Neurosurgical Review (2020) 43:1357–1364
https://doi.org/10.1007/s10143-019-01167-4

ORIGINAL ARTICLE

Risk factors for decompressive craniectomy after endovascular treatment in acute ischemic stroke

Guoyi Peng[1] · Chuming Huang[2] · Weiqiang Chen[3] · Chukai Xu[2] · Mingfa Liu[1] · Haixiong Xu[1] · Chuwei Cai[1,4]

Received: 23 April 2019 / Revised: 7 August 2019 / Accepted: 20 August 2019 / Published online: 4 September 2019

Abstract

Endovascular treatment (EVT) is safe and effective for acute ischemic stroke (AIS) caused by large artery occlusion in the anterior circulation. However, some patients require decompressive craniectomy (DC), despite having undergone a timely EVT. This study aimed to evaluate the risk factors for subsequent DC after EVT. This retrospective cohort study comprised 138 patients who received EVT between April 2015 and June 2019 at our center. The need for subsequent DC was defined as cerebral edema or/and hemorrhagic transformation caused by large ischemic infarction, with a ≥5-mm midline shift and clinical deterioration after EVT. The relationship between risk factors and DC after EVT was assessed via univariate and multivariable logistic regression. Thirty (21.7%) patients required DC. These patients tended to have atrial fibrillation ($P = 0.037$), sedation ($P = 0.049$), mechanical ventilation ($P = 0.008$), poorer collateral circulation ($P = 0.003$), a higher baseline National Institutes of Health Stroke Scale (NIHSS) score ($P < 0.001$), heavier thrombus burden ($P < 0.001$), a lower baseline Alberta Stroke Program Early Computed Tomography Score (ASPECTS) ($P < 0.001$), and unsuccessful recanalization ($P < 0.001$). In the multivariate analysis, higher baseline NIHSS score [odds ratio (OR), 1.17; 95% confidence interval (CI), 1.03–1.32], heavier thrombus burden [OR, 1.35; 95% CI, 1.02–1.79], baseline ASPECTS ≤8 [OR, 7.41; 95% CI, 2.43–22.66], and unsuccessful recanalization [OR, 7.49; 95% CI, 2.13–26.36] were independent risk factors for DC after EVT. DC remains an essential treatment for some AIS patients after EVT, especially those with higher baseline NIHSS scores, heavier thrombus burden, baseline ASPECTS ≤8, and unsuccessful recanalization.

Keywords Artery occlusion · Thrombectomy · Stroke · Malignant MCA infarction · Decompressive craniectomy

Introduction

Intracranial carotid artery (ICA) and proximal middle cerebral artery (MCA) occlusions often result in malignant MCA infarction [1]. Although malignant MCA infarction accounts for only 1–10% of all supratentorial ischemic strokes [2], it has an almost 80% case fatality rate [1]. Decompressive craniectomy (DC) is a lifesaving surgical treatment for patients with malignant MCA infarction caused by anterior circulation artery occlusion [3]. Reports have validated that timely DC could not only reduce mortality but also improve functional outcomes [4]. Actually, DC plus standard medical treatment is the major therapeutic method for patients with malignant MCA infarction caused by anterior circulation artery occlusion.

Recently, endovascular treatment (EVT) has been proven to be a safe and effective treatment for acute ischemic stroke (AIS) caused by anterior circulation artery occlusion [5–9]. Most of those patients had a good outcome and avoided

✉ Haixiong Xu
haixiongxu18@126.com

✉ Chuwei Cai
cwcai2012@126.com

1 Department of Neurosurgery, Shantou Central Hospital, Affiliated Shantou Hospital of Sun Yat-Sen University, 114 Waima Road, Shantou 515041, Guangdong, China

2 Department of Neurology, Shantou Central Hospital, Affiliated Shantou Hospital of Sun Yat-Sen University, 114 Waima Road, Shantou 515041, Guangdong, China

3 Department of Neurosurgery, First Affiliated Hospital, Shantou University Medical College, 57 Changping Road, Shantou 515041, Guangdong, China

4 Department of Intervention Neuroradiology, Shantou Central Hospital, Affiliated Shantou Hospital of Sun Yat-Sen University, 114 Waima Road, Shantou 515041, Guangdong, China

malignant MCA infarction [5–9]. However, a mortality and disability rate of approximately 40–55.5% remains after EVT [9, 10]. Most of the cases contributing to this rate are caused by life-threatening cerebral edema or/and hemorrhagic transformation after malignant MCA infarction [10–13]. On the one hand, even though a large proportion of patients achieved recanalization by EVT, as many as 12.0–27.4% patients could not achieve recanalization [9, 11]. On the other hand, some patients still required DC even after successful recanalization. The details remain unclear. Therefore, timely identification of patients who require DC after EVT has significant clinical value.

