Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Association between Lamina Terminalis Fenestration and Shunt-Dependent Chronic Hydrocephalus After Ruptured Anterior Circulation Aneurysms: A Single-Center Retrospective Cohort Study

Okay Baykara

okaybaykara@gmail.com

Osmaniye Training and Research Hospital

Faruk İldan

Çukurova University

Metin Tuna

Çukurova University

Kerem Mazhar Özsoy

Çukurova University

Ali Ufuk Keçebaş

Şanlıurfa Eyyübiye Training and Research Hospital

Halil Emre Alcan

Bingöl State Hospital

Research Article

Keywords: aneurysmal subarachnoid hemorrhage, hydrocephalus, lamina terminalis, ventriculoperitoneal shunt, microsurgical clipping

Posted Date: September 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10757237/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage increases long-term morbidity. This study evaluated the association between lamina terminalis fenestration (LTF) during microsurgical clipping of ruptured anterior circulation aneurysms and shunt-dependent chronic hydrocephalus.

Methods

Patients who underwent craniotomy and microsurgical clipping between January 2016 and February 2023 were retrospectively reviewed. Patients who died within 14 days were excluded because of substantial comorbidity, coagulation disorders, multiorgan failure, or high mortality. Patients were grouped according to LTF status. The primary outcome was permanent ventriculoperitoneal shunt placement. The risk difference (RD), relative risk (RR), and odds ratio (OR) were calculated. Logistic regression models adjusted for aneurysm location and expanded exploratory models were constructed. The sensitivity analyses included patients with anterior communicating artery (ACom) aneurysms and survivors.

Results

Among the 138 patients, 48 (34.8%) underwent LTF, and 19 (13.8%) developed shunt-dependent hydrocephalus. The shunt rates were 16.7% (8/48) with LTF and 12.2% (11/90) without LTF (RD, 4.4 percentage points; 95% CI, − 8.1–17.0; RR = 1.36; 95% CI, 0.59–3.16; OR = 1.44; 95% CI, 0.54–3.85; p = 0.605). ACom aneurysms constituted 87.5% and 15.6% of the cases in the LTF and non-LTF groups, respectively (p < 0.001). LTF remained nonsignificant after adjustment for ACom location (OR = 0.68; 95% CI, 0.18–2.56; p = 0.569) and in the expanded model (OR = 0.76; 95% CI, 0.20–2.95; p = 0.690). Sensitivity analyses were also nonsignificant for ACom aneurysms (RR = 0.58; 95% CI, 0.20–1.70; p = 0.439) and survivors (RR = 1.31; 95% CI, 0.47–3.68; p = 0.751).

Conclusion

No significant association was found between LTF and shunt dependency. Limited events, wide confidence intervals, strong anatomical selection bias, and exclusion of early deaths limit certainty; therefore, these findings indicate that an independent association could not be established rather than conclusively demonstrating ineffectiveness.

Introduction

Aneurysmal subarachnoid hemorrhage (aSAH) is a severe cerebrovascular condition associated with high mortality and a substantial risk of permanent neurological disability. Despite advances in diagnostic

techniques, aneurysm treatment, and neurocritical care, aSAH remains an important cause of morbidity and mortality [1, 2].

Although aneurysm rupture most commonly results in bleeding into the subarachnoid space, intraventricular, intraparenchymal, or subdural hemorrhage may also occur. Increased intracranial pressure, early brain injury, rebleeding, vasospasm, delayed cerebral ischemia, and hydrocephalus are among the major complications that determine the clinical course after hemorrhage [1, 3]. Hydrocephalus may cause impaired consciousness and increased intracranial pressure during the acute phase, whereas chronic hydrocephalus may require permanent cerebrospinal fluid diversion.

Blood products within the subarachnoid and intraventricular spaces may cause mechanical obstruction of cerebrospinal fluid pathways and impair absorption through the arachnoid granulations [4–6]. External ventricular drainage (EVD) may be used for temporary cerebrospinal fluid diversion in patients who develop acute symptomatic hydrocephalus. However, some patients cannot be successfully weaned from EVD or subsequently develop chronic hydrocephalus requiring permanent ventriculoperitoneal shunt placement [3, 7].

Shunt-dependent hydrocephalus is an important complication that may prolong hospitalization, delay functional recovery, and lead to repeated surgical interventions. Although ventriculoperitoneal shunting is effective in treating symptomatic chronic hydrocephalus, it carries risks such as infection, obstruction, overdrainage, and the need for revision surgery [7]. A poor clinical grade, a high subarachnoid or intraventricular blood burden, acute hydrocephalus, and the need for EVD are among the factors most frequently associated with shunt dependency [8].

The lamina terminalis is a thin anatomical structure that forms the anterior wall of the third ventricle. When opened microsurgically, it may provide an alternative pathway for cerebrospinal fluid flow between the ventricular system and the basal cisterns [9]. On this anatomical basis, lamina terminalis fenestration (LTF) has been proposed as a means of facilitating cerebrospinal fluid circulation and reducing the risk of chronic hydrocephalus and permanent shunt dependency. Although an early single-center study reported findings favoring LTF [10], subsequent cohort studies and a systematic review failed to demonstrate a consistent reduction in shunt requirements [11, 12]. Studies evaluating combined fenestration techniques and more recent patient series have also yielded heterogeneous results [13, 14].

The primary objective of this study was to evaluate the association between LTF and shunt-dependent hydrocephalus requiring permanent ventriculoperitoneal shunt placement during follow-up in patients who underwent microsurgical clipping for ruptured anterior circulation aneurysms. As a secondary objective, the potential confounding effect of aneurysm location was examined via sequential logistic regression models. The robustness of the findings was further assessed through sensitivity analyses restricted to patients with anterior communicating artery (ACom) aneurysms and those who survived during follow-up.

