

Risk Factors for Prognosis in Intracranial Tuberculosis Patients Based on Contrast-Enhanced MRI

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Abstract

Objective

To investigate clinical and contrast-enhanced cranial MRI factors associated with poor long-term prognosis in patients with intracranial tuberculosis, aiming to provide a basis for clinical management and early intervention.

Methods

We retrospectively analyzed clinical data and contrast-enhanced cranial MRI images of 119 patients with intracranial tuberculosis admitted to our hospital from January 2018 to March 2026. Recorded variables included age, sex, initial Glasgow Coma Scale (GCS) score, imaging classification, meningeal thickening, acute cerebral infarction, hydrocephalus, Evans index, cerebral arteritis, tuberculoma, and tuberculous abscess. All patients were followed for more than 12 months and classified into a favorable prognosis group (modified Rankin Scale [mRS] 0–2, n=67) and a poor prognosis group (mRS 3–6, n=52). Differences in clinical and imaging characteristics were compared, and multivariate logistic regression analysis was performed to identify independent risk factors for poor prognosis. The discriminatory performance of the model was evaluated using receiver operating characteristic (ROC) curves.

Results

Compared with the favorable prognosis group, patients in the poor prognosis group were older, had a higher proportion of males, and more frequently exhibited meningeal-type or mixed-type intracranial tuberculosis. They also had higher incidences of meningeal thickening, involvement of basal and pericallosal cisterns, multi-site meningeal involvement, acute cerebral infarction, hydrocephalus, and cerebral arteritis, while the proportions of parenchymal-type intracranial tuberculosis and tuberculoma were lower (all $P < 0.05$). Multivariate logistic regression identified age, acute cerebral infarction, and hydrocephalus as independent risk factors for poor long-term prognosis. The logistic regression model based on these factors achieved an area under the ROC curve (AUC) of 0.861, with a sensitivity of 70.1%, specificity of 89.6%, and overall accuracy of 80.7%.

Conclusions

Age, acute cerebral infarction, and hydrocephalus are independent predictors of poor long-term prognosis in patients with intracranial tuberculosis. Contrast-enhanced cranial MRI plays a critical role in detecting key imaging complications such as cerebral infarction and hydrocephalus, providing valuable guidance for prognostic assessment.

1. Introduction

Intracranial tuberculosis (ICT) is a non-purulent inflammation of the brain parenchyma and meninges caused by *Mycobacterium tuberculosis* invading the central nervous system via hematogenous spread.

According to the World Health Organization's Global Tuberculosis Report 2024, an estimated 10.8 million people developed tuberculosis worldwide in 2023 [1]. Although the incidence of ICT among tuberculosis patients is only approximately 1% [2], it represents the most severe form of tuberculosis, with high mortality and disability rates [3]. A systematic meta-analysis of pediatric ICT cases across ten countries over a 50-year period reported a mortality rate of 20%, and about half of the survivors experienced long-term neurological sequelae [4].

Early symptoms of ICT are often non-specific, including fever, headache, vomiting, meningeal irritation, and altered consciousness, which can easily be confused with other central nervous system infections, leading to misdiagnosis or delayed diagnosis [5]. In some cases, a definitive diagnosis is only established after severe complications such as parenchymal brain damage, hydrocephalus, cerebral infarction, or cerebral arteritis have occurred, delaying optimal treatment [6, 7].

In recent years, contrast-enhanced magnetic resonance imaging (CE-MRI) has emerged as an important imaging tool for the diagnosis, classification, and evaluation of ICT. CE-MRI can clearly demonstrate meningeal enhancement, parenchymal lesions, cerebrospinal fluid circulation abnormalities, and vascular-related complications [8–11], providing valuable information for prognostic assessment in ICT patients. Functional recovery after central nervous system injury largely depends on neurogenesis, angiogenesis, and neural plasticity, which require considerable time, necessitating long-term follow-up for these patients [5].

Therefore, this study retrospectively collected clinical data and contrast-enhanced cranial MRI features of ICT patients, with follow-up of at least 12 months. Long-term neurological outcomes were assessed using the modified Rankin Scale (mRS). The study aimed to identify clinical and imaging risk factors associated with poor prognosis and further evaluate the discriminatory performance of a multivariate logistic regression model using receiver operating characteristic (ROC) curves. The findings are intended to provide a basis for early identification of high-risk patients and optimization of individualized treatment strategies.

2. Materials and Methods

2.1 General Information

We retrospectively collected data from patients with intracranial tuberculosis (ICT) who were initially admitted to Hangzhou Red Cross Hospital between January 2021 and March 2026 and followed up regularly for at least 12 months. The study protocol was approved by the Medical Ethics Review Committee of Hangzhou Red Cross Hospital (NO.2024-118-001).

