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ORIGINAL ARTICLE - BRAIN TUMORS

Cerebrospinal fluid diversion and outcomes for lung cancer patients with leptomeningeal carcinomatosis

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Abstract

Objective To investigate the outcomes of cerebrospinal fluid (CSF) diversion in lung cancer patients with leptomeningeal carcinomatosis (LMC).

Methods A retrospective review of consecutive lung cancer patients with LMC suffering from increased intracranial pressure (IICP) and hydrocephalus between February 2017 and February 2020. We evaluated the survival benefit of CSF diversion surgery and assessed the outcomes of treatments administered post-LMC in terms of overall survival and shunt-related complications.

Results The study cohort included 50 patients (median age: 59 years). Ventricular peritoneal (VP) shunts were placed in 33 patients, and lumbar peritoneal (LP) shunts were placed in 7 patients. Programmable shunts were placed in 36 patients. Shunt adjustment was performed in 19 patients. Kaplan-Meier analysis revealed that shunt placement increased overall survival from 1.95 months to 6.21 months ($p = 0.0012$) and increased Karnofsky Performance Scores (KPS) from 60 to 70. Univariate analysis revealed no difference between VP or LP shunts in terms of survival. No differences in post-shunt systemic treatments (tyrosine kinase inhibitors (TKIs) or systemic treatments) were observed in overall survival. Shunt-related complications were noted in 7 patients, including shunt obstruction ($n = 4$), infection ($n = 1$), and over-drainage ($n = 2$).

Conclusion CSF diversion (VP or LP shunt) appears to be an effective and safe treatment for lung cancer patients with LMC and hydrocephalus. Programmable shunts should be considered for complex cases, which commonly require pressure adjustments as the disease progresses.

Keywords Leptomeningeal carcinomatosis · Shunt · Hydrocephalus · Lung cancer · Brain metastasis · EGFR mutation

Abbreviations

CSF	Cerebral spinal fluid
EGFR	Epidermal growth factor receptor
KPS	Karnofsky Performance Score
LP	Lumbar-peritoneal
LMC	Leptomeningeal carcinomatosis
MRI	Magnetic resonance imaging
TKI	Tyrosine kinase inhibitor
VP	Ventricular-peritoneal

This article is part of the Topical Collection on *Brain Tumors*

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Introduction

Leptomeningeal carcinomatosis (LMC) occurs in approximately 3–5% of lung cancer patients [17]. Communicating hydrocephalus develops in 18% of patients with LMC [8]. LMC-related hydrocephalus often produces severe symptoms of increased intracranial pressure and shortens the duration of

survival. Note also that LMC-related hydrocephalus also reduces the likelihood that the patient will receive further treatment. LMC-related hydrocephalus and brain metastasis is more common in Asia than in other parts of the world due to an elevated prevalence of mutations in the epidermal growth factor receptor (EGFR) [5]. Note also that improvements in lung cancer therapy and survival may contribute to the incidence of LMC and brain metastasis [12, 17]. LMC is generally considered an end-stage disease manifestation that is associated with reduced quality of life and is sufficient to negate the survival benefits of primary source control [14].

Lung cancer patients with LMC generally require multidisciplinary treatment [15, 17] including radiation, intrathecal chemotherapy, tyrosine kinase inhibitors (TKIs), re-challenge or dose increasing therapy [10, 20], and cerebrospinal fluid (CSF) diversion. The placement of ventricular-peritoneal (VP) or lumbar-peritoneal (LP) shunts is a simple procedure with extensive benefits for patients with LMC-related hydrocephalus [11, 13, 14]. Previous studies reported an elevated rate of malfunctions in LP shunts for the treatment of LMC [11], and some series suggested that LMC patients benefit from valves for the adjustment of pressure [19]. In the current study, we evaluated the survival benefit of CSF diversion surgery in lung cancer patients with LMC-associated hydrocephalus and assessed the outcomes of the treatments.