Methods

This single-center retrospective cohort study evaluated patients who underwent microsurgical treatment for ruptured anterior circulation aneurysms at the Department of Neurosurgery, Çukurova University Faculty of Medicine, between January 2016 and February 2023. The study was conducted in accordance with the principles of the Declaration of Helsinki following approval by the Ethics Committee of Çukurova University Faculty of Medicine, Balcalı Hospital (April 7, 2023; approval no. 132/2).

Patients who presented with a first episode of aneurysmal subarachnoid hemorrhage during the study period and underwent craniotomy and microsurgical clipping of an anterior circulation aneurysm were included. The exclusion criteria were nonaneurysmal subarachnoid hemorrhage, another type of cerebrovascular event, and the absence of microsurgical treatment. Patients who died within the first 14 days after subarachnoid hemorrhage were excluded from the study because of their substantial comorbidity burden, presence of coagulation disorders, development of multiorgan failure, and overall high total mortality rate. Eligible patients were assigned to the LTF or control group according to whether LTF was performed during aneurysm clipping.

Demographic, clinical, laboratory, radiological, and surgical data were obtained from the hospital information management system (Enlil HBYS–Mergentech), medical records, operative reports, intensive care and outpatient records, and archived imaging studies. Post-discharge information was supplemented via institutional records and the Turkish Ministry of Health's e-Nabız personal health record system. The recorded variables included age, sex, aneurysm location, World Federation of Neurosurgical Societies (WFNS) and Hunt–Hess grades, modified Fisher and Barrow Neurological Institute (BNI) grades, modified Graeb score, acute hydrocephalus, external ventricular drainage, intraparenchymal hemorrhage, symptomatic vasospasm, delayed cerebral ischemia, meningitis, mortality during follow-up, and ventriculoperitoneal shunt placement. Noncontrast brain computed tomography (CT) scans obtained at admission were retrospectively assessed for subarachnoid and intraventricular blood burden and hydrocephalus. Subarachnoid blood burden was evaluated via the modified Fisher and BNI grading systems. The BNI grade was assigned on a scale of 1–5 by measuring the maximum thickness of blood within a cistern or fissure on axial CT images, perpendicular to the long axis of the corresponding anatomical structure.

The intraventricular hemorrhage burden was assessed via the modified Graeb score. The amount of blood and accompanying ventricular enlargement in the third and fourth ventricles, lateral ventricles, and occipital and temporal horns were scored separately. The total score ranges from 0 to 32, with higher scores indicating a greater intraventricular blood burden [15]. The modified Graeb score was analyzed as a continuous variable without categorization.

The diagnosis of hydrocephalus was based on clinical findings together with evidence of ventricular enlargement on serial CT examinations. An Evans index > 0.30, enlargement of the temporal horns, periventricular edema, prominence of the frontal horns, and effacement of the cortical sulci were considered supportive radiological findings.

All patients underwent microsurgical aneurysm clipping via craniotomy. In patients who underwent LTF, the lamina terminalis was dissected and exposed after aneurysm clipping. A 6–7-mm opening was created in

its avascular midline portion via a sharp microsurgical instrument or the tip of bipolar forceps, thereby opening the anterior wall of the third ventricle. Successful fenestration was confirmed by observing cerebrospinal fluid flow from the third ventricle. The decision to perform LTF was based on the surgeon's intraoperative assessment, the available surgical exposure, and the anatomical location of the aneurysm. Whether LTF had been performed was verified from the operative reports. For surviving patients, clinical and radiological records available through the hospital information system, outpatient records, and e-Nabız were reviewed for a minimum of six months. Patients who died after the 14th day were followed until the date of death.

Ventricular enlargement detected within the first 72 hours after subarachnoid hemorrhage was classified as acute hydrocephalus, whereas hydrocephalus persisting beyond or newly developing after day 14 was classified as chronic hydrocephalus. The decision to perform EVD was made by the treating surgical team on the basis of the patient's neurological condition, ventricular enlargement, and evidence of increased intracranial pressure. Shunt-dependent chronic hydrocephalus was defined as the placement of a permanent ventriculoperitoneal shunt during follow-up because of clinically and radiologically confirmed hydrocephalus. Neurological deterioration not attributable to an alternative cause, accompanied by ventricular enlargement, and failure of EVD weaning or clamping trials were the principal criteria considered when assessing the need for shunt placement. Radiological ventriculomegaly without corresponding clinical findings and without shunt placement was classified as asymptomatic hydrocephalus.

Study Outcomes

The primary outcome was the development of shunt-dependent chronic hydrocephalus during follow-up among patients who did and did not undergo LTF. The primary analysis evaluated the unadjusted association between LTF and shunt-dependent hydrocephalus. To account for the marked influence of aneurysm anatomy on the decision to perform LTF, the aneurysm location was additionally categorized as the anterior communicating artery (ACom) or other anterior circulation locations. An analysis restricted to patients with ACom aneurysms was conducted as an anatomical sensitivity analysis. To assess the potential influence of deaths during follow-up on the outcome, a second sensitivity analysis was performed after excluding patients whose data were recorded as deceased.

Statistical analysis

Categorical variables are presented as numbers and percentages, whereas continuous variables are summarized as the means±standard deviations or medians (interquartile ranges) according to their distributions. Normality was assessed via the Shapiro–Wilk test. Continuous variables were compared between the LTF groups via Welch's independent-samples *t* test or the Mann–Whitney U test, as appropriate. Categorical variables were compared via Pearson's chi-square test or Fisher's exact test. Rank-biserial correlation was calculated as the effect size for the Mann–Whitney U test. The overall distribution of aneurysm locations and the targeted comparisons between ACom and other anterior circulation locations were evaluated via Fisher's exact test.