Inclusion criteria: 1) Patients with a first-time confirmed or clinically diagnosed ICT; 2) Follow-up duration of 12 months or longer; 3) No prior history of cerebrovascular disease, HIV infection, or other significant comorbidities; 4) Complete clinical data available.

Exclusion criteria: 1) Patients with unclear ICT diagnosis; 2) Patients with other central nervous system diseases, such as other infections or tumors; 3) Patients with recurrent ICT; 4) Patients with missing clinical data or follow-up less than one year.

The diagnostic criteria for ICT were based on the clinical research standards proposed by Marais et al. [7]: Definitive diagnosis: Presence of central nervous system tuberculosis symptoms (e.g. headache, vomiting, neck stiffness, altered consciousness) plus at least one of the following: positive acid-fast bacilli smear of cerebrospinal fluid (CSF); positive *Mycobacterium tuberculosis* culture in CSF; positive nucleic acid amplification test for *Mycobacterium tuberculosis* in CSF. CSF biochemical results consistent with tuberculous meningitis.

Clinical diagnosis: Imaging findings consistent with ICT and a diagnostic score ≥ 12 points.

2.2 Equipment and Methods

MRI was performed using Philips Achieva 3.0 T and GE Signa Explorer 1.5 T scanners. Sequences included axial T1WI, T2WI, FLAIR, DWI, and sagittal fat-suppressed T2WI (FOV 220 mm, slice thickness 5 mm, gap 1 mm). Contrast-enhanced scans used Gd-DTPA (0.1 mmol/kg) with sagittal T1WI (FOV 240 mm, slice thickness 1 mm, gap 1 mm, matrix 224×320). All patients underwent the same MRI protocol at admission and follow-up.

2.3 Clinical Data and Imaging Feature Analysis

The following information was collected: 1) Basic patient information: age, sex, and other demographic data; 2) Consciousness status at admission: assessed using the Glasgow Coma Scale (GCS); 3) Modified Rankin Scale (mRS) score at 12-month follow-up: patients with scores of 0–2 were classified into the favorable prognosis group, and those with scores of 3–6 were classified into the poor prognosis group; 4) Contrast-enhanced cranial MRI data: MRI images were independently reviewed by one attending radiologist and one associate chief physician, and imaging features were recorded, including imaging classification, presence and location of meningeal enhancement, presence and enhancement characteristics of parenchymal lesions, presence of hydrocephalus and Evans index measurement, presence and location of acute cerebral infarction, presence of cerebral arteritis, and presence of tuberculomas or tuberculous abscesses.

Locations of meningeal thickening and enhancement were classified as pericallosal cistern, basal cistern, lateral fissure cistern, convexity meninges, and others, with attention to the presence of meningeal nodules. Cerebral arteritis was primarily assessed for encasement of the Circle of Willis or the main trunks of the anterior, middle, and posterior cerebral arteries, as well as for stenosis or nodular changes.

Based on imaging features, all cases were categorized as meningeal type, parenchymal type, or mixed type ICT. In cases of disagreement between the two radiologists, a third chief physician adjudicated the findings.

2.4 Statistical Analysis

Statistical analyses were conducted using SPSS 22.0. Continuous data are presented as mean $\pm$ SD and compared with t-tests; categorical data as n (%) and compared with chi-square or Fisher's exact tests. Variables with $P < 0.05$ in univariate analysis were included in binary logistic regression to identify independent risk factors for poor long-term prognosis in intracranial tuberculosis. ROC curves were plotted from predicted probabilities, with AUC, sensitivity, specificity, and accuracy calculated. Heatmaps of clinical and imaging features by prognosis were generated using R. The Evans index was multiplied by 100 for easier interpretation of regression coefficients and odds ratios.

3. Results

A total of 326 patients with intracranial tuberculosis were initially collected, of whom 207 were excluded for not meeting the inclusion criteria, leaving 119 patients for final analysis. The age of the included patients ranged from 4 to 84 years, with 71 males and 48 females. There were 67 patients in the favorable prognosis group and 52 patients in the poor prognosis group (Fig. 1).

3.1 Comparison of Clinical and Imaging Features Between Prognosis Groups

Clinical data: The mean age of patients in the favorable prognosis group was 41.34 ± 20.30 years, compared with 49.04 ± 20.20 years in the poor prognosis group, with a statistically significant difference ($P < 0.05$). The proportion of males was 50.7% in the favorable prognosis group and 71.2% in the poor prognosis group, also showing a statistically significant difference ($P < 0.05$). The proportion of patients with a GCS score of 3–10 was 32.7% in the poor prognosis group, slightly higher than 25.4% in the favorable prognosis group, but this difference was not statistically significant ($P > 0.05$).

