gonzalez NR, Wallace MP. Bioabsorbable polymeric material coils for embolization of intracranial aneurysms: a preliminary experimental study. *J Neurosurg*. 2001;94(3):454–463. https://doi.org/10.3171/jns.2001.94.3.0454.
17. Li Y, Dai W, Zhang J. Anxiety, depression and quality of life in patients with a treated or untreated unruptured intracranial aneurysm. *J Clin Neurosci*. 2017;45: 223–226. https://doi.org/10.1016/j.jocn.2017.07.019.
18. Ploghaus A, Narain C, Beckmann CF, et al. Exacerbation of pain by anxiety is associated with activity in a hippocampal network. *J Neurosci*. 2001;21(24): 9896–9903. https://doi.org/10.1523/jneurosci.21-24-09896.2001.
19. Deruty R, Pelissou-Guyotat I, Mottolese C, Amat D. Management of unruptured cerebral aneurysms. *Neurol Res*. 1996;18(1):39–44. https://doi.org/10.1080/01616412.1996.11740375.
20. De Silva DA, Woon FP, Gan HY, et al. Arterial stiffness is associated with intracranial large artery disease among ethnic Chinese and South Asian ischemic stroke patients. *J Hypertens*. 2009;27(7):1453–1458. https://doi.org/10.1097/HJH.0b013e32832a8dc5.
21. Kotsis V, Stabouli S. Arterial stiffness, vascular aging, and intracranial large artery disease. *Am J Hypertens*. 2011;24(3):252. https://doi.org/10.1038/ajh.2010.251.
22. Gu DQ, Duan CZ, Li XF, He XY, Lai LF, Su SX. Effect of endovascular treatment on headache in elderly patients with unruptured intracranial aneurysms. *AJNR Am J Neuroradiol*. 2013;34(6):1227–1231. https://doi.org/10.3174/ajnr.A3353.
23. Iversen HK, Nielsen TH, Olesen J, Tfelt-Hansen P. Arterial responses during migraine headache. *Lancet*. 1990;336(8719):837–839. https://doi.org/10.1016/0140-6736(90)92339-j.
24. Khan S, Amin FM, Hauerberg J, et al. Post procedure headache in patients treated for neurovascular arteriovenous malformations and aneurysms using endovascular therapy. *J Headache Pain*. 2016;17(1):73. https://doi.org/10.1186/s10194-016-0666-1.