In the primary analysis, the rates of shunt-dependent hydrocephalus in the LTF and non-LTF groups were compared via Fisher's exact test. Effect estimates are reported as the absolute risk difference, relative risk, and odds ratio, together with their corresponding 95% confidence intervals.

Three logistic regression models were constructed with shunt-dependent hydrocephalus as the dependent variable. The first model included LTF alone. The second model included LTF and ACom locations, whereas the third model included age, sex, and the dichotomized modified Fisher grade (1–2 vs. 3–4). Because only 19 shunt events were observed, the third model was considered exploratory. The results are reported as odds ratios with 95% confidence intervals. Model fit was assessed via the likelihood-ratio chi-square test and Nagelkerke R^2, whereas multicollinearity was evaluated via the variance inflation factor.

Sensitivity analyses were performed for patients with ACom aneurysms and those who were alive at the end of follow-up. Comparisons other than the primary outcome analysis were considered exploratory, and no adjustment for multiple testing was applied. All tests were two-sided, and $p < 0.05$ was considered statistically significant. Statistical analyses were performed via IBM SPSS Statistics, version 20.0.

Results

A total of 138 patients were included in the study. Of these, 75 (54.3%) were women, and 63 (45.7%) were men, with a mean age of 55.09 ± 13.78 years. Lamina terminalis fenestration was performed in 48 patients (34.8%), whereas 90 patients (65.2%) did not undergo LTF. The aneurysms were located in the anterior communicating artery in 56 patients (40.6%), the middle cerebral artery in 40 patients (29.0%), the internal carotid artery in 21 patients (15.2%), the posterior communicating artery in 12 patients (8.7%), and the anterior cerebral artery in nine patients (6.5%). Among patients who underwent LTF, 42 patients had aneurysms located in the anterior communicating artery; three, the middle cerebral artery; and one, the anterior cerebral, and posterior communicating arteries.

At admission, 89 patients (64.5%) had WFNS grades 1–2, and 80 (58.0%) had Hunt–Hess grades 1–2. The modified Fisher grade was 1–2 in 50 patients (36.2%) and 3–4 in 88 (63.8%). The median modified Graeb score in the overall cohort was 2, with an interquartile range of 8. The detailed distributions of demographic, clinical, and radiological characteristics are presented in Table 1.

Table 1
Demographic, clinical, and radiological characteristics according to LTF status

Variable	Overall N = 138	LTF performed n = 48	LTF not performed n = 90	p
Age, years, mean ± SD	55.09 ± 13.78	58.50 ± 11.66	53.28 ± 14.52	0.024
Sex				**0.029**
Female	75 (54.3)	20 (41.7)	55 (61.1)	
Male	63 (45.7)	28 (58.3)	35 (38.9)	
Aneurysm location				**< 0.001**
ICA	21 (15.2)	1 (2.1)	20 (22.2)	
MCA	40 (29.0)	3 (6.3)	37 (41.1)	
ACA	9 (6.5)	1 (2.1)	8 (8.9)	
ACom	56 (40.6)	42 (87.5)	14 (15.6)	
PCom	12 (8.7)	1 (2.1)	11 (12.2)	
WFNS				**0.831**
GCS 15, no deficit	56 (40.6)	19 (39.6)	37 (41.1)	
GCS 13–14, no deficit	33 (23.9)	14 (29.2)	19 (21.1)	
GCS 13–14, deficit present	12 (8.7)	3 (6.3)	9 (10.0)	
GCS 7–12	29 (21.0)	9 (18.8)	20 (22.2)	
GCS 3–6	8 (5.8)	3 (6.3)	5 (5.6)	
Hunt–Hess				**0.478**
Grade 1	23 (16.7)	6 (12.5)	17 (18.9)	
Grade 2	57 (41.3)	19 (39.6)	38 (42.2)	
Grade 3	26 (18.8)	13 (27.1)	13 (14.4)	

Abbreviations: ACA, anterior cerebral artery; ACom, anterior communicating artery; BNI, Barrow Neurological Institute; CI, confidence interval; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; ICA, internal carotid artery; IQR, interquartile range; LTF, lamina terminalis fenestration; MCA, middle cerebral artery; PCom, posterior communicating artery; SD, standard deviation; WFNS, World Federation of Neurosurgical Societies. Data are presented as the n (%), mean ± SD, or median (IQR). Welch's t test was used for age, the Mann–Whitney U test was used for the modified Graeb score, and Pearson's chi-square test or Fisher's exact test was used for categorical variables. The overall distribution of aneurysm locations was compared via Fisher's exact test ($p < 0.001$). The clinically prespecified targeted comparison of ACom versus other locations also revealed a significant difference in distribution (Fisher's exact test, $p < 0.001$).