Imaging data: The incidence of meningeal thickening was higher in the poor prognosis group (71.2%) compared with the favorable prognosis group (40.3%). Regarding ICT imaging classification, 27% of patients in the poor prognosis group had meningeal-type ICT, higher than 9.0% in the favorable prognosis group; 44.2% of the poor prognosis group had mixed-type ICT, compared with 31.3% in the favorable prognosis group; while parenchymal-type ICT was observed in 28.8% of the poor prognosis group, lower than 59.7% in the favorable prognosis group ($P < 0.05$).

Meningeal thickening involving the pericallosal and basal cisterns was observed in 48.1% of the poor prognosis group, higher than 20.9% in the favorable prognosis group. The proportion of patients with meningeal thickening in multiple regions was also higher in the poor prognosis group (48.1%) than in the favorable prognosis group (22.4%). The occurrence of cerebral infarction, hydrocephalus, and cerebral arteritis was 50.0%, 46.2%, and 25.0% in the poor prognosis group, respectively, compared with 4.5%, 11.9%, and 6.0% in the favorable prognosis group. The proportion of patients with tuberculomas was 85.1% in the favorable prognosis group, higher than 67.3% in the poor prognosis group. The baseline

Evans index was 0.26 ± 0.02 in the favorable prognosis group, lower than 0.29 ± 0.03 in the poor prognosis group. All the above differences were statistically significant ($P < 0.05$).

The incidence of tuberculous abscess was 28.8% in the poor prognosis group, slightly higher than 23.9% in the favorable prognosis group, but the difference was not statistically significant ($P > 0.05$). Detailed data are presented in Table 1.

Table 1

Comparison of Baseline Clinical and Imaging Characteristics Among Patients with Different Prognostic Groups

Variables	Favorable Prognosis Group(n = 67)	Poor Prognosis Group(n = 52)	B	P-value
Clinical Data				
Age	41.34 ± 20.30	49.04 ± 20.20	0.209	0.042
Gender			5.067	0.024
Male	34 (50.7%)	37 (71.2%)		
Female	33 (49.3%)	15 (28.8%)		
GCS Score			0.769	0.381
3–10	17 (25.4%)	17 (32.7%)		
11–15	50 (74.6%)	35 (67.3%)		
Imaging Features				
Types of intracranial tuberculosis			12.970	0.002
Meningeal Type	6 (9.0%)	14 (27%)		
Parenchymal Type	40 (59.7%)	15 (28.8%)		
Mixed Type	21 (31.3%)	23 (44.2%)		
Cerebral Infarction			32.918	<0.001
No	64 (95.5%)	26 (50.0%)		
Yes	3 (4.5%)	26 (50.0%)		
Meningeal Thickening			11.214	<0.001
No	40 (59.7%)	15 (28.8%)		
Yes	27 (40.3%)	37 (71.2%)		
basal/ambient cistern involved			9.818	0.002
No	53 (79.1%)	27 (51.9%)		
Yes	14 (20.9%)	25(48.1%)		
multifocal meningeal involved			8.658	0.003
No	52 (77.6%)	27 (51.9%)		

Variables	Favorable Prognosis Group(n = 67)	Poor Prognosis Group(n = 52)	B	P-value
Yes	15 (22.4%)	25 (48.1%)		
Hydrocephalus			17.432	<0.001
No	59 (88.1%)	28 (53.8%)		
Yes	8 (11.9%)	24 (46.2%)		
Cerebral Arteritis			8.659	0.003
No	63 (94.0%)	39 (75.0%)		
Yes	4 (6.0%)	13 (25.0%)		
Cerebral Tuberculoma			5.269	0.022
No	10(14.9%)	17 (32.7%)		
Yes	57 (85.1%)	35 (67.3%)		
Tuberculous Brain Abscess			0.375	0.540
No	51 (76.1%)	37 (71.2%)		
Yes	16 (23.9%)	15 (28.8%)		
Baseline Evans index($\times 100$)	26.46 $\pm$ 2.35	27.87 $\pm$ 3.60	8.742	0.012

3.2 Multivariate Logistic Regression Analysis

Variables with $P < 0.05$ in the univariate analysis, including age, sex, GCS score, intracranial tuberculosis classification, meningeal thickening, basal/cisternal meningeal thickening, multi-site meningeal thickening, concomitant cerebral infarction, hydrocephalus, cerebral vasculitis, and tuberculoma, were included in a binary logistic regression model. The results showed that age, concomitant cerebral infarction, and hydrocephalus were independent predictors of prognosis in patients with intracranial tuberculosis (Table 2, Fig. 2). Based on this multivariate logistic regression model, a ROC curve was plotted (Fig. 3), with an area under the curve (AUC) of 0.861. Using 0.499 as the optimal cutoff value, the model predicted poor prognosis with a sensitivity of 70.1%, specificity of 89.6%, positive predictive value of 83.8%, negative predictive value of 78.9%, and overall accuracy of 80.7%. Additionally, a heatmap (Fig. 4) illustrated the relative effect sizes of each independent predictor, showing that cerebral infarction and hydrocephalus had larger effect sizes, while age had a relatively smaller effect size.