Methods

Patient Cohort

This retrospective review comprised consecutive lung cancer patients with LMC treated at our medical center between February 2017 and February 2020. The diagnosis of LMC was based on the presence of tumor cells in CSF or evidence of tumor seeding in high-resolution magnetic resonance imaging (MRI) results. Indications of LMC in MRI included enhancement of the cranial nerve, sulcal enhancement, dural thickening, and folia enhancement (Fig. 1). The diagnosis of hydrocephalus was based on imaging evidence of ventricular enlargement (Fig. 2) or opening pressure of lumbar puncture > 20 cm H_2O and clinical symptoms associated with hydrocephalus. All forms of therapy were recorded, including anti-cancer medications (e.g., chemotherapy, TKIs, and immunomodulators), whole brain radiotherapy, stereotactic radiosurgery, craniotomy for tumor resection, and CSF diversion surgery. The Karnofsky Performance Score (KPS) before and after diversion surgery and shunt-related complications (e.g., infection, shunt malfunction, and peritoneal seeding) was also recorded.

Fifty patients (18 males, and 32 females) who met the inclusion criteria were included in our analysis, the clinical characteristics of which are listed in Table 1. The median age at the time of LMC diagnosis was 59 years (range: 41.9–74.8 years). The distribution of patients in terms of cancer type was as follows: adenocarcinoma (48 patients; 96%), mixed-type adenocarcinoma with small cell lung cancer (1 patient, 2.0%), and squamous cell carcinoma (1 patient, 2.0%). Extra-cranial metastasis was observed in 32 patients (64%). The distribution of EGFR mutations was as follows: no mutations (3 patients; 6.0%), L858R point mutation (24 patients; 48.0%), exon 19 deletion (16 patients; 32.0%), exon 20 insertion (1 patient; 2.0%), G719X point mutation (3 patients; 6.0%), and L861Q point mutation (1 patient; 2.0%). The distribution of preoperatively symptoms was as follows: headache (52.0%), gait disturbance (78.0%), and nausea/vomiting (54.0%).

CSF Diversion Procedures

The choice of VP versus LP shunt and programmable versus non-programmable valves (Strata NSC programmable LP

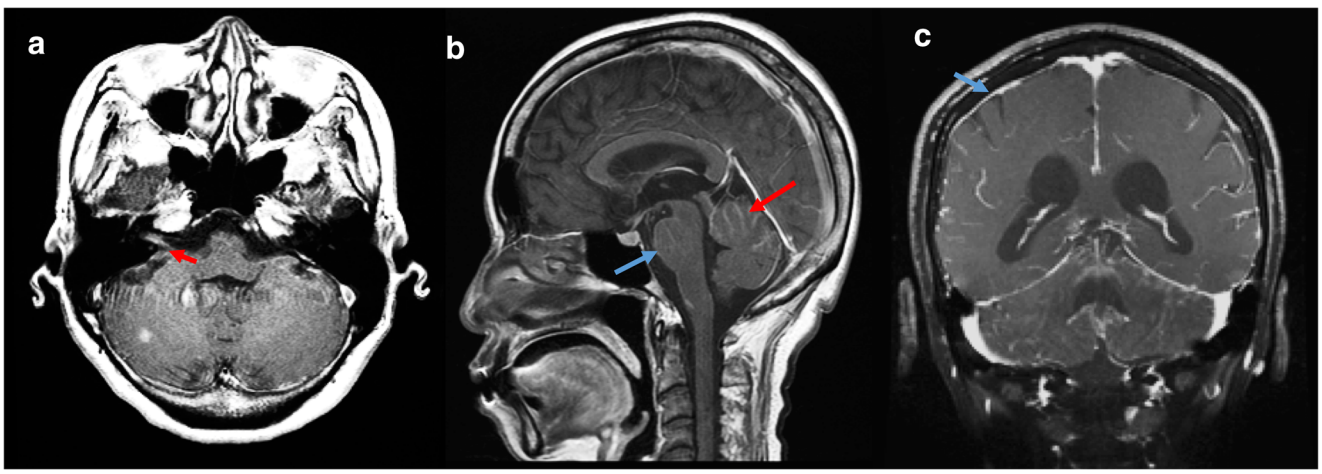

Fig. 1 LMC in contrast-enhanced MRI.**a** Cranial nerve enhancement. **b** Folia enhancement and medullary surface enhancement. **c** Sulcal and dural enhancement

Table 1 Clinical characteristics of patients with leptomeningeal metastasis and hydrocephalus due to lung cancer

