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Article

Effects of lumbar cerebrospinal fluid drainage on infection, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus and mortality among patients with aneurismal subarachnoid hemorrhage

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Abstract: Lumbar drainage (LD) has been proposed as a treatment to remove blood from the subarachnoid space in subarachnoid hemorrhage (SAH), but its effects on outcomes in aneurysmal SAH (aSAH) remain debated. This study analyzes the impact of continuous lumbar cerebrospinal fluid (CSF) drainage on infection, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus, and mortality in aSAH patients. A systematic search across PubMed, Web of Science, Embase, Elsevier Science Direct, and Springer Link identified 11 studies with 2059 patients for meta-analysis. The study evaluates the association between lumbar CSF drainage and clinical outcomes, considering how changes in intracranial pressure (ICP) and CSF dynamics may influence pathophysiology in aSAH. The pooled odds ratio (OR) for infection, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus, and mortality in the lumbar drainage group was 1.17 (95% CI: 0.81–1.70; $P = 0.39$), 0.75 (95% CI: 0.37–1.54; $P = 0.44$), 0.60 (95% CI: 0.48–0.75; $P < 0.00001$), 0.48 (95% CI: 0.35–0.64; $P < 0.00001$), 0.53 (95% CI: 0.22–1.24; $P = 0.14$), and 0.55 (95% CI: 0.36–0.84; $P = 0.005$), respectively, compared with the no-lumbar drainage group. Results indicate that lumbar CSF drainage does not significantly affect the occurrence of infection, rebleeding, or hydrocephalus. However, it reduces clinical vasospasm, cerebral infarction, and mortality, likely due to improved ICP management and enhanced cerebral perfusion. These findings suggest that continuous lumbar CSF drainage may benefit aSAH patients by mitigating ischemic injury, but further studies are needed to confirm its broader applicability and long-term effects on outcomes.

Keywords: subarachnoid hemorrhage; lumbar drainage; infection; rebleeding; vasospasm

1. Introduction

Subarachnoid hemorrhage is a serious neurological condition and a significant cause of stroke, accounting for 5% to 10% of all strokes. Aneurysms are responsible for 85% of SAH cases [1], with the rupture of an aneurysm representing a life-threatening event that can lead to numerous complications, including rebleeding, ICP, hydrocephalus, delayed ischemic neurological deficits (DIND), and cerebral infarction due to vasospasm. Effective management of aSAH requires prompt and well-coordinated intervention to minimize these risks and improve patient outcomes [2,3]. From a biomechanical perspective, the pathophysiology of aSAH involves complex alterations in intracranial dynamics, including shifts in ICP, cerebrospinal fluid (CSF) flow, and cerebral perfusion pressure (CPP). These biomechanical changes are central to the development of secondary brain injuries and influence clinical outcomes [4]. The brain operates in a delicate biomechanical environment,

where the balance between intracranial volume components—blood, CSF, and brain tissue—plays a key role in maintaining optimal brain function. When an aneurysm ruptures, blood enters the subarachnoid space, disrupting this balance and elevating ICP, which can compress brain tissue, impede blood flow, and lead to ischemia [5–7]. Furthermore, the presence of blood in the CSF triggers inflammatory responses, which can cause vasospasm, a narrowing of cerebral vessels that compromises blood flow to the brain, leading to DIND and cerebral infarction. One of the immediate and critical concerns in the management of aSAH is the risk of rebleeding, which significantly contributes to morbidity and mortality. Rebleeding not only exacerbates the mechanical stress on the brain but also increases ICP, which can impair cerebral perfusion and lead to further ischemic damage. Another biomechanical consideration is the development of hydrocephalus, a condition in which the CSF accumulates in the ventricles, increasing ICP and further impeding brain function. Elevated ICP and hydrocephalus can exacerbate neurological damage, making it essential to control and regulate CSF flow in these patients. The role of cerebral vasospasm in aSAH is another key biomechanical challenge. After the initial hemorrhage, blood in the subarachnoid space triggers a cascade of events that can lead to the constriction of the cerebral arteries. This vasospasm is associated with impaired cerebral blood flow, leading to DIND, which can result in significant neurological deficits, including ischemia and infarction. The exact biomechanical mechanisms behind vasospasm are complex, but it is believed that the blood products in the CSF cause endothelial dysfunction, smooth muscle contraction, and altered nitric oxide signaling, all of which contribute to the narrowing of blood vessels. Given these biomechanical concerns, the timely removal of blood from the subarachnoid space is an essential intervention to mitigate the risks associated with aSAH. Removing blood can reduce the inflammatory response, lower the risk of vasospasm, and improve the mechanical environment of the brain, thus reducing secondary damage such as ischemia. Various techniques for removing blood from the subarachnoid space include flushing blood from the basal cisterns, creating openings in the lamina terminalis, administering plasminogen activators intrathecally, and implementing external drainage systems. Among these methods, lumbar drainage (LD) has gained attention for its potential to manage CSF dynamics and reduce ICP in a non-invasive manner. Lumbar drainage offers a biomechanical approach to managing aSAH by allowing controlled removal of CSF from the lumbar cistern, thus reducing ICP and mitigating the risk of hydrocephalus. By facilitating the drainage of CSF, LD helps maintain a balance between the brain's intracranial components, potentially improving cerebral perfusion and reducing the mechanical stress on the brain [8]. Additionally, lumbar drainage may help remove subarachnoid blood through gravitational forces, particularly when the blood is anatomically linked to the spinal cisterns. This could potentially lower the risk of vasospasm by reducing the amount of irritant blood in the CSF. However, despite its potential benefits, LD is not without risks. The procedure involves the insertion of a catheter into the lumbar cistern, which carries potential complications such as infection, persistent CSF leakage, and neurological deficits caused by damage to lumbar nerves or the conus medullaris. The biomechanical impact of these risks should be carefully considered, as infections or CSF leakage can alter the pressure dynamics of the subarachnoid space, exacerbating