Table 2
Multivariate Logistic Regression Analysis

Variables	B	P	OR	95%CI
Age	0.035	0.020	1.036	1.006–1.067
Gender				
Female				1.0
Male	-0.675	0.207	0.509	0.178–1.453
Types of intracranial tuberculosis				
Meningeal Type				1.0
Parenchymal Type	-1.026	0.375	0.359	0.037–3.452
Mixed Type	-0.275	0.813	0.759	0.077–7.454
Cerebral Infarction				
No				1.0
Yes	3.216	< 0.001	24.940	4.035–154.152
basal/ambient cistern involved				
No				1.0
Yes	-1.463	0.169	0.232	0.029–1.862
multifocal meningeal involved				
No				1.0
Yes	0.344	0.696	1.410	0.252–7.904
Hydrocephalus				
No				1.0
Yes	1.827	0.041	6.217	1.078–35.857
Cerebral Arteritis				
No				1.0
Yes	1.124	0.205	3.078	0.542–17.475
Cerebral Tuberculoma				
No				1.0
Yes	-0.628	0.496	0.534	0.088–3.253

Variables	B	P	OR	95%CI
Baseline Evans index($\times 100$) (For every 0.01 increase)	-0.139	0.270	0.870	0.679–1.114

4. Discussion

The onset of tuberculous meningitis (TBM) can be variable, and early symptoms are often nonspecific. Pathogen detection rates are low, making differentiation from other central nervous system infections challenging. Currently, diagnosis primarily relies on a comprehensive assessment of clinical presentation, laboratory tests, and imaging findings[12], which may lead to misdiagnosis or delayed diagnosis. Treatment is often difficult, and TBM is associated with relatively high rates of disability and mortality. In this study, we analyzed factors influencing long-term neurological outcomes in patients with intracranial tuberculosis, based on enhanced cranial MRI features and clinical data. Our results showed that patients with poor prognosis were older and had higher proportions of meningeal and mixed-type intracranial tuberculosis. Imaging abnormalities—including meningeal thickening, involvement of basal or ambient cisterns, multifocal meningeal involvement, cerebral infarction, hydrocephalus, and cerebral vasculitis—were more frequently observed in this group. Multivariate logistic regression analysis further identified age, cerebral infarction, and hydrocephalus as independent predictors of poor long-term neurological outcomes in patients with intracranial tuberculosis.

In this study, all patients were followed up for at least 12 months. Although the clinical condition at discharge can predict long-term prognosis, some patients still had uncontrolled disease at the time of discharge but achieved favorable long-term outcomes after prolonged anti-tuberculosis treatment and regular follow-up[5]. Our results indicate that cerebral infarction is an important independent factor associated with poor prognosis in patients with intracranial tuberculosis, which is largely consistent with previous studies. Li et al.[10] analyzed MRI data from 420 patients with intracranial tuberculosis and found that cerebral infarction was not only an independent risk factor for poor short-term prognosis but also for poor long-term outcomes. This finding suggests that cerebral infarction is not merely a concomitant phenomenon, but an important imaging marker reflecting disease severity and irreversible neurological damage. Its pathophysiological basis mainly involves tuberculous inflammatory exudates surrounding basal cerebral vessels, leading to perivascular inflammatory infiltration, vascular wall thickening, luminal stenosis, or even occlusion, ultimately resulting in ischemic cerebral infarction[13]. Previous studies on tuberculous meningitis complicated by cerebral infarction have also noted that infarction significantly increases mortality and disability, with its occurrence closely related to vasculitic damage[14]. Therefore, in patients with intracranial tuberculosis, the presence of cerebral infarction on imaging often indicates vascular involvement and organic brain injury, which portends a poor prognosis. Hydrocephalus is another critical predictor of poor outcome. Intracranial tuberculosis most commonly affects the basal meninges, with exudation and fibrosis obstructing cerebrospinal fluid pathways, leading to either obstructive or communicating hydrocephalus[15]. Progressive ventricular enlargement increases intracranial pressure, reduces cerebral perfusion, and compresses brain

parenchyma, resulting in secondary neurological deterioration[16]. Raut et al.[15] and Cao et al.[17] have identified hydrocephalus as a key predictor of mortality and disability in tuberculous meningitis. Li et al. [10] further confirmed that hydrocephalus is an independent risk factor for long-term mortality. Our study is consistent with these findings, showing that the proportion of patients with hydrocephalus in the poor prognosis group was 46.2%, significantly higher than 11.9% in the favorable prognosis group. This suggests that hydrocephalus reflects extensive meningeal involvement and severe cerebrospinal fluid circulation disturbance. Chronic hydrocephalus and elevated intracranial pressure can compress the skull base and brain parenchyma, leading to sequelae such as facial paralysis, blindness, aphasia, and paralysis, thereby affecting long-term outcomes. Early detection and, when necessary, surgical intervention are recommended[5, 10].