Characteristic	Value	Percentage or range
Sex (Male: Female)	18:32	36.0%
Age (y/o)	59.0	41.9–74.8
Ventricular enlargement	46	92.0%
Leptomeningeal metastasis pattern		
Dural enhancement	21	42.0%
Sulcus enhancement	30	60.0%
CN enhancement	25	50.0%
Folia enhancement	36	72.0%
None	3	6.0%
Extracranial metastasis	32	64.0%
KPS (median) before shunting	60	40-80
KPS (median) after shunting	70	50-90
Neurological deficits (IICP sign)		
Headache	26	52.0%
Gait disturbance	39	78.0%
Nausea/vomiting	27	54.0%
CN palsy	3	6.0%
Visual field deficits	12	24.0%
High cortical dysfunction	14	28.0%
Asymptomatic	0	
Systemic therapy		
Before LM		
Gefitinib	9	18.0%
Afatinib	19	38.0%
Erlotinib	27	54.0%
Osimertinib	18	36.0%
Chemotherapy	32	64.0%
After LM		
Gefitinib	1	2.0%
Afatinib	5	10.0%
Erlotinib	7	14.0%
Osimertinib	20	40.0%
Chemotherapy	12	24.0%
Radiation therapy		
Before LMC		
WBRT	16	32.0%
SRS only	3	6.0%
WBRT + SRS	9	18.0%
No RT	22	44.0%
After LMC		
WBRT	6	12.0%
SRS	1	2.0%
No RT	43	86.0%
Tumor histology		
Adenocarcinoma	48	96.0%
AdenoCA+ small cell CA	1	2.0%
SqCC	1	2.0%
EGFR mutation from lung pathology		
No mutation	3	6.0%

Table 1 (continued)

Characteristic	Value	Percentage or range
L858R point mutation	24	48.0%
Exon 19 deletion	16	32.0%
Exon 20 insertion	1	2.0%
G719X point mutation	3	6.0%
L861Q point mutation	1	2.0%
Unknown	1	2.0%
Shunting type		
VP shunt	33	66.0%
LP shunt	7	14.0%
None	10	20.0%
Shunt complications	7	17.5%
Median survival (months) (death only)	4.9	0.4-36.2
Median follow-up period (months)	5.0	0.4-36.2
Average time period between ventricle enlargement to shunting procedure (months)	0.52	0.03-10.0
Average time period of hydrocephalus symptoms to shunting procedure (months)	0.28	0.0-10.8
Average time period between initial setting of valve to first pressure adjustment (months)	2.5	0.23-11.7

Abbreviations: *CA* carcinoma, *CN* cranial nerve, *LP* lumbar-peritoneal, *RT* radiotherapy, *SqCC* squamous cell carcimoma, *SRS* stereotactic radiosurgery, *VP* ventriculo-peritoneal, *WBRT* whole brain radiotherapy

shunt, Medtronic, USA; Strata adjustable VP shunt, Medtronic, USA; Codman Hakim non-programmable shunt, Integra, USA; ProGav programmable shunt, B. Braun, Germany) was at the discretion of treating physician and patient. Programmable valves are not covered under Taiwan's national health insurance and therefore incur an out-of-pocket expense for patients. VP shunts were typically inserted by ventricular puncture at Kocher's point. A distal end of a catheter is tunneled through a subxiphoid incision prior to insertion into the peritoneal cavity. LP shunts were inserted via a lumbar puncture from the L3/L4 or L4/L5 level and through a subcutaneous tunnel into the peritoneal cavity. CSF samples were collected for genetic analysis at the time of shunt insertion. Routine follow-up was conducted every month following shunt insertion.

Shunt re-programming

The settings of programmable shunts were adjusted in accordance with the symptomology. The pressure setting was increased in cases presenting symptoms of over-shunting (e.g., nausea, vomiting, or headache relieved by supine position) and imaging findings (e.g., slit ventricle or subdural effusion or hematoma). The pressure setting was lowered in cases where improvements after surgery did not meet expectations and the patient presented ventricular dilation. The pressure setting was also lowered in cases where the patient initially presented an improvement but later developed symptoms indicative of increased intracranial pressure (e.g., unsteady gait, nausea, vomiting, and lowered consciousness).

Statistics

Statistical analysis involved conventional bivariate tests, including independent *t*-tests and one-way analysis of variance (ANOVA). Categorical variables were analyzed using the chi-square test. Variables and interaction expansion covariates with a p-value < 0.2 were subsequently subjected to Cox proportional analysis and multivariable logistic analysis as deemed appropriate. Overall, p-values < 0.05 were considered statistically significant. Kaplan-Meier plots were used to assess overall survival, and the log-rank test was used for the comparison of survival rates. All statistical analysis was performed using the SAS statistical package, version 9.4.