Variable	Overall N = 138	LTF performed n = 48	LTF not performed n = 90	p
Grade 4	26 (18.8)	8 (16.7)	18 (20.0)	
Grade 5	6 (4.3)	2 (4.2)	4 (4.4)	
Modified Fisher grade				**0.319**
Grade 1	39 (28.3)	12 (25.0)	27 (30.0)	
Grade 2	11 (8.0)	6 (12.5)	5 (5.6)	
Grade 3	45 (32.6)	18 (37.5)	27 (30.0)	
Grade 4	43 (31.2)	12 (25.0)	31 (34.4)	
BNI grade				**0.674**
No blood	41 (29.7)	16 (33.3)	25 (27.8)	
<5 mm	26 (18.8)	6 (12.5)	20 (22.2)	
5–10 mm	32 (23.2)	11 (22.9)	21 (23.3)	
10–15 mm	27 (19.6)	11 (22.9)	16 (17.8)	
>15 mm	12 (8.7)	4 (8.3)	8 (8.9)	
Modified Graeb score, median (IQR)	2 (8)	4 (8)	2 (7)	0.028
Intraparenchymal hemorrhage				**0.926**
Present	31 (22.5)	11 (22.9)	20 (22.2)	
Absent	107 (77.5)	37 (77.1)	70 (77.8)	
Acute hydrocephalus				**0.453**
Present	35 (25.4)	14 (29.2)	21 (23.3)	
Absent	103 (74.6)	34 (70.8)	69 (76.7)	
EVD				**0.315**

Abbreviations: ACA, anterior cerebral artery; ACom, anterior communicating artery; BNI, Barrow Neurological Institute; CI, confidence interval; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; ICA, internal carotid artery; IQR, interquartile range; LTF, lamina terminalis fenestration; MCA, middle cerebral artery; PCom, posterior communicating artery; SD, standard deviation; WFNS, World Federation of Neurosurgical Societies. Data are presented as the n (%), mean ± SD, or median (IQR). Welch's t test was used for age, the Mann–Whitney U test was used for the modified Graeb score, and Pearson's chi-square test or Fisher's exact test was used for categorical variables. The overall distribution of aneurysm locations was compared via Fisher's exact test ($p < 0.001$). The clinically prespecified targeted comparison of ACom versus other locations also revealed a significant difference in distribution (Fisher's exact test, $p < 0.001$).

Variable	Overall N = 138	LTF performed n = 48	LTF not performed n = 90	p
Present	28 (20.3)	12 (25.0)	16 (17.8)	
Absent	110 (79.7)	36 (75.0)	74 (82.2)	
Vasospasm				**0.625**
Present	48 (34.8)	18 (37.5)	30 (33.3)	
Absent	90 (65.2)	30 (62.5)	60 (66.7)	
Meningitis				**0.058**
Present	28 (20.3)	14 (29.2)	14 (15.6)	
Absent	110 (79.7)	34 (70.8)	76 (84.4)	
Delayed ischemia				**0.465**
Present	49 (35.5)	19 (39.6)	30 (33.3)	
Absent	89 (64.5)	29 (60.4)	60 (66.7)	

Abbreviations: ACA, anterior cerebral artery; ACom, anterior communicating artery; BNI, Barrow Neurological Institute; CI, confidence interval; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; ICA, internal carotid artery; IQR, interquartile range; LTF, lamina terminalis fenestration; MCA, middle cerebral artery; PCom, posterior communicating artery; SD, standard deviation; WFNS, World Federation of Neurosurgical Societies. Data are presented as the n (%), mean ± SD, or median (IQR). Welch's t test was used for age, the Mann–Whitney U test was used for the modified Graeb score, and Pearson's chi-square test or Fisher's exact test was used for categorical variables. The overall distribution of aneurysm locations was compared via Fisher's exact test ($p < 0.001$). The clinically prespecified targeted comparison of ACom versus other locations also revealed a significant difference in distribution (Fisher's exact test, $p < 0.001$).

During follow-up, acute hydrocephalus was identified in 35 patients (25.4%), external ventricular drainage was required in 28 (20.3%), vasospasm occurred in 48 (34.8%), meningitis in 28 (20.3%), and radiographic delayed ischemia in 49 (35.5%). Patients who died within the first 14 days after subarachnoid hemorrhage were excluded from the study; among those included in the analytical cohort, 39 patients (28.3%) died during follow-up.

The mean age was 58.50 ± 11.66 years in the LTF group and 53.28 ± 14.52 years in the non-LTF group. The difference in mean age was statistically significant (Welch's $t(115.2) = 2.30$; $p = 0.024$). Men accounted for 58.3% of the LTF group and 38.9% of the non-LTF group ($p = 0.029$). The overall distribution of aneurysm locations differed between the LTF groups (Fisher's exact test, $p < 0.001$). ACom aneurysms accounted for 87.5% of the cases in the LTF group and 15.6% of those in the non-LTF group; the targeted comparison between ACom and other anterior circulation locations was also significant (Fisher's exact test, $p < 0.001$). The median modified Graeb score was 4 (IQR = 8) in the LTF group and 2 (IQR = 7) in the non-LTF group (Mann–Whitney U = 1676; $p = 0.028$; rank-biserial correlation = 0.224). The distributions of WFNS, Hunt–Hess, modified Fisher, and BNI grades, as well as the rates of intraparenchymal hemorrhage, acute

hydrocephalus, EVD placement, vasospasm, meningitis, and delayed ischemia, did not differ significantly between the LTF groups (all $p > 0.05$).

Shunt-dependent hydrocephalus developed in 19 patients (13.8%). A VP shunt was placed in eight of 48 patients (16.7%) in the LTF group and 11 of 90 patients (12.2%) in the non-LTF group. The absolute risk difference between the groups was 4.4 percentage points (95% CI, − 8.1–17.0). No statistically significant between-group difference was identified (RR = 1.36; 95% CI, 0.59–3.16; OR = 1.44; 95% CI, 0.54–3.85; Fisher's exact test, $p = 0.605$) (Table 2).