With increasing age, we observed a higher risk of complications in patients, indicating a poorer long-term prognosis. This may be attributed to a greater burden of comorbidities, reduced cerebrovascular reserve, and diminished neural repair capacity, resulting in decreased tolerance to injury from infection, inflammation, ischemia, and elevated intracranial pressure, thereby increasing the likelihood of persistent neurological deficits. Our study demonstrated that advanced age is an independent predictor of poor prognosis in patients with intracranial tuberculosis, consistent with the findings of Sanchit Shailendra Chouksey, Kalita, and Yang Zhengrong[4, 5, 18].

Notably, in this study, cerebral vasculitis, involvement of the basal or sylvian cisterns, and multifocal meningeal involvement were associated with prognosis in univariate analysis but did not demonstrate independent predictive value in multivariate analysis. This may be due to a certain pathological continuity among these imaging features. Meningeal thickening with enhancement, basal cistern involvement, and cerebral vasculitis reflect inflammatory exudates at the skull base and perivascular inflammation, but the primary contributors to long-term functional impairment are likely the subsequent development of cerebral infarction and hydrocephalus[19, 20]. Consequently, when both cerebral infarction and hydrocephalus are included in the model, the independent effects of these pathologically continuous imaging features are attenuated.

Additionally, we found that, regarding intracranial tuberculosis imaging classification, the poor prognosis group was predominantly meningeal or mixed type, whereas the favorable prognosis group was mainly parenchymal type, consistent with previous studies[10]. Meningeal and mixed types are more prone to complications such as vasculitis, cerebral infarction, and hydrocephalus, resulting in significantly worse outcomes. In contrast, isolated parenchymal tuberculomas typically present with milder clinical symptoms, fewer complications, and better recovery[21]. Enhanced MRI classification allows rapid risk stratification and has important clinical implications for decision-making[22, 23].

Certainly, this study has several limitations. First, it is a single-center retrospective study, which may be subject to selection bias. Second, the sample size is relatively limited, and the estimates for some variables in the multivariate analysis may lack stability. Third, this study used the modified Rankin Scale (mRS) at discharge as the primary outcome measure. Although clinically practical, it cannot fully

substitute for long-term functional outcome assessment. Finally, this study primarily focused on clinical and imaging factors, without incorporating treatment-related variables such as timing of corticosteroid use, surgical interventions, or differences in anti-tuberculosis regimens, all of which could influence prognosis. Future studies with larger sample sizes, multicenter design, and prospective follow-up are needed to further validate our findings and to develop a more generalizable prognostic assessment model.

In conclusion, our study indicates that age, cerebral infarction, and hydrocephalus are independent predictors of poor long-term outcomes in patients with intracranial tuberculosis. Enhanced MRI is valuable for identifying imaging subtypes of intracranial tuberculosis, the extent of meningeal involvement, and key complications. Among these, cerebral infarction and hydrocephalus are more indicative of long-term functional risk than isolated meningeal enhancement or parenchymal lesions. Clinically, early risk stratification based on enhanced MRI should be emphasized, and patients who are older or present with cerebral infarction or hydrocephalus should receive intensified monitoring and comprehensive interventions to improve long-term prognosis.

Declarations

Ethics approval and consent to participate

The study was reviewed and approved by the Ethics Committee of the Medical Ethics Review Committee of Hangzhou Red Cross Hospital (Approval No. [2024] Research Ethics No. 118-001). All procedures were performed in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Consent to participate declaration

Not applicable.

Declaration of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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Author's contributions

Study concept and design:YJ Wang and XS Huang. Data collection and analysis: YJ Wang, WQ Li and YN Hu. Drafting of the manuscript:XS Huang and Xiaowei Qiu. Amending and editing the manuscript: YN Hu

and YJ Wang. Translation of the manuscript:YJ Wang. All authors read and approved the final manuscript.