Results

Clinical Outcomes

Fifty patients who met the inclusion criteria were included in our analysis, the clinical characteristics of which are listed in Table 1**.** A total of 40 patients (80% of the cohort) underwent surgery for shunt placement, including VP (n = 33) and LP (n = 7). In the VP shunt group, 22 (67%) of the devices were equipped with programmable valves. Patients with ventricles of normal size (n = 4; 8.0%) presented high opening pressure during lumbar puncture. The distribution of post-LMC treatment was as follows: no further treatment (16 patients), erlotinib pulse therapy at 600 mg/4 days (7 patients), osimertinib 80 mg (18 patients), osimertinib 160 mg (2 patients), and

systemic chemotherapy including alimta, carboplatin, bevacizumab and/or docetaxel (12 patients).

The median survival of patients who underwent shunt surgery exceeded that of patients who did not undergo shunt surgery (Kaplan-Meier survival curve: 6.21 months (0.8–36.2) vs. 1.95 months (0.4–22.4), $p = 0.0012$) (Fig. 3a). Kaplan-Meier survival analysis revealed no difference between patients receiving osimertinib, erlotinib pulse therapy, or other therapy in terms of survival (Fig. 3b). The shunt cohort outperformed the no-treatment cohort in terms of survival (Fig. 3b). The study also examined the effects of different shunts on overall survival. Figure 3c demonstrates that the overall survival was not related to the programmable or non-programmable shunt (p-value = 0.6839), and Fig. 3d demonstrates that the overall survival was not related to LP vs. VP shunt as well (p-value = 0.5991).

Shunting was shown to improve average KPS scores from 60 (before placement) to 70 (after placement). Shunt placement (HR = 0.19, CI: 0.06–0.64, $p = 0.008$) and sulcal pattern of LMC (HR = 0.22, CI = 0.08–0.67, $p = 0.007$) were independent predictors of survival (Table 2). Among the 36 patients who received programmable valves, 19 underwent at least one shunt setting adjustment within the first 2.5 months after placement. Some patients underwent pressure adjustment up to 4 times until patient deceased (range 1–4). Illustrative cases are presented in Fig. 2.

Complications related to CSF diversion

Infection was detected in 1 VP shunt patient (2.5%), which necessitated multiple revision surgeries. Shunt obstruction was detected in 3 VP shunt patients and 1 LP shunt patient (10% overall). Two cases of obstruction were treated using revision surgery and two underwent hospice care. Symptoms of over-shunting were observed in 2 patients (5%), both of which were corrected by adjusting the valve settings. Two patients were suspected of peritoneal metastasis; however, that diagnosis was made prior to shunt placement. None of the patients presented symptoms of ascites at the time of shunt surgery.

Discussion

LMC in lung cancer patients portends to a survival of less than 3 months. In patients with hydrocephalus, we found that palliative shunt placement can prolong patient survival to 6.21 months. However, it must be noted that continuation of neurosurgical care remained important as 52.7% of the patients required at least one shunt readjustment, and with some patients requiring up to 4 readjustments. This also underscored the utility of programmable shunt valves in these patients. Subgroup comparisons between different types of shunts (VP vs. LP shunt, and programmable vs. non-programmable shunt) did not reveal superiority of one over the other. However, the ability to detect these differences may be limited by the sample sizes. The overall effect of shunt placement was the most important predictor of survival in these patients. Taken together, shunt placement may provide survival benefit in lung cancer patients with LMC. Programmable shunts may be preferred given the frequency of readjustments observed in this study cohort.

As the study cohort derived purely from an Asian population, which is known to have a high rate of EGFR mutation, we also sought to determine whether shunt placement resulted in a survival benefit among patients being treated with different targeted therapies. Prolonging survival in patients with hydrocephalus status post shunting may allow time for these therapies to take effect. No difference in survival was observed among the shunted patients who underwent different therapies, although this may be limited by their small sample sizes. However, the longer survival in the shunted patients may call for more aggressive approach in these targeted therapies.