the patient's condition. Furthermore, mechanical injury to the lumbar region could lead to long-term complications, including motor or sensory deficits. This study aims to systematically evaluate the role of lumbar CSF drainage in managing the biomechanical environment after aSAH, with a particular focus on its impact on clinical outcomes such as CSF or exit-site infections, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus, and mortality. By incorporating a biomechanical perspective, this research seeks to deepen our understanding of how lumbar drainage interacts with the brain's mechanical environment, including ICP, CSF dynamics, and cerebral perfusion. By better understanding these relationships, clinicians can make more informed decisions about the use of lumbar drainage in aSAH treatment, optimizing patient care and improving outcomes. Ultimately, through a comprehensive analysis of both the benefits and risks associated with lumbar drainage, this study seeks to provide valuable insights for clinicians. A biomechanical approach to treating aSAH, which takes into account the intricate balance between CSF pressure, cerebral blood flow, and the mechanical properties of the brain, can help refine treatment strategies and enhance patient recovery.

2. Method

2.1. Literature search

In conducting the literature review for this analysis, we employed a systematic approach to identify relevant studies on aSAH and the use of LD as a treatment modality. The primary search terms included "aneurysm," "subarachnoid hemorrhage," "lumbar drainage," "cerebrospinal fluid drainage," "infection," "rebleeding," "vasospasm," "delayed ischemic neurological deficit," "cerebral infarction," "hydrocephalus," and "mortality." These keywords were specifically selected to encompass a wide array of topics related to the pathophysiology, complications, and management of aSAH, as well as the potential role of lumbar drainage in mitigating these complications. To ensure a comprehensive review, we conducted a broad search across multiple academic databases, including PubMed, Web of Science, Embase, and Elsevier Science Direct, focusing on peer-reviewed articles published within the past two decades. Additionally, we examined the reference lists of key articles to identify studies that may have been overlooked in the initial database search. This step was crucial in capturing any relevant literature not immediately apparent from the online search results. In order to incorporate the most current and emerging findings, we also explored ongoing clinical trials related to lumbar drainage and aSAH. This inclusion of trial data helped to integrate cutting-edge evidence into the analysis. By combining database searches, reference reviews, and trial investigations, this multi-source approach strengthened the comprehensiveness and depth of the literature review, ensuring a robust analysis of the existing evidence on lumbar drainage in the management of aSAH.

2.2. Inclusion and exclusion criteria

The following inclusion criteria were applied to select relevant comparative studies for the analysis: (1) the study design should be a randomized clinical trial,

prospective cohort study, or retrospective cohort study that specifically investigates the use of lumbar cerebrospinal fluid drainage in patients with aSAH; (2) the study should include a minimum of 10 participants to ensure adequate sample size for statistical power; and (3) studies must be published in English and involve human subjects. These criteria were established to focus on high-quality clinical evidence directly related to the outcomes of lumbar CSF drainage in the treatment of aSAH. Exclusion criteria were applied to filter out studies that did not meet the standards for inclusion. Specifically, the following types of studies were excluded: (1) laboratory-based studies, case reports, conference abstracts, or studies that lacked a control group, as these types of studies generally do not provide robust comparative data; (2) publications not written in English, in order to standardize the analysis to English-language literature; and (3) studies that presented incomplete, insufficient, or unreliable data, making it impossible to draw meaningful conclusions or perform a valid comparison. Furthermore, additional patient-specific inclusion and exclusion criteria were established to ensure the appropriate patient population was represented in the analysis: (1) studies should include only adult patients (≥18 years old) diagnosed with aSAH who received lumbar CSF drainage for clinical management; (2) studies were excluded if they involved patients with contraindications to lumbar drainage, such as severe coagulopathies, infection, or prior neurological conditions that would confound the results of the treatment; (3) studies with patients who received lumbar drainage for conditions other than aSAH (e.g., traumatic brain injury, idiopathic intracranial hypertension) were excluded. These exclusion criteria were designed to ensure that only studies with adequate methodological rigor and complete datasets were included in the final analysis, thus strengthening the validity and reliability of the results.

2.3. Data extraction

All extract data were searched for the following information: (1) study details, author, year of publication, sample size, type of drainage and control; (2) participant demographics (patient population, number of patients, age, sex,); (3) results of infection of CSF or the LD exit site, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus and mortality.