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Figures

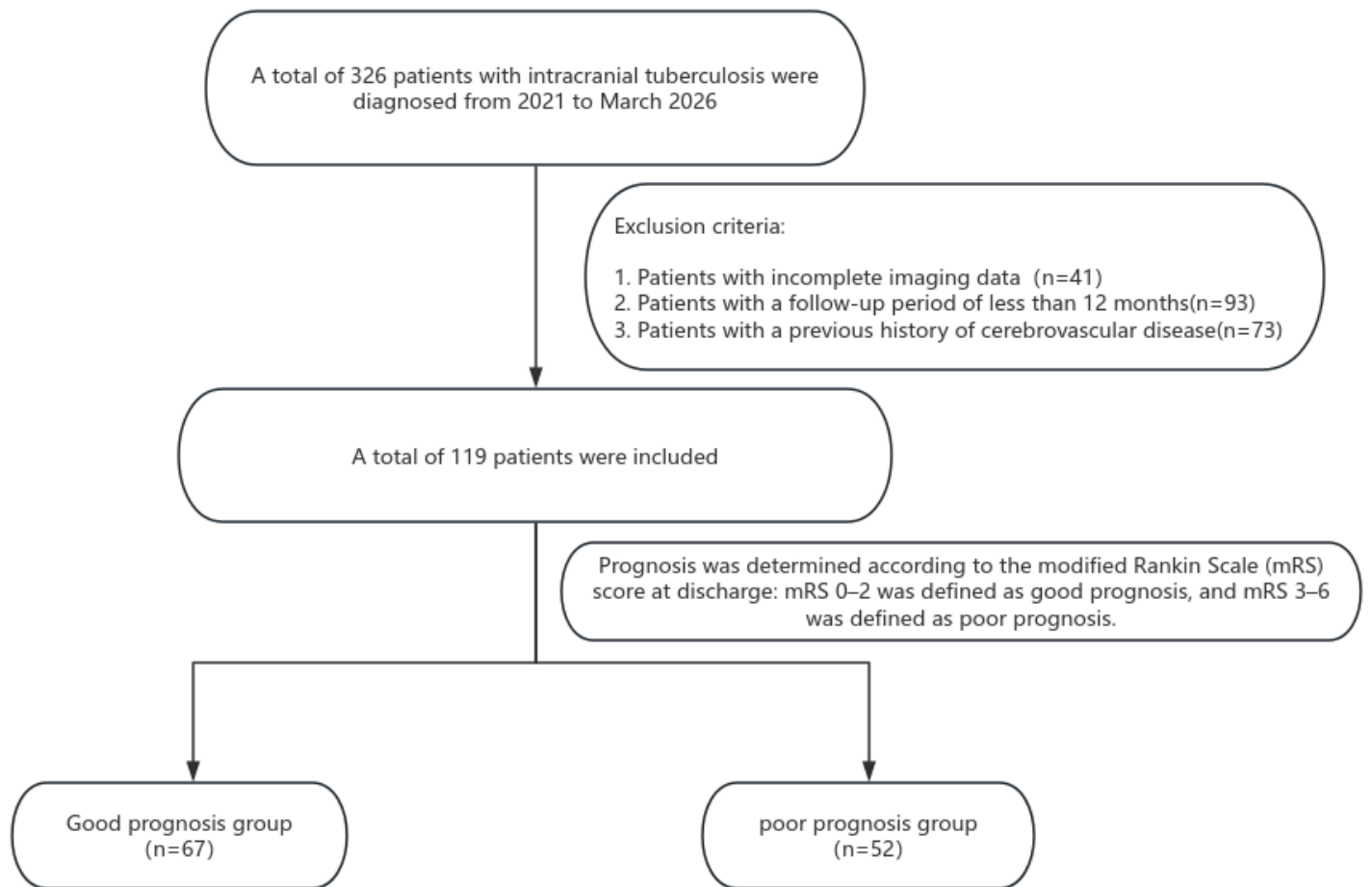


Figure 1

Flowchart

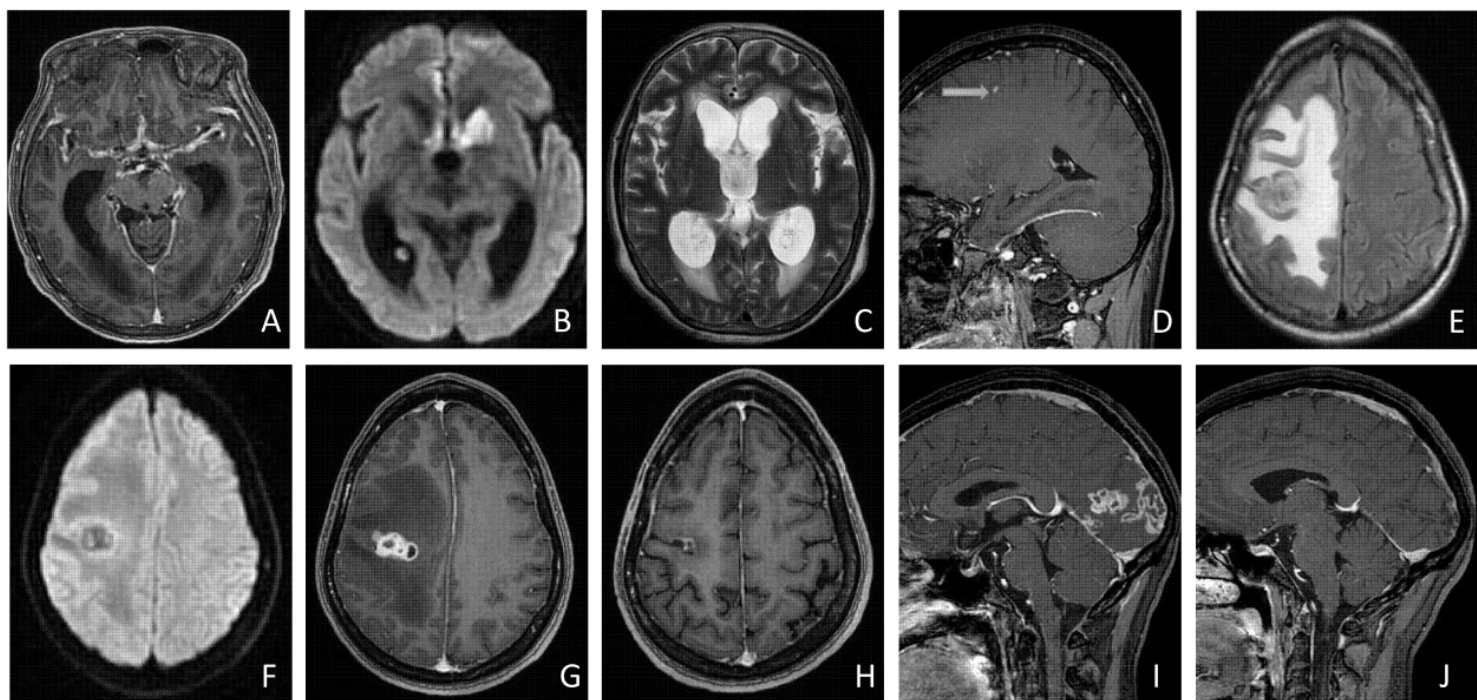


Figure 2

A–D: A 57-year-old woman with meningeal-type intracranial tuberculosis, basal cerebral arteritis, hydrocephalus (Evans index 0.34), and acute bilateral basal ganglia and frontal lobe infarctions. She discontinued anti-tuberculosis therapy after 3 months due to limb numbness. Eight months later, headache recurred; MRI showed improved meningeal thickening but new parenchymal lesions((D), grey arrow). Total follow-up 13 months; mRS 3. E–H: A 46-year-old woman with multiple tuberculous brain abscesses in the right frontal and parietal lobes with edema underwent surgical resection. One-year follow-up was normal(H); mRS 3. I–J: A 33-year-old woman with mixed-type intracranial tuberculosis completed 19 months of standard therapy. Follow-up imaging showed complete lesion resolution(J); mRS 1.