Shunt placement in lung cancer patients with LMC is often treated as a form of palliative treatment; therefore, the decision of proceeding with the surgery can be difficult for the physician, patient, and patient's family. Previous research indicated that shunting for LMC provides a number of benefits in terms of symptom relief as well as prolonged survival (Table 3). It has been reported that 77–84% of patients who underwent shunting were relieved of hydrocephalus-related symptoms until the end of life [11, 13, 16]. Improvements in KPS have also been reported by Gonda [3] and Murakami [14]. Shunting was shown to improve overall survival from 1.7 to 5.7 months in a series by Jung [8] and from 1.95 to 6.21 in the current study. Shunting has also demonstrated advantages in terms of functional improvement and prolonged survival [11, 13]. Note that the EGFR mutation is an issue in Asian populations; therefore, we also examined survival as a function of shunting in combination with various TKIs. Erlotinib pulse therapy and high doses of osimertinib after CSF diversion therapy did not appear to provide any benefits in terms of survival.

We determined that CSF diversion and sulcal patterns of LMC were positive prognostic factors for survival. The overall survival duration of patients who underwent shunt placement exceeded that of patients who did not undergo the procedure (6.21 vs. 1.95 months). Jung et al. previously reported the survival benefits of shunt surgery based on a series of 18 patients with hydrocephalus and LMC due to various forms of cancer. The prognosis for patients with LMC-related hydrocephalus is generally far worse than for patients with hydrocephalus related to other etiologies. Furthermore, most medical therapies for LMC-related hydrocephalus fail to control the symptoms [4].