2.4. Statistical analyses

The meta-analysis was conducted using Review Manager Version 5.4, provided by the Cochrane Collaboration. Dichotomous data are presented as OR with corresponding 95% CI. Heterogeneity was assessed using the I2 statistic, with a value of <50% indicating the use of a fixed-effect model, and values ≥50% prompting the use of a random-effects model. A p-value of <0.05 was considered statistically significant for all outcomes. Additionally, funnel plots were utilized to assess the presence of publication bias.

3. Results

3.1. The characteristics of studies and patients

The flowchart of detailed literature search was illustrated in **Figure 1**. Through an extensive searching program, 11 studies [9–19] and 2059 patients were finally enrolled. There were no significant differences between the LD (experimental) group and non-LD (control) group in baseline data. Among all these studies, 4 studies reported infection in 933 patients, 3 studies assessed rebleeding in 973 patients, 9 studies evaluated clinical vasospasm in 1710 patients, 5 studies evaluated cerebral infarction in 898 patients, 6 papers focused on hydrocephalus in 751 patients, and 4 studies illustrated mortality at discharge in 980 patients. The characteristics of included studies and patients were presented in **Table 1**.

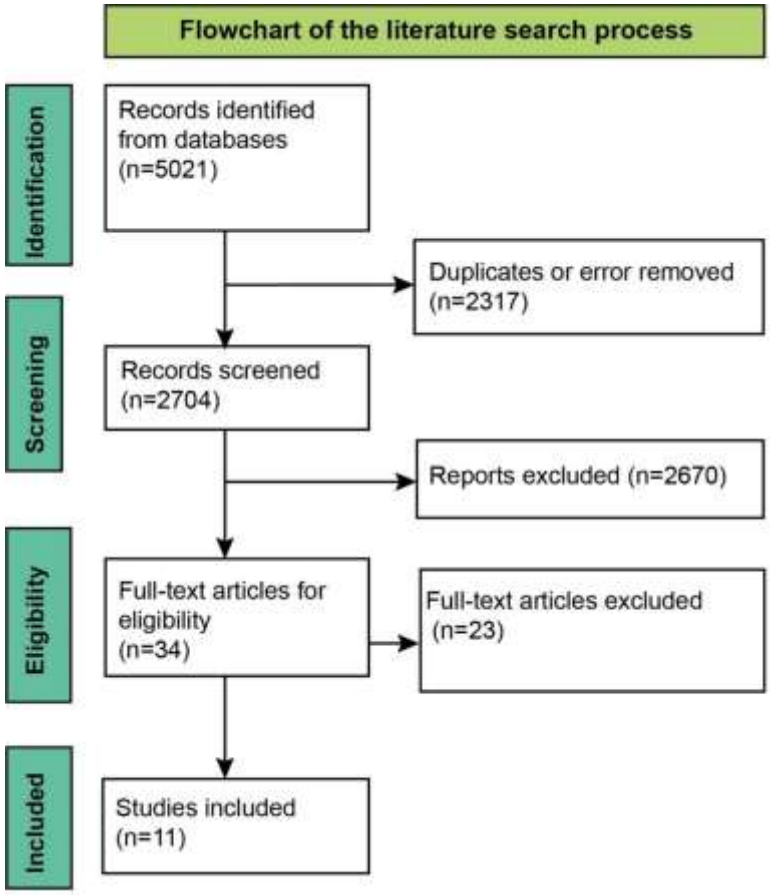

Figure 1. Flowchart of detailed literature search. 5021 records were identified, 2704 were screened after removing duplicates, 34 full-text articles were assessed for eligibility, and 11 studies were ultimately included in the final analysis.

Table 1. Details on all of the included studies.

			Number of patients		Average age (years)		Gender (male/female)	
Study	**Year**	**Sample size**	**Lumbar drainage**	**No lumbar drainage**	**Lumbar drainage**	**No lumbar drainage**	**Lumbar drainage**	**No lumbar drainage**
Wolf S	2023	187	144	143	54 (48–63)	54 (48–63)	46/98	44/99
Kim DY	2023	438	229	209	58.48 ± 12.60	56.33 ± 12.24	68/161	81/128
Chen YH	2023	89	48	41	58.3 ± 10.4	58.7 ± 13.7	10/40	16/41
Jeong JH	2020	107	28	79	52.3 ± 12.4	58.1 ± 12.7	8/28	29/79
Fang Y	2020	193	113	80	55.0 (29–77)	56.6 (31–77)	48/113	32/80

Table 1. (*Continued*).

			Number of patients		Average age (years)		Gender (male/female)	
Study	**Year**	**Sample size**	**Lumbar drainage**	**No lumbar drainage**	**Lumbar drainage**	**No lumbar drainage**	**Lumbar drainage**	**No lumbar drainage**
Borkar SA	2018	60	30	30	48.4 ± 10.2	48.4 ±10.2	13/17	14/16
Park S	2015	234	126	108	56.7 (23–76)	56.7 (23–76)	1: 1.6	1: 1.6
Sun C	2014	148	72	76	56.8 ± 8.9	56.8 ±8.9	35/37	38/38
Maeda Y	2013	51	34	17	72.8 (36–91)	63.5 (38–82)	8/26	8/9
Al-Tamimi YZ	2012	210	105	105	53.0 (50.6–55.4)	54.8 (52.3–57.2)	1:3.6	1:4
Ruijs AC	2005	342	18	324	59 ± 14.2	56 ± 13.7	6/12	98/226