Table 2
Associations between LTF and shunt-dependent hydrocephalus: primary and sensitivity analyses

Analysis	LTF performed: shunt/n (%)	LTF not performed: shunt/n (%)	Risk difference, % (95% CI)	RR (95% CI)	OR (95% CI)	p*
Overall cohort (N = 138)	8/48 (16.7)	11/90 (12.2)	4.4 (− 8.1 to 17.0)	1.36 (0.59–3.16)	1.44 (0.54–3.85)	0.605
ACom subgroup (N = 56)	7/42 (16.7)	4/14 (28.6)	−11.9 (− 38.1 to 14.3)	0.58 (0.20–1.70)	0.50 (0.12–2.06)	0.439
Surviving patients (N = 99)	5/32 (15.6)	8/67 (11.9)	3.7 (− 11.1 to 18.5)	1.31 (0.47–3.68)	1.37 (0.41–4.56)	0.751

Abbreviations: ACom, anterior communicating artery; CI, confidence interval; LTF, lamina terminalis fenestration; OR, odds ratio; RR, relative risk. The risk difference was calculated as LTF performed minus LTF not performed. *Fisher's exact test was used. Patients coded as deceased were excluded from the surviving-patient analysis.

In the analysis of the 56 patients with ACom aneurysms, shunt-dependent hydrocephalus developed in seven of 42 patients (16.7%) who underwent LTF and four of 14 patients (28.6%) who did not. The absolute risk difference was − 11.9 percentage points (95% CI, − 38.1–14.3), the RR was 0.58 (95% CI, 0.20–1.70), and the OR was 0.50 (95% CI, 0.12–2.06). The between-group difference was not statistically significant (Fisher's exact test, $p = 0.439$). In the sensitivity analysis, which was restricted to the 99 patients who were alive at the end of follow-up, the shunt placement rate was 15.6% (5/32) in the LTF group and 11.9% (8/67) in the non-LTF group. In this analysis, the absolute risk difference was 3.7 percentage points (95% CI, − 11.1–18.5), the RR was 1.31 (95% CI, 0.47–3.68), and the OR was 1.37 (95% CI, 0.41–4.56) (Fisher's exact test, $p = 0.751$) (Table 2).

The results of the overall unadjusted logistic regression model were not statistically significant (likelihood ratio $\chi^2(1) = 0.509$; $p = 0.476$; Nagelkerke $R^2=0.007$; AIC = 114). In this model, the OR for LTF was 1.44 (95% CI, 0.54–3.85; $p = 0.472$). The second model, which additionally included aneurysm location categorized as ACom versus other anterior circulation locations, was also not significant overall ($\chi^2(2) = 3.01$; $p = 0.222$; Nagelkerke $R^2=0.039$; AIC = 114). In the second model, the OR was 0.68 for LTF (95% CI, 0.18–2.56; $p = 0.569$) and 2.92 for ACom location (95% CI, 0.79–10.80; $p = 0.109$).

The overall test of the expanded exploratory model, which additionally included age, sex, and the dichotomized modified Fisher grade, was statistically significant (likelihood ratio $\chi^2(5) = 15.1$; $p = 0.010$; Nagelkerke R^2=0.188; AIC = 107). In this model, the OR was 0.76 for LTF (95% CI, 0.20–2.95; $p = 0.690$), 3.26 for ACom location (95% CI, 0.82–13.00; $p = 0.094$), 0.67 for male sex (95% CI, 0.22–2.01; $p = 0.471$), 13.79 for modified Fisher grades 3–4 (95% CI, 1.74–109.18; $p = 0.013$), and 1.00 for each one-year increase in age (95% CI, 0.96–1.04; $p = 0.825$). All variance inflation factor values were less than 2 across the models (Table 3).

Table 3
Logistic regression models for shunt-dependent hydrocephalus

Model	Variable	OR	95% CI	p
Model 1	LTF performed (reference: not performed)	1.44	0.54–3.85	0.472
Model 2	LTF performed (reference: not performed)	0.68	0.18–2.56	0.569
	ACom (reference: other locations)	2.92	0.79–10.80	0.109
Model 3	LTF performed (reference: not performed)	0.76	0.20–2.95	0.690
	ACom (reference: other locations)	3.26	0.82–13.00	0.094
	Male sex (reference: female)	0.67	0.22–2.01	0.471
	Modified Fisher grade 3–4 (reference: 1–2)	13.79	1.74–109.18	0.013
	Age, per 1-year increase	1.00	0.96–1.04	0.825

The dependent variable was the presence of shunt-dependent hydrocephalus. Model 1: AIC = 114, likelihood ratio $\chi^2(1) = 0.509$, p = 0.476, Nagelkerke R^2=0.007. Model 2: AIC = 114, $\chi^2(2) = 3.01$, p = 0.222, Nagelkerke R^2=0.039. Model 3: AIC = 107, $\chi^2(5) = 15.1$, p = 0.010, Nagelkerke R^2=0.188. Because Model 3 included only 19 events and five coefficients, it should be considered exploratory. Abbreviations: ACom, anterior communicating artery; AIC, Akaike information criterion; CI, confidence interval; LTF, lamina terminalis fenestration; OR, odds ratio.

Discussion

In this single-center retrospective cohort, no significant association was identified between LTF performed during microsurgical clipping of ruptured anterior circulation aneurysms and shunt-dependent hydrocephalus. The shunt placement rate was 16.7% among patients who underwent LTF and 12.2% among those who did not (RR = 1.36; OR = 1.44). However, the wide confidence intervals and the fact that the absolute risk difference encompassed the possibility of both benefit and harm precluded the exclusion of a clinically meaningful effect. Therefore, these findings should not be interpreted as demonstrating that LTF is ineffective; rather, a protective effect could not be established in this cohort.