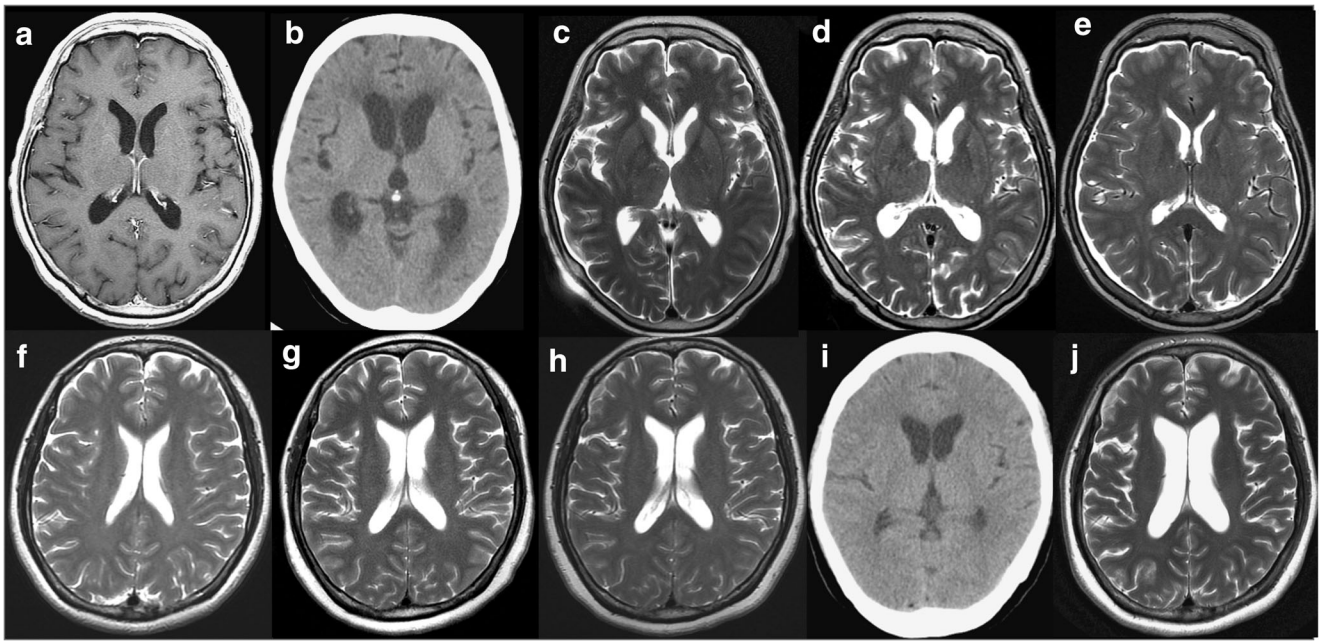

Fig. 2 Case illustration: Case 1: A 62-year-old female patient with lung cancer and brain metastasis, EGFR status L861Q, treated using afatinib and osimertinib between 2018 and 2019. CSF cytology revealed adenocarcinoma. **a** Normal ventricle size before LMC. **b** The patient developed LMC with progressive headache, unsteady gait, and nausea/vomiting. Brain CT revealed dilated ventricles. The patient showed improvements after VP shunt insertion. **c** One month after shunt surgery, MRI revealed reduction in ventricle size. **d** Two months after surgery, the patient suffered from drooling and asymmetrical facial expressions with generalized weakness. Brain MRI revealed ventricle dilation compared with **c**. The symptoms gradually receded after pressure was adjusted. **e** Four months after pressure adjustment, MRI revealed a reduction in ventricle size with no symptoms of hydrocephalus. Case 2: A 58-year-old female patient with lung cancer and brain metastasis, EGFR status L858R, treated using afatinib, tarceva, and oseimertinib between 2016 and 2020. CSF cytology revealed adenocarcinoma. **f** Ventricles of normal size at the time of initial diagnosis of lung cancer. **g** Two years later, the patient developed LMC without significant enlargement of ventricles; however, the patient presented with dizziness, nausea, and vomiting. Lumbar puncture revealed opening pressure of 25 cm H_2O. **h** At three months after LP shunt insertion, ventricle size remained stable. **i** At five months after shunt insertion, mild ventricle dilation was observed with progressive dizziness, nausea, vomiting, and unsteady gait. The severity of the symptoms decreased after lowering the pressure setting. **j** Slight dilatation of ventricles, compared with the first MRI. Note, however, that there were no signs of periventricular lucency and the patient remained asymptomatic

At present, CSF shunt surgery is the only way to relieve the symptoms associated with elevated intracranial pressure and extend survival; however, its clinical importance remains unclear. Other factors related to a favorable prognosis include good KPS at the time of LMC diagnosis, the systemic use of medication (e.g., blood-brain barrier-penetrating TKIs), and good local tumor control [8, 13]. CSF diversion surgery should be considered a treatment option for most patients, particularly those for whom medical management failed.

We observed an improvement in KPS from 60 to 70 after shunt placement. Other studies have also reported clinical improvements after shunt placement such as improvements in KPF and ECOG as well as improvements in the level of consciousness and relief of headache, nausea, and vomiting [13, 14, 16]. Elevated intracranial pressure can be relieved within few hours after surgery [7, 14].

VP and LP shunts both proved effective in the treatment of hydrocephalus in lung patients with LMC. Murakami, Yamashiro, and Kim et al. reported similar results [11]. The advantages of LP shunts over VP shunts include their applicability to ventricles of all sizes and the fact that LP shunts do not require ventricular puncture, thereby reducing the risk of brain injury [14, 19]. Kim et al. reported that in cases involving LP shunts, there is a higher incidence of malfunction and infection requiring revision surgery. In the current study, only three of the patients required revision surgery for shunt obstruction or infection. Ko et al. reported that up to 50% of LMC patients with lumbar puncture pressure > 20 cm H_2O presented no indications of ventricular enlargement [2]. LP shunts might be particularly beneficial for patients with ventricles of normal size.

Our results revealed that programmable valves can be of benefit in cases of lung cancer with LMC-related hydrocephalus by largely eliminating the need for revision of surgical procedures due to under- or over-drainage. One small-scale series involving 4 patients who received LP shunts with programmable valves reported that multiple adjustments are often required to optimize the effectiveness of the devices [19]. A larger study involving 70 patients also reported the benefits of programmable valves in preventing revision surgeries [11]. CSF diversion surgery is generally considered a palliative procedure; therefore, devices that allow pressure adjustment are far preferable to shunt revision.

We determined that erlotinib pulse therapy and osimertinib treatment following CSF diversion therapy