3.2. Infection of CSF or the LD exit site

Four studies were included in this analysis to evaluate the impact of lumbar CSF drainage on the incidence of infections, either in the CSF or at LD exit site. The total sample size across these studies was 933 patients, with 475 receiving lumbar CSF drainage and 458 not undergoing the procedure. Both groups were monitored for infection occurrences during the treatment period, as infection is a major concern in procedures involving external drainage of CSF, given the risk of bacterial entry into the subarachnoid space. In the lumbar CSF drainage group, infections were observed in 19.8% of patients (94 out of 475), while the control group exhibited a slightly lower infection rate of 18.8% (86 out of 458). Statistical analysis revealed no significant difference between the two groups, with an OR of 1.17, and a 95% CI ranging from 0.81 to 1.70 (p-value = 0.39) (**Figure 2**). The p-value suggests that the difference in infection rates between the groups is not statistically significant, indicating that lumbar CSF drainage does not increase the risk of infection compared to the control group. Additionally, the I^2 statistic for heterogeneity was 0%, suggesting that the studies included in this analysis were homogenous in terms of infection outcomes. These findings are important from a biomechanical perspective, particularly when considering the role of lumbar CSF drainage in modifying the mechanical environment of the brain and spinal cord. One of the primary functions of lumbar CSF drainage is to regulate ICP by removing CSF and adjusting the CSF volume in the spinal and cranial compartments. This can help reduce the risk of hydrocephalus and ICP elevation, which are both critical factors in the management of aSAH. Furthermore, lumbar drainage may alleviate mechanical stress on the brain's vasculature, potentially reducing the risk of cerebral vasospasm and improving cerebral perfusion, thus decreasing the likelihood of delayed ischemic neurological deficits and infarction. However, the biomechanical changes brought about by the drainage procedure do not appear to significantly alter the infection rate, suggesting that the mechanical environment influenced by lumbar drainage—such as changes in CSF dynamics—does not inherently increase the risk of infection at the drainage site or within the CSF. The results underscore the safety of lumbar drainage in the management of aSAH, particularly in the context of infection risk. Although infection is a concern with any invasive procedure, these findings indicate that lumbar drainage, when properly managed, does not pose a significantly higher risk compared to the control group. In summary, this analysis provides valuable insights

into the safety profile of lumbar CSF drainage in aSAH treatment, emphasizing that, in terms of infection rates, lumbar CSF drainage may not present a higher risk compared to non-drainage methods. The lack of significant differences in infection rates, combined with the potential biomechanical benefits such as reduced ICP and improved cerebral perfusion, supports the continued use of lumbar drainage in aSAH management while highlighting the importance of proper monitoring to prevent complications.

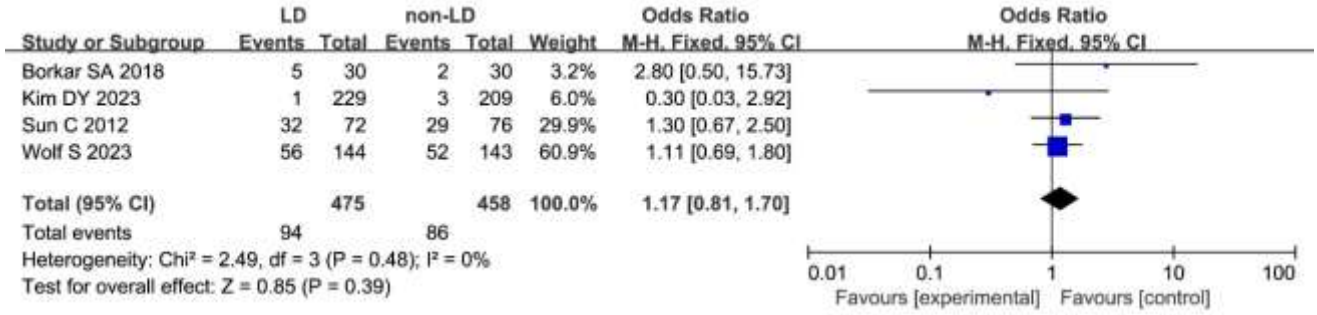

Figure 2. Forest plots of infection of CSF or the LD exit site.

3.3. Rebleeding

The effect of lumbar CSF drainage on rebleeding in aSAH was evaluated, with the forest plot shown in **Figure 3**. Aneurysm rebleeding is a catastrophic complication of aSAH, contributing significantly to in-hospital mortality. In this study, 12 out of 360 patients who underwent lumbar CSF drainage experienced rebleeding, compared to 58 out of 613 control patients who did not receive lumbar drainage. The OR was 0.75, with a 95% CI of 0.37–1.54 (P = 0.44), indicating no statistically significant difference in rebleeding rates between the two groups (I^2 = 38%) (**Figure 3**). From a biomechanical standpoint, lumbar CSF drainage aims to regulate ICP and CSF dynamics, which can influence the mechanical environment of the brain. However, despite the potential for reduced ICP and improved perfusion, this study suggests that lumbar CSF drainage does not significantly impact the risk of rebleeding, possibly due to factors such as the timing of drainage and the underlying aneurysm pathology.