The use of LTF was strongly associated with aneurysm location. ACom aneurysms accounted for 87.5% of the cases in the LTF group but only 15.6% of those in the non-LTF group. This marked imbalance suggests

that the decision to perform LTF may have been influenced by anatomical location, surgical accessibility, and surgeon preference. In the analysis restricted to patients with ACom aneurysms, the shunt placement rate was numerically lower among those who underwent LTF (16.7% vs. 28.6%), although the difference was not statistically significant. Because this analysis included only 56 patients and 11 shunt events and yielded a wide confidence interval for the RR (95% CI, 0.20–1.70), it does not permit a reliable conclusion regarding a protective effect.

When the aneurysm location was added to the model, the OR for LTF shifted from 1.44 to 0.68, suggesting that the unadjusted association was influenced by treatment selection confounding. The exploratory model incorporating age, sex, and modified Fisher grade similarly produced a nonsignificant estimate in favor of LTF. Nevertheless, residual confounding due to unmeasured factors, including surgeon preference and undocumented anatomical characteristics, cannot be excluded. Thus, the reversal in the direction of the adjusted estimates should not be regarded as evidence of benefit from LTF; instead, it highlights the sensitivity of the unadjusted result to patient selection.

The sensitivity analysis of the 99 patients who were alive at the end of follow-up also revealed no significant between-group differences (15.6% vs. 11.9%; RR = 1.31; OR = 1.37). This finding suggests that the primary result was not attributable solely to deaths during follow-up. However, because an analysis limited to survivors is susceptible to selection bias, it should be regarded as a complementary assessment of the consistency of the findings rather than an alternative to the primary analysis.

In a retrospective study of 369 patients by Komotar et al., shunt-dependent hydrocephalus occurred in 25% of patients who underwent LTF and 20% of those who did not, with no statistically significant difference between the groups. In the matched analysis, the corresponding shunt rates were 29% and 20%, respectively [11]. A systematic review conducted by the same research group likewise failed to demonstrate that LTF consistently reduced the occurrence of shunt-dependent hydrocephalus [12]. Similarly, in a retrospective study of 151 surgically treated patients with aneurysmal subarachnoid hemorrhage, Tabibkhooei et al. performed LTF in 36 patients and reported no significant association between LTF and shunt-requiring hydrocephalus [16]. Ayyad et al. retrospectively evaluated 113 patients who underwent microsurgical clipping, 84 of whom underwent lamina terminalis opening. Although all four ventriculoperitoneal shunts were placed in the LTF group, the difference was not statistically significant (4.8% vs. 0%; $p = 0.57$). Postoperative hydrocephalus rates were also similar between the groups (35.7% vs. 34.5%; $p = 1.00$) [17]. These studies are consistent with our finding that a reduction in shunt requirements associated with LTF could not be demonstrated. Nevertheless, the observational designs of both the previous studies and the present investigation prevent the effects of treatment selection on the outcomes from being fully excluded.

Conversely, an earlier study by Komotar et al. reported findings favoring LTF [10]. In the series by Lehto et al., in which a catheter was advanced into the third ventricle through the fenestrated lamina terminalis, no significant association was identified between LTF and shunt requirements [18]. Jiang et al. reported a lower shunt rate in patients who underwent combined fenestration of the lamina terminalis and the membrane of Liliequist than in those treated with clipping alone or clipping with LTF. Because combined

opening of the lamina terminalis and the membrane of Liliequist represents a different surgical intervention from LTF alone, the findings of combined fenestration studies should not be considered directly comparable with those of the present cohort [13].

In a retrospective study of 77 patients who underwent microsurgical clipping for anterior circulation aneurysms, Iqbal et al. reported lower rates of shunt-dependent hydrocephalus associated with LTF, particularly among patients with high Fisher grades. However, the single-center retrospective design, limited sample size, and insufficient control of potential confounding variables warrant cautious interpretation of these findings [14]. Differences across studies may be attributable to variations in patient selection, aneurysm location, hemorrhage severity, fenestration technique, criteria for performing LTF, and institutional practices governing shunt placement.

The overall shunt rate of 13.8% in our cohort was comparable to the 13% rate reported by Paisan et al. in a series of 888 patients [19]. In contrast, the shunt rate was 31.2% in the BRAT analysis of 471 patients conducted by Zaidi et al. [20] and 17.7% among patients who survived for at least 14 days in a multicenter study of 1,533 patients by Adams et al. [21]. These variations may be related to differences in patient selection, hemorrhage severity, inclusion of posterior circulation aneurysms, treatment modality, criteria for EVD and shunt placement, and early mortality. In the present study, excluding patients who died within the first 14 days after subarachnoid hemorrhage may have influenced both the overall shunt rate and its comparability with rates reported in other studies.

In the exploratory multivariable model, modified Fisher grades 3–4 were associated with shunt requirements. The direction of the association between a high subarachnoid blood burden and shunt dependency is biologically and clinically consistent with the findings of previous meta-analyses [8]. However, the wide 95% confidence interval around the OR estimate of 13.79 (1.74–109.18) indicates substantial statistical uncertainty. Because the model included five coefficients but only 19 shunt events, this finding should be regarded as hypothesis-generating and exploratory rather than as evidence of a confirmed independent predictor. Likewise, the absence of significant associations for age and sex should not be interpreted as evidence that these variables have no potential effect, given the limited statistical power.

Previous large cohorts have suggested that posterior circulation aneurysms, in particular, may be associated with an increased risk of shunt dependency [20, 22]. Because the present study included only anterior circulation aneurysms, the potential influence of posterior circulation location could not be evaluated. In this cohort, however, the principal importance of aneurysm location was not its direct association with shunt outcome but its role as a treatment-selection confounder that strongly influenced whether LTF was performed.