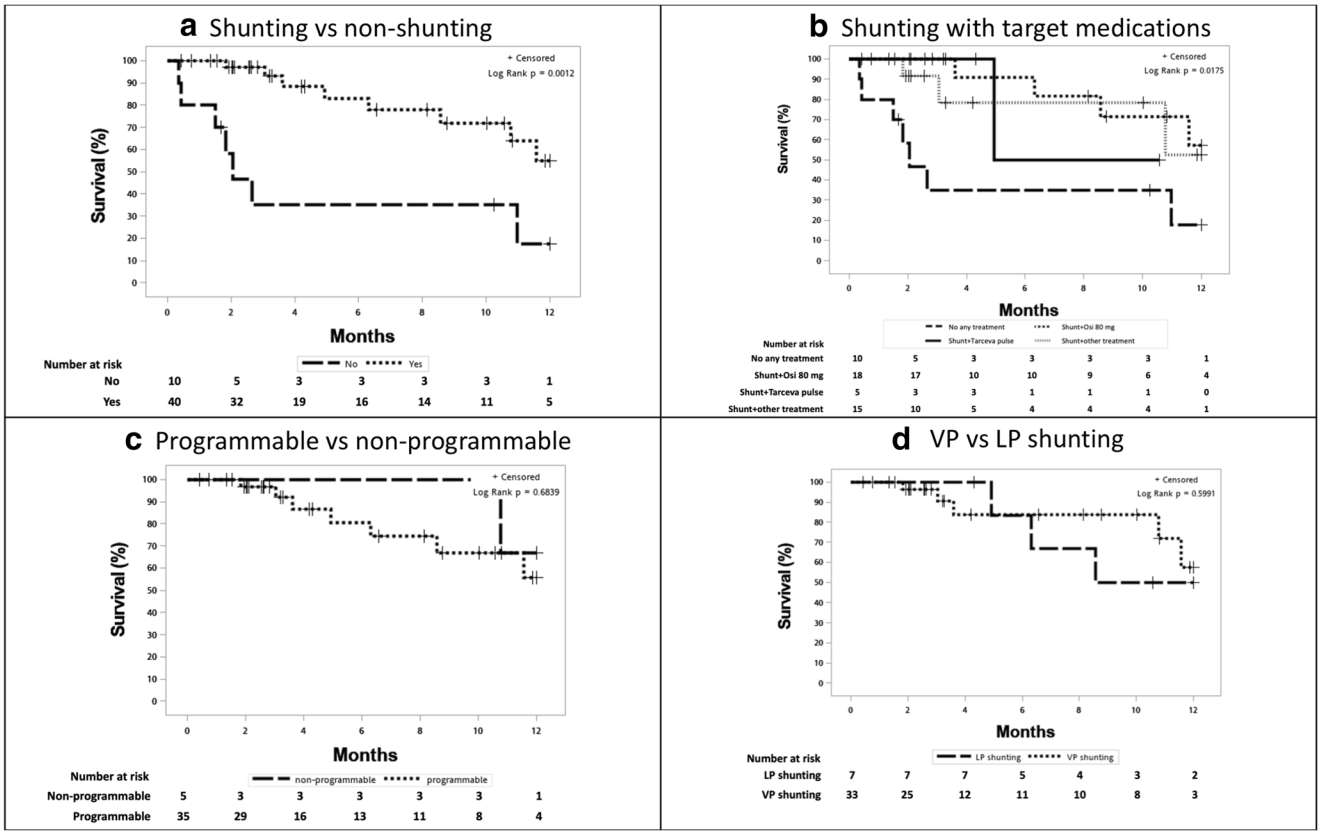

Fig. 3 **a** Difference in survival between patients who did and did not undergo shunt placement. **b** Difference in survival between patients who used pulsatile erlotinib or osimertinib versus other forms of systemic chemotherapy, bevacizumab, or afatinib. **c** Difference in survival between patients who underwent shunting surgeries with programmable or non-programmable shunt. **d** Difference in survival between patients who underwent shunting surgeries with LP vs. VP shunt

Table 2: Prognostic factors associated with overall survival following diagnosis of LMC (derived using *Cox regression analysis*)

	Overall survival					
	Univariate			Multivariate		
Factors	p-value	HR ratio	95% CI	p-value	HR ratio	95% CI
Age (y/o)	0.21	0.96	0.91–1.02			
Gender (male vs. female)	0.03	2.47	1.09–5.58	0.06	2.29	0.95-5.49
EGFR mutation from lung pathology	0.54	0.64	0.15–2.75			
EGFR mutation from CSF (T790M vs. non-T790M)	0.86	0.91	0.32–2.63			
Extracranial metastasis (yes vs. no)	0.55	1.31	0.54–3.18			
LMC pattern (dural vs. others)	0.12	1.94	0.84–4.47	0.12	2.09	0.82–5.33
LMC pattern (sulcus vs. others)	0.11	0.48	0.20–1.18	0.007	0.22	0.08–0.67
LMC pattern (CN vs. others)	0.38	1.44	0.64–3.24			
LMC pattern (folia vs. others)	0.49	0.74	0.31–1.74			
Pre-KPS score	0.50	0.98	0.93–1.03			
Post-KPS score	0.04	0.96	0.92–0.99	0.99	1.00	0.95–1.05
Post-WBRT (yes vs. no)	0.39	0.52	0.12–2.31			
Shunting (yes vs. no)	0.03	0.26	0.11–0.63	0.008	0.19	0.06–0.64
Shunt type (VP vs. LP)	0.42	1.62	0.50–5.21			