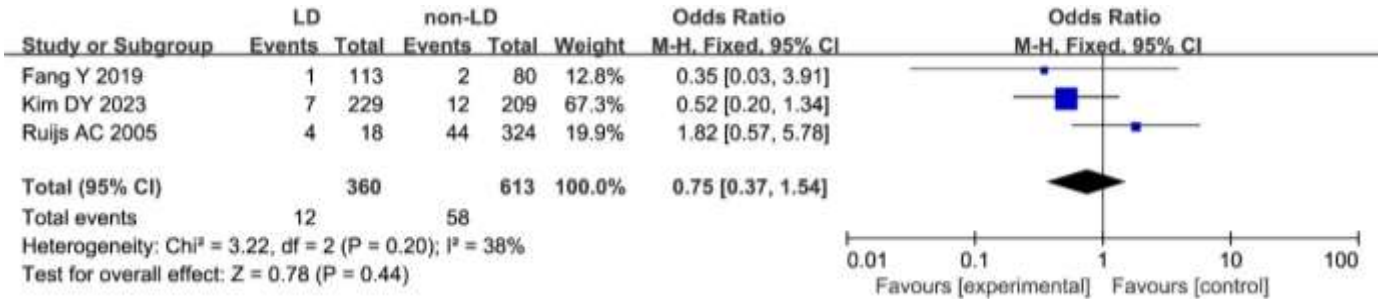

Figure 3. Forest plots of rebleeding.

3.4. Clinical vasospasm

A total of five studies, involving 898 patients, were included to investigate the association between lumbar CSF drainage and the occurrence of cerebral infarction

in patients with aSAH. Among the participants, 433 received lumbar CSF drainage, while 465 did not. The results revealed that 25.2% of patients in the lumbar drainage group (109 out of 433) developed cerebral infarction, compared to 38.3% in the control group (178 out of 465) (**Figure 4**). Statistical analysis showed a significant reduction in the incidence of cerebral infarction in the lumbar CSF drainage group, with an OR of 0.60 (95% CI, 0.48–0.75; $P < 0.00001$) and an I^2 of 40%, indicating moderate heterogeneity between studies. From a biomechanical perspective, lumbar CSF drainage plays a critical role in modulating ICP and improving cerebrovascular dynamics. By removing CSF from the lumbar cistern, the procedure helps reduce ICP, thereby alleviating mechanical stress on the brain and cerebral vasculature. This can enhance cerebral perfusion and potentially reduce the incidence of cerebral vasospasm, a key contributor to ischemia and infarction in aSAH. The reduction in infarction rates observed in this analysis suggests that lumbar CSF drainage may help restore a more favorable biomechanical environment for cerebral blood flow, ultimately lowering the risk of ischemic damage.

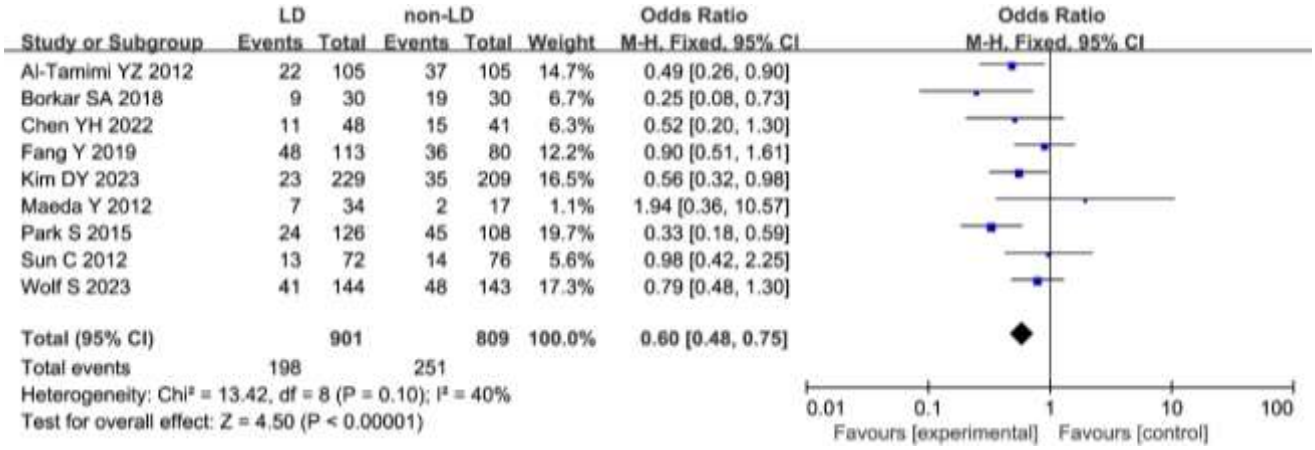

Figure 4. Forest plots of clinical vasospasm.