The current American Heart Association/American Stroke Association guidelines recommend urgent cerebrospinal fluid diversion for acute symptomatic hydrocephalus after aneurysmal subarachnoid hemorrhage and permanent cerebrospinal fluid diversion for chronic symptomatic hydrocephalus. LTF is not a standard or routine preventive strategy for reducing shunt-dependent hydrocephalus [3]. The present study likewise provides no evidence to support the routine use of LTF solely to reduce the need for shunt

placement. Nevertheless, because of the limited number of outcome events and the wide confidence intervals, the possibility of either benefit or harm cannot be conclusively excluded.

Strengths

One of the strengths of this study is its focus on a relatively homogeneous cohort of patients with anterior circulation aneurysms who underwent microsurgical treatment at the same center over a period exceeding seven years. Clearly, defining the primary outcome as permanent VP shunt placement provided a clinically meaningful outcome measure that could be reliably verified from patient records. Reporting the association between LTF and shunt placement via the absolute risk difference, RR, OR, and 95% confidence intervals, rather than relying solely on *p* values, enabled the magnitude of the association and its statistical uncertainty to be evaluated together.

The strong association between LTF use and aneurysm location clarified why the unadjusted group comparison could not be interpreted as a causal effect. Addressing this issue through both a sensitivity analysis restricted to ACom aneurysms and sequential logistic regression models incorporating aneurysm location represents another strength of the study. In addition, the sensitivity analysis restricted to surviving patients allowed assessment of the potential influence of mortality and the opportunity to undergo shunt placement during follow-up on the primary finding.

Limitations

The principal limitations of this study are its retrospective, single-center design and the absence of standardized indications for LTF. Because the decision to perform LTF was influenced by the aneurysm location and surgeon preference, treatment selection bias may have occurred, particularly given the marked imbalance in the distribution of ACom aneurysms between the groups. Despite statistical adjustment, residual confounding due to unmeasured anatomical and intraoperative variables cannot be excluded. The small number of shunt events (n = 19) reduced the precision of the effect estimates and increased the risk of overfitting in the multivariable model; therefore, the model should be considered exploratory. Furthermore, excluding patients who died within the first 14 days may have introduced survival bias. The lack of fully standardized and detailed documentation of both the indications for shunt placement and the LTF technique also limits the generalizability of the findings. For these reasons, the observed associations should not be interpreted as causal.

Conclusion

In patients who underwent microsurgical clipping for ruptured anterior circulation aneurysms, lamina terminalis fenestration was not independently associated with the development of shunt-dependent chronic hydrocephalus. Neither the unadjusted analyses nor the models adjusted for aneurysm location and the sensitivity analyses demonstrated a reduction in shunt requirement associated with LTF. Nevertheless, the limited number of outcome events, wide confidence intervals, and strong association between the use of LTF and aneurysm location prevent the possibility of clinically relevant benefit or harm from being

conclusively excluded. These findings do not support the routine use of LTF solely to prevent shunt-dependent hydrocephalus. Prospective, multicenter studies with standardized surgical indications and adequate sample sizes are needed to establish the effectiveness of LTF.

Abbreviations

LTF
lamina terminalis fenestration
aSAH
aneurysmal subarachnoid hemorrhage
EVD
external ventricular drainage
RD
risk difference
OD
odds ratio
RR
relative risk
CI
confidence interval
AIC
Akeike information criterion
SD
standard deviation
IQR
interquartile range
GCS
Glasgow Coma Scale
CT
computed tomography
ICA
internal carotid artery
Acom
anterior communicating artery
MCA
middle cerebral artery
ACA
anterior cerebral artery
Pcom
posterior communicating artery
BNI

Barrow Neurological Institute
VP
ventriculoperitoneal
WFNS
World Federation of Neurosurgical Societies

Declarations

Compliance with Ethical Standards:

Funding

Disclosure of potential conflicts of interest:

All the authors certify that they have no conflicts of interest related to any part of this study.

Ethical approval and consent to participate:

The study was conducted in accordance with the principles of the Declaration of Helsinki following approval by the Ethics Committee of Çukurova University Faculty of Medicine, Balcalı Hospital (April 7, 2023; approval no. 132/2). All participants provided written informed consent prior to inclusion in the study.

Author Contribution

O.B. contributed to the design of this study, the determination of which data would be collected, the literature review, and the writing of the manuscript.F.İ contributed to the design of this and the manuscript editing process.M.T. contributed to design of this study.K.M.Ö. was one of the surgeons who performed these surgeries and contributed the literatüre review.A.U.K. contributed to the data collection and data processing part of the study.H.E.A. contributed to the data collection and data processing part of the study.

Acknowledgments:

None

Data Availability

A dataset relevant to this study is available and can be provided. It can be accessed through the link below.https://1drv.ms/u/c/87bd763f07c8bb5b/IQBbu8gHP3a9IICHGRsAAAAAAb9hFsQpqbkrYkvcp4HrRpU