In this study, we analyzed the potential risk factors and derived a predictive score for patients requiring DC after EVT.

Patients and methods

This study was approved by the Ethics Committee of Shantou Central Hospital. This retrospective observational study was conducted in the Department of Neurosurgery, Shantou Central Hospital, between April 2015 and June 2019. Written consent for patient information to be stored in the hospital database and used for research purposes was given by the patients or their families.

Normally, intravenous thrombolysis with tissue-type plasminogen activator (tPA) would be allowed if the patients were able to receive treatment within 4.5 h after symptom onset. Direct thrombectomy was also performed in some patients, especially those with contraindications for intravenous thrombolysis. Patients meeting the following criteria received EVT [10]: 1, patients were diagnosed with AIS; 2, age ≥ 18 and a National Institutes of Health Stroke Scale (NIHSS) score ≥ 4 before treatment; and 3, treatment could be performed within 7.3 h of symptom onset. For patients who missed the therapeutic window, treatment was still performed if they had an Alberta Stroke Program Early Computed Tomography Score (ASPECTS) ≥ 7 and were considered to have a favorable benefit-risk ratio. We excluded patients with posterior circulation and anterior cerebral artery occlusions alone, patients with intracranial hemorrhage before treatment, and patients treated only with intra-arterial thrombolysis.

Patients were admitted to an intensive care unit or stroke unit after EVT and received standard medical treatment [10]. Patients would receive incubation and mechanical treatment if there were coma and in consideration of insufficient respiration after EVT. Patients would receive sedation treatment if they exhibited signs of restless or with incubation and mechanical ventilation. Follow-up computed tomography (CT) was performed within 24 h after EVT or immediately when neurologic deterioration was detected. Clinical deterioration was defined as follows [4, 10]: the presence of anisocoria. The need for DC was defined as previously reported [4]: 1, ≥ 2/3 ischemic stroke in the territory of the MCA on the follow-up CT; 2, cerebral edema with or without hemorrhagic transformation caused by ischemic infarction, leading to ≥ 5 mm midline shifting; and 3, the presence of clinical deterioration. DC was recommended for patients meeting those requirements; ultimately, the decision was left to their families. These patients received standardized DC treatment as previously reported [3].

Data collected

We used NIHSS [14] and ASPECTS [15] to assess the severity of stroke and cerebral ischemic extension in the acute phase, respectively. The American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology (ASITN/SIR) grading system was used to evaluate the collateral circulation, and an ASITN/SIR grade < 2 indicated poor collateral circulation [16]. A modified thrombolysis in cerebral infarction (mTICI) score of ≥ 2b was considered to indicate successful recanalization. The calculated method of thrombus burden was modified from a previous report [17]; the number of thrombi was calculated by digital subtraction angiography (DSA) instead of computed tomography angiography (CTA), allotting major arteries 10 points for the presence of the ipsilateral intracranial thrombus on DSA. Two points each were calculated for the presence of thrombus in the proximal M1 segment, distal M1 segment, or supraclinoid ICA and one point each for the infraclinoid ICA, M2 branches, or A1 segment. The sum of the scores indicates the burden of thrombus. A thrombus score = 10 indicates occlusion of all major ipsilateral intracranial anterior circulation arteries. A thrombus score ≥ 4 was defined as heavier thrombus burden. Patient outcomes were assessed with the Modified Rankin Scale (mRS) at 30 days after EVT. A mRS of 0–3 was considered indicative of good recovery and a mRS of 4–6 indicated poor recovery. A predictive DC score was derived based on the results of the multivariate regression and the odds of the risk factors.