3.5. Cerebral infarction

Five studies, encompassing a total of 898 patients, were included to assess the effect of lumbar CSF drainage on the incidence of cerebral infarction in patients with aSAH (**Figure 5**). Among these, 433 patients received lumbar CSF drainage, while 465 did not. The results indicated a significant reduction in the incidence of cerebral infarction in the lumbar drainage group. In this group, 25.2% of patients (109 out of 433) experienced cerebral infarction, compared to 38.3% in the control group (178 out of 465). The odds ratio (OR) was 0.48 (95% CI: 0.35–0.64, $P < 0.00001$), with a relatively low heterogeneity ($I^2 = 23\%$), suggesting a consistent effect across studies. From a biomechanical perspective, the reduction in cerebral infarction can be explained by the role of lumbar CSF drainage in mitigating elevated ICP and improving cerebral perfusion. After an aneurysmal rupture, blood accumulation in the subarachnoid space can lead to increased ICP, impairing cerebral circulation and promoting vasospasm, which contributes to cerebral infarction. By removing excess CSF, lumbar drainage helps to alleviate the mechanical pressure on the brain, improving blood flow and reducing the likelihood of ischemic damage. This biomechanical intervention thus plays a crucial role in minimizing infarction and

enhancing overall brain function in aSAH patients, as demonstrated in the forest plot (**Figure 5**).

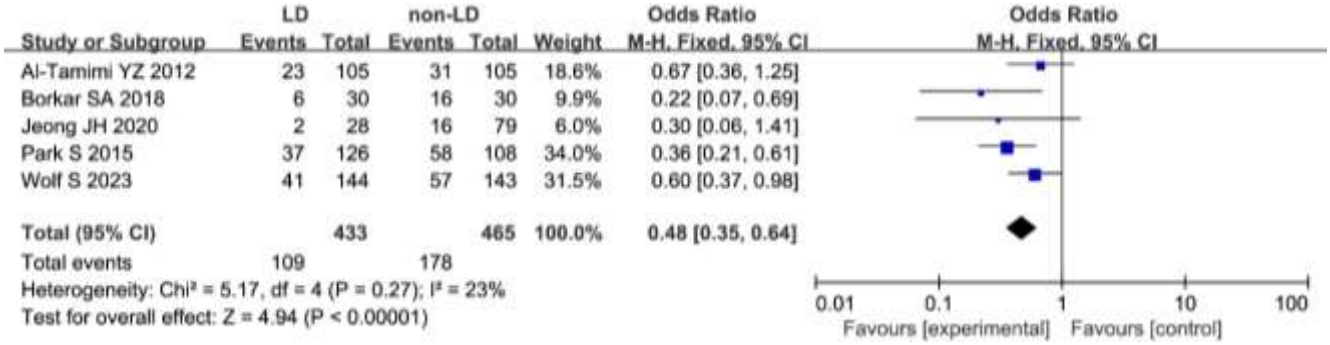

Figure 5. Forest plots of cerebral infarction.

3.6. Hydrocephalus

A total number of 6 studies including 751 patients were enrolled to investigate the association of lumbar CSF drainage with hydrocephalus. Among all these studies, 402 underwent lumbar CSF drainage and 349 patients underwent non-lumbar CSF drainage. The incidence of hydrocephalus between the LD group and non-LD group did not show a significant difference (OR: 0.53; 95% CI, 0.22–1.24; $P = 0.14$; $I^2 = 75\%$). The forest plot of hydrocephalus was performed in **Figure 6**. From a biomechanical perspective, hydrocephalus arises when the balance of CSF production and absorption is disrupted, leading to an accumulation of CSF in the ventricles, which increases ICP and causes mechanical compression of brain structures. Lumbar CSF drainage is intended to reduce ICP by removing CSF from the lumbar cistern, potentially preventing the accumulation of fluid and alleviating the risk of hydrocephalus. However, despite its theoretical benefits, this analysis suggests that lumbar drainage may not significantly impact hydrocephalus occurrence, possibly due to variations in the underlying causes of hydrocephalus or timing of drainage in relation to aSAH pathology.

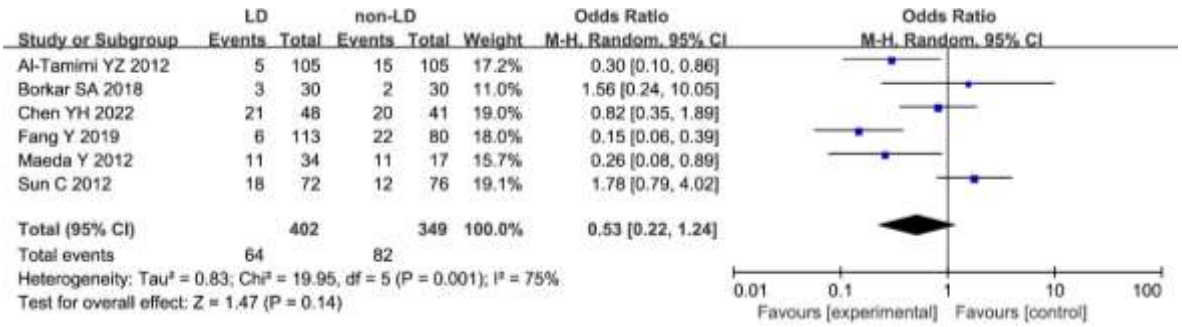

Figure 6. Forest plots of hydrocephalus.