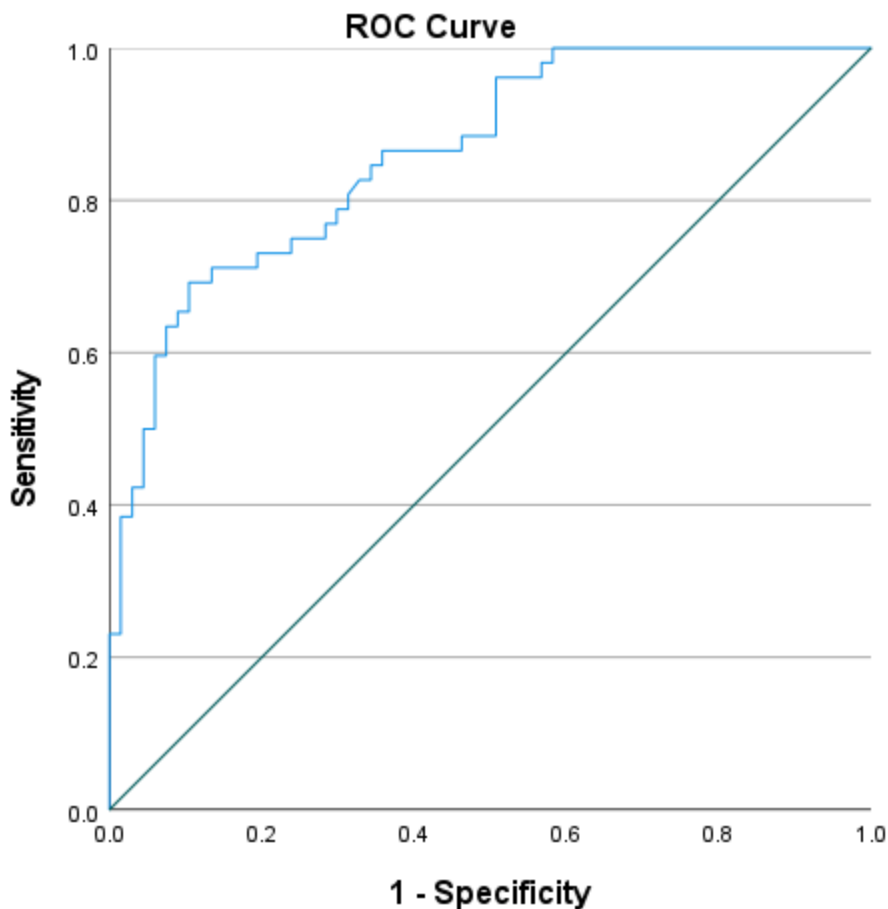


Figure 3

ROC curve of the multivariable logistic regression model for prognosis in patients with intracranial tuberculosis.

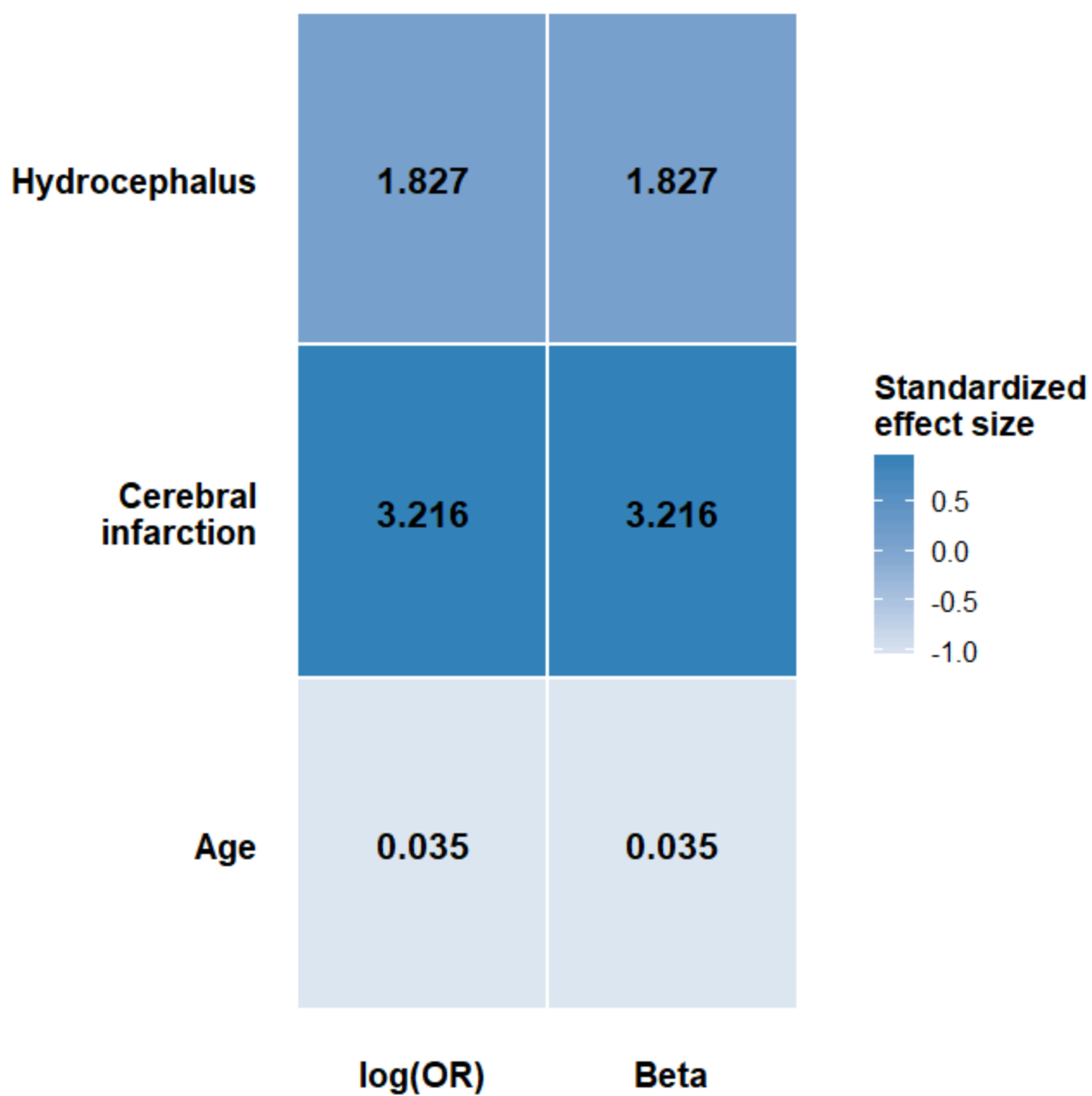


Figure 4

Heatmap of effect sizes for independent predictors of prognosis in patients with intracranial tuberculosis.