Abbreviations: *CN* cranial nerve, *LP* lumbar-peritoneal, *VP* ventriculo-peritoneal

Table 3 Series of shunting outcomes among patients with LMC-related hydrocephalus

	Case No.	Shunt type	Programmable valve	Tumor origin	Survival	Symptom relief
Omuro et al. 2005 USA [16]	37	VP (37)	VP (3)	Breast (23), lung (6), melanoma (8), other cancers (5)	2 months	In 77% of patient
Gonda et al. 2012 USA [3]	36	VP (36)	VP (0)	Lung (13), melanoma (10), breast (9), renal (3), colon (1)	5.5 month	KPS 69 ➔ 84 on average
Jung et al. 2014 South Korea [8]	71*	VP (7)	VP (3)	Lung (45), breast (14), gastric (4), liver (2), others (6)	No shunt vs. shunt: 1.7 vs. 5.7 months	Not mentioned
Yamashiro et al. 2017 Japan [20]	4	LP (4)	LP (4)	Lung (4)	3–30 months	In 3 patients
Murakami et al. 2018 Japan [14]	11	VP (8) LP (3)	VP (8) LP (3)	Lung (4), breast (4), others (3)	3.3 months	KPS 40 ➔ 60 on average
Kim et al. 2019 South Korea [11]	70	VP (51) LP (19)	VP (46) LP (13)	Brain (15), lung (45), breast (6), leukemia (2), others (2)	3.9 months	In 84% of patients
Mituya et al. 2019 Japan [13]	31	VP (13) LP (18)	VP (13) LP (18)	Lung (31)	3.5 months	In 84% of patients
Su et al. 2020 Taiwan	50*	VP (33) LP (7)	VP (22) LP (7)	Lung (40)	No shunt vs. shunt: 1.95 vs. 6.21 months,	KPS 60 ➔ 70 on average

Abbreviations: *No*. number, *LP* lumbar-peritoneal, *VP* ventriculo-peritoneal

*Not all patients underwent shunting for LMC.

had no survival benefits over conventional chemotherapy (e.g., alimta, carboplatin, avastin, and docetaxel), getitinib, or afatinib after shunting. Previous studies reported that pulsatile erlotinib or osimertinib was highly effective in treating LMC patients and particularly among those testing positive for the EGFR mutation [1, 6, 9, 10, 18]. Saboundji et. al. reported that osimertinib can be beneficial to overall survival and progression-free survival in cases that are resistant to erlotinib. Zhu et. al. reported that some patients presented a partial response to pulse therapy for 9 to 13 months [21]. In the current study, we saw no evidence of this; however, this discrepancy may be due to relative short follow-up times for patients receiving osimertinib (median: 106 days and mean: 250 days) or erlotinib (median: 64 days and mean: 69 days). Shunting could conceivably be used to provide immediate relief from hydrocephalus in conjunction with post-shunting pulsatile TKIs or osimertinib to improve the outcomes of LMC.

Study limitations

This study has a number of limitations that should be considered in the interpretation of our results. This was a small retrospective study at a single medical center, which means that it was ill-suited to randomized control trials. The relatively low incidence of LMC-related hydrocephalus resulted in a small sample size and also limited the follow-up time. This study was also subject to selection bias due to the fact that the decision to proceed with shunt placement was likely based on the prognosis of extracranial disease and insurance coverage. In addition, the selection of shunt type was at the discretion of the treating physician and patient, and the specific reasons could not be adjusted for. The heterogeneity of shunt type in this study reflects the situation in most real-world medical centers. Furthermore, this study may suffer from performance bias due to the fact that clinical assessments throughout the follow-up were not blinded. Finally, the diagnosis of LMC that is based solely on neuroimaging results is often contentious without the support of CSF cytology.

Conclusions

CSF diversion using VP or LP shunts for lung cancer patients with LMC is correlated with improved clinical outcomes and has low complication rates. Programmable valves may reduce the likelihood of revision surgeries in response to under- or over-drainage.

Declarations

Ethical approval All procedures in studies involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee (Department of Research

Programs Walter Reed National Military Medical Center Institutional Review Board) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study, formal consent was not required.

Conflict of interest The authors declare that they have no conflicts of interest.

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