3.7. Mortality at discharge

Four studies, involving 980 patients, were included to explore the association between lumbar CSF drainage and mortality in patients with aSAH. Among the participants, 473 underwent lumbar CSF drainage, while 507 did not. The mortality rate was 8.0% in the drainage group (38 out of 473), compared to 12.6% in the

control group (64 out of 507). Statistical analysis revealed that lumbar CSF drainage significantly reduced mortality, with an odds ratio (OR) of 0.55 (95% CI: 0.36–0.84; $P = 0.005$) and an I^2 of 0%, indicating no heterogeneity between the studies (**Figure 7**). From a biomechanical perspective, lumbar CSF drainage helps regulate ICP by removing CSF and thus alleviating the mechanical stress on the brain. By reducing ICP, lumbar drainage can improve cerebral perfusion, prevent secondary brain injury, and decrease the likelihood of complications such as cerebral infarction and vasospasm, which contribute to mortality in aSAH. The observed reduction in mortality underscores the potential benefit of lumbar drainage in managing the mechanical consequences of aSAH.

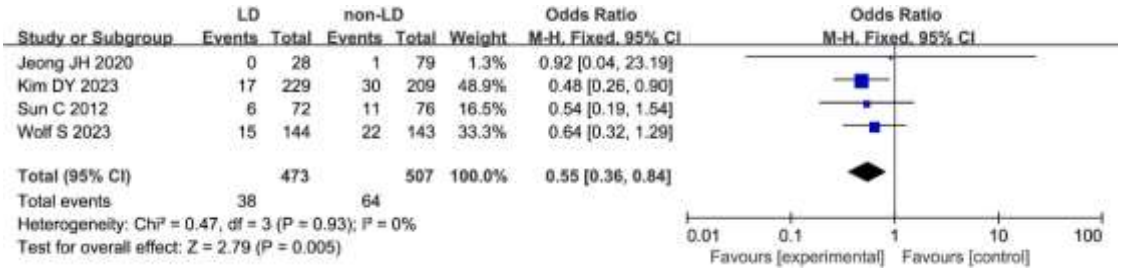

Figure 7. Forest plots of and mortality.

3.8. Publication bias

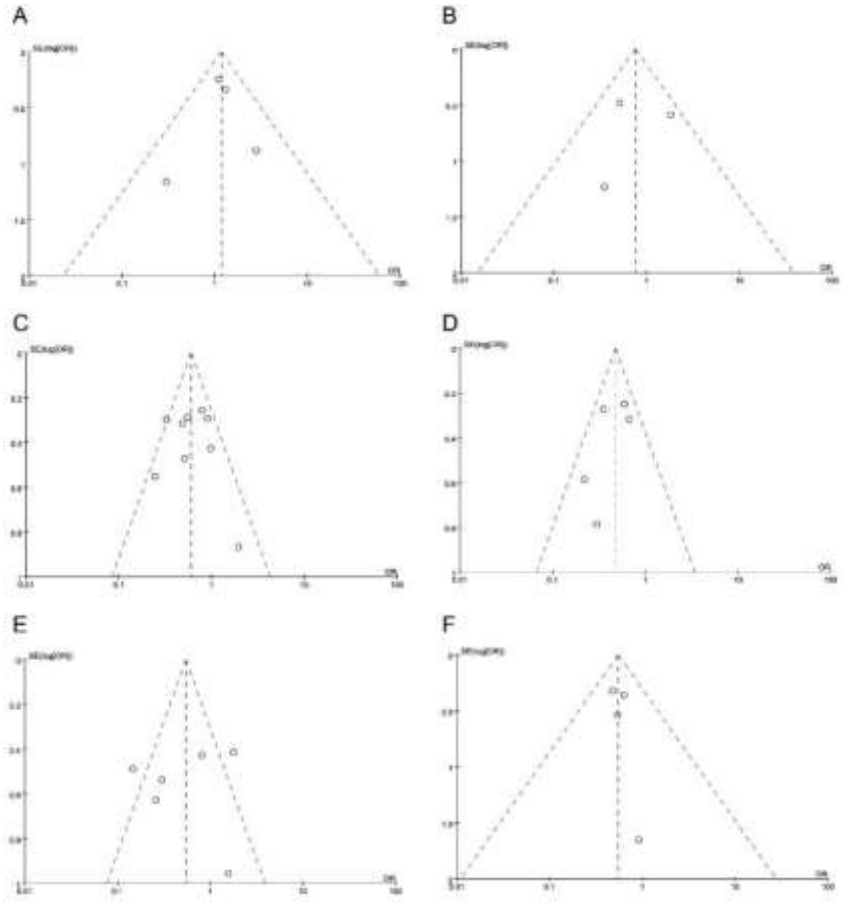

Figure 8. Funnel plots of publication bias **(A)** Infection; **(B)** Rebleeding; **(C)** Clinical vasospasm; **(D)** Cerebral infarction; **(E)** Hydrocephalus; **(F)** Mortality.

Figure 8 displays the results of the publication bias assessment. The funnel plot revealed a symmetrical distribution of the studies, suggesting the absence of significant publication bias.