References

1. Macdonald RL, Schweizer TA. Spontaneous subarachnoid hemorrhage. Lancet. 2017;389(10069):655–66. 10.1016/S0140-6736(16)30668-7.
2. Nieuwkamp DJ, Setz LE, Algra A, Linn FHH, de Rooij NK, Rinkel GJE. Changes in case fatality of aneurysmal subarachnoid hemorrhage over time, according to age, sex, and region: a meta-analysis. Lancet Neurol. 2009;8(7):635–42. 10.1016/S1474-4422(09)70126-7.
3. Hoh BL, Ko NU, Amin-Hanjani S, et al. 2023 Guideline for the Management of Patients With Aneurysmal Subarachnoid Hemorrhage: A Guideline From the American Heart Association/American Stroke Association. Stroke. 2023;54(7):e314–70. 10.1161/STR.0000000000000436.
4. Shapey J, Toma AK, Saeed SR. Physiology of cerebrospinal fluid circulation. Curr Opin Otolaryngol Head Neck Surg. 2019;27(5):326–33.
5. Yamada S, Kelly E. Cerebrospinal fluid dynamics and the pathophysiology of hydrocephalus: new concepts. Semin Ultrasound CT MR. 2016;37(2):84–91.
6. van Gijn J, Hijdra A, Wijdicks EFM, Vermeulen M, van Crevel H. Acute hydrocephalus after aneurysmal subarachnoid hemorrhage. J Neurosurg. 1985;63(3):355–62.
7. O'Kelly CJ, Kulkarni AV, Austin PC, Urbach D, Wallace MC. Shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage: incidence, predictors, and revision rates. J Neurosurg. 2009;111(5):1029–35. 10.3171/2008.9.JNS08881.
8. Wilson CD, Safavi-Abbasi S, Sun H, et al. Meta-analysis and systematic review of risk factors for shunt dependency after aneurysmal subarachnoid hemorrhage. J Neurosurg. 2017;126(2):586–95. 10.3171/2015.11.JNS152094.
9. de Divitiis O, Angileri FF, d'Avella D, Tschabitscher M, Tomasello F. Microsurgical anatomic features of the lamina terminalis. Neurosurgery. 2002;50(3):563–9.
10. Komotar RJ, Olivi A, Rigamonti D, et al. Microsurgical fenestration of the lamina terminalis reduces the incidence of shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage. Neurosurgery. 2002;51(6):1403–12.
11. Komotar RJ, Hahn DK, Kim GH, et al. The impact of microsurgical fenestration of the lamina terminalis on shunt-dependent hydrocephalus and vasospasm after aneurysmal subarachnoid hemorrhage. Neurosurgery. 2008;62(1):123–34. 10.1227/01.NEU.0000311069.48862.C8.
12. Komotar RJ, Hahn DK, Kim GH, et al. Efficacy of lamina terminalis fenestration in reducing shunt-dependent hydrocephalus following aneurysmal subarachnoid hemorrhage: a systematic review. J Neurosurg. 2009;111(1):147–54. 10.3171/2009.1.JNS0821.
13. Jiang W, You L, Hu D. Effect of combined fenestration of lamina terminalis and Liliequist membrane during surgical clipping on the incidence of chronic hydrocephalus in patients with anterior circulation ruptured aneurysms. Clin Neurol Neurosurg. 2023;225:107580. 10.1016/j.clineuro.2022.107580.
14. Iqbal IK, Ansari N, Subhan M, et al. Outcomes of Fenestration of Lamina Terminalis for Hydrocephalus Following Clipping of Ruptured Aneurysms of Anterior Circulation. Pak J Med Sci. 2024;40(12):S37–40. 10.12669/pjms.40.12(PINS).11122.
15. Morgan TC, Dawson J, Spengler D, et al. The modified Graeb score: an enhanced tool for intraventricular hemorrhage measurement and prediction of functional outcome. Stroke.

2013;44(3):635–41.

16. Tabibkhooei A, Azar M, Taheri M, Ghalaenovi H, Fattahi A, Kheradmand H. Effect of microscopic third ventriculostomy (lamina terminalis fenestration) on shunt-needed hydrocephalus in patients with aneurysmal subarachnoid hemorrhage. Prague Med Rep. 2021;122(1):14–24. 10.14712/23362936.2021.2.
17. Ayyad A, Khan MM, Msheik A, Shah N, Hussein M, Eid A, et al. Assessing the influence of lamina terminalis opening in aneurysm surgery: clinical outcomes and ventriculoperitoneal shunt insertion rates. Cureus. 2025;17(12):e99425. 10.7759/cureus.99425.
18. Lehto H, Dashti R, Karatas A, Niemela M, Hernesniemi JA. Third ventriculostomy through the fenestrated lamina terminalis during microneurosurgical clipping of intracranial aneurysms: an alternative to conventional ventriculostomy. Neurosurgery. 2009;64(3):430–4. 10.1227/01.NEU.0000338433.81852.75.
19. Paisan GM, Ding D, Starke RM, Crowley RW, Liu KC. Shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage: predictors and long-term functional outcomes. Neurosurgery. 2018;83(3):393–402. 10.1093/neuros/nyx393.
20. Zaidi HA, Montoure A, Elhadi A, Nakaji P, McDougall CG, Albuquerque FC, et al. Long-term functional outcomes and predictors of shunt-dependent hydrocephalus after treatment of ruptured intracranial aneurysms in the BRAT trial: revisiting the clip vs coil debate. Neurosurgery. 2015;76(5):608–15. 10.1227/NEU.0000000000000677.
21. Adams H, Ban VS, Leinonen V, Aoun SG, Huttunen J, Saavalainen T, et al. Risk of shunting after aneurysmal subarachnoid hemorrhage: a collaborative study and initiation of a consortium. Stroke. 2016;47(10):2488–96. 10.1161/STROKEAHA.116.013739.
22. Jabbarli R, Bohrer AM, Pierscianek D, Müller D, Wrede KH, Dammann P, et al. The CHESS score: a simple tool for early prediction of shunt dependency after aneurysmal subarachnoid hemorrhage. Eur J Neurol. 2016;23(5):912–8. 10.1111/ene.12962.