4. Discussion

This study conducted a meta-analysis of 11 studies focusing on lumbar CSF drainage in patients with aSAH. The results demonstrated that that the compared with the no-lumbar drainage. Lumbar continuous CFS drainage after aSAH is able to obviously reduce the incidence of clinical vasospasm, cerebral infarction, and mortality without improving the rate of infection, rebleeding and hydrocephalus. The role of lumbar CSF drainage in aSAH treatment is closely linked to biomechanical principles, particularly the regulation of ICP and the restoration of cerebrovascular homeostasis [20–23]. In the case of aSAH, the rupture of an aneurysm leads to blood entering the subarachnoid space, which can increase ICP, disrupt CSF flow, and create a hostile mechanical environment for the brain [24–26]. These disturbances can further exacerbate neurological damage by impairing cerebral perfusion, causing ischemic damage, and contributing to complications such as vasospasm and delayed ischemic DIND.

Lumbar continuous CSF drainage has emerged as a potential strategy to improve outcomes in patients with aSAH. A thorough understanding of infections related to LD in spontaneous SAH patients is crucial for taking appropriate preventive and therapeutic measures [20]. The prognosis of patients with aneurysmal SAH is heavily influenced by the risk of re-bleeding, which can be triggered by various factors, including aneurysm size, location, and the patient's Hunt & Hess grade [21,22]. Early interventions like aneurysm clipping or coiling have significantly lowered re-bleeding rates; however, DIND and cerebral infarction due to vasospasm remain significant risks, contributing to both mortality and disability [23]. The presence of blood clots and their degradation products in the subarachnoid space has been linked to the onset of vasospasm [24]. Given this, numerous approaches have been explored to address this challenge, with continuous CSF drainage being one of the most discussed and promising techniques in recent research [27,28].

Our study found that among the patients who received lumbar CSF drainage, the pooled OR for infection, rebleeding, clinical vasospasm, cerebral infarction, hydrocephalus and mortality was 1.17 (95% confidence interval [CI]: 0.81–1.70; P = 0.39; I^2 = 0%), 0.75 (95% CI: 0.37–1.54; P = 0.44; I^2 = 38%), 0.60 (95% CI: 0.48–0.75, P < 0.00001, I^2 = 40%), 0.48 (95% CI: 0.35–0.64, P < 0.00001, I^2 = 23%), 0.53 (95% CI: 0.22–1.24; P = 0.14; I^2 = 75%), and 0.55 (95% CI: 0.36–0.84; P = 0.005; I^2 = 0%), respectively. These findings suggest that the removal of spasmogenic blood clots through LD do not improve infection, rebleeding and hydrocephalus, but it can significantly improve the rates of clinical vasospasm, cerebral infarction, and mortality.

While our study provides valuable insights, several limitations must be carefully considered to ensure the findings are interpreted accurately and to guide future research. First, the relatively small number of studies included in the meta-

analysis could limit the generalizability of our results. With a total of 11 studies and 980 patients, the sample size is moderate, but still insufficient to draw definitive conclusions that can be applied to all aSAH patient populations. A larger and more diverse pool of studies, including multicenter trials with more varied patient demographics, would help to strengthen the external validity and applicability of these findings. Second, many of the studies included in the analysis lacked standardized inclusion and exclusion criteria, and there were variations in diagnostic methods and treatment protocols. Different hospitals and clinical settings may have applied lumbar CSF drainage in slightly different ways, which could introduce biases in the outcomes. For example, factors such as the timing of lumbar CSF drainage initiation, the duration of the drainage process, and the monitoring protocols may have varied significantly across studies, impacting the consistency and comparability of the results. These inconsistencies could lead to outcome heterogeneity, potentially influencing the pooled results, particularly for clinical outcomes such as infection and rebleeding, where timely intervention and proper procedural management are critical. Third, there was a lack of comprehensive data on complications associated with lumbar CSF drainage, such as infections, neurological deficits, or long-term adverse effects like chronic headache or back pain. Most studies did not provide detailed data on these complications, which limits the ability to fully assess the safety profile of lumbar CSF drainage. In addition, the long-term follow-up of patients after the procedure is essential to understanding whether the benefits of lumbar drainage in terms of vasospasm and mortality are sustained over time. Future studies should aim to include detailed data on these adverse effects, as well as longer-term follow-up, to provide a more thorough risk-benefit analysis. Lastly, the variability in the methodological rigor of the included studies poses a challenge. Some studies may have employed retrospective designs or had smaller sample sizes, which could introduce biases and reduce the strength of the evidence. Larger, well-designed, multicenter RCTs with uniform inclusion criteria and standardized diagnostic protocols are needed to further substantiate the findings of this meta-analysis and to refine clinical guidelines for lumbar CSF drainage in aSAH management. In conclusion, while the current study offers valuable insights into the potential benefits of lumbar CSF drainage for improving outcomes in aSAH, addressing these limitations in future research will enhance the reliability and applicability of the findings. More robust and detailed studies will be crucial for optimizing treatment protocols and ensuring the safe, effective use of lumbar CSF drainage in clinical practice.

5. Conclusion

In summary, our meta-analysis revealed the impact of lumbar CSF drainage on the health outcomes of patients with aSAH. The findings suggested that lumbar CSF drainage might decrease the likelihood of clinical vasospasm, cerebral infarction, and death in aSAH patients. However, no significant effects on infection, recurrent bleeding, or hydrocephalus were noted. Despite these results, we continue to advocate for the use of continuous lumbar CSF drainage in the management of aSAH. Additional research exploring the link between lumbar drainage and clinical

outcomes is necessary to validate the broader applicability of these findings.

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