Variables including age, sex, baseline NIHSS score, history of hypertension, diabetes mellitus, atrial fibrillation, sedation before clinical deterioration, incubation and mechanical ventilation before clinical deterioration, intravenous thrombolysis with tPA, mean arterial pressure (MAP) when the patient arrived in the intervention department, baseline ASPECTS, time from symptom onset to groin puncture, time of EVT, collateral circulation, thrombus burden score, need for DC, and patient outcomes at 30 days after EVT were recorded.

Statistical analysis

All data analyses were carried out using SPSS 19 (SPSS Inc., Chicago, Illinois, USA). Sex, history of hypertension, diabetes mellitus, atrial fibrillation, sedation, mechanical ventilation, intravenous tPA, collateral circulation, mTICI, the need for DC after EVT, and 30-day mortality were compared using the chi-square test or Fisher's exact test. Age and MAP were compared using Student's *t* test. The time from symptom onset to groin puncture, time of EVT, burden of thrombus, baseline NIHSS score, and baseline ASPECTS were analyzed by the Mann-Whitney *U* test. Univariate logistic regression and multivariate forward stepwise logistic regression were performed to explore the risk factors for the need for DC. A receiver-operator characteristic (ROC) curve was used to evaluate the value of the predictive score. The results are presented as the mean with standard deviation (SD), mean with interquartile range (IQR), and odds ratio (OR) with 95% confidence interval (CI). A value of $P < 0.05$ was considered indicative of statistical significance.

Results

General characteristics

A total of 175 patients received EVT between April 2015 and June 2019 at our center. Thirty-seven patients were excluded due to the following reasons: posterior circulation artery occlusion ($n = 20$), anterior cerebral artery occlusion alone ($n = 2$), treated with intra-arterial thrombolysis alone ($n = 8$), EVT performed beyond 7.3 h of symptom onset and ASPECTS < 7 ($n = 3$), discharge before a follow-up CT ($n = 1$), hemorrhage by EVT ($n = 2$), and the presence of anisocoria with loss of the light reflex during EVT ($n = 1$).

Ultimately, 138 patients were included in this study. There were 85 men and 53 women, and the mean age was 64.12 years (range 29–87). The baseline median NIHSS score was 17 (IQR, 13–19), and the baseline ASPECTS was 9 (IQR, 8–10). Of the 138 patients, 62 (44.9%) received intravenous thrombolysis with tPA. The MAP was 112.28 mmHg (SD, 16.10). The time from symptom onset to groin puncture and time of EVT were 4.68 (IQR, 3.81–6.10) and 2.14 (IQR, 1.58–2.84), respectively. The time of clinical deterioration after EVT was 28.1 h (IQR, 11.28–37.50). Among the 138 patients, 17 patients received EVT beyond 7.3 h and showed no statistically significant difference between the time from symptom onset to groin puncture and the need for DC. The mean thrombus burden score was 2 (IQR, 2–4). Among the 138 patients, 114 (82.6%) underwent successful recanalization (mTICI ≥ 2b). The subgroup (mTICI ≥ 2b) included 74 men and 40 women, and the mean age was 60.33 years. The baseline median NIHSS score was 16 (IQR, 13–19), and the baseline ASPECTS was 9 (IQR, 8–10). Of the 114 patients, 50 (43.9%) received intravenous thrombolysis with tPA. The MAP was 111.57 mmHg (SD, 16.16). The time from symptom onset to groin puncture and time of EVT were 4.69 (IQR, 3.85–6.14) and 2.00 (IQR, 1.42–2.67), respectively. The mean thrombus burden score was 2 (IQR, 2–4). The need for DC following EVT occurred more frequently in subjects who failed to achieve recanalization (12/24; 50.0%) than in patients who had achieved recanalization (18/114; 15.8%) ($P < 0.001$). Sixty-six (47.8%) patients had functional outcomes (mRS 0–3), and the 30-day mortality was 17.4% (24/138).

Ultimately, 30 of the 138 patients (21.7%) required DC due to severe herniation caused by cerebral edema after malignant MCA infarction, and 19 of the 30 (63.3%) patients also had hemorrhagic transformation. Among the 30 patients who required DC, 11 patients had DC at the will of their family, and the other 19 patients received only standard medical treatment. At 30 days after EVT, 7 of the 11 surgical patients (63.6%) survived, whereas only 4 of the 19 (21.1%) nonsurgical subjects survived ($P = 0.047$).

In addition, patients needing DC had atrial fibrillation, sedation, mechanical ventilation, a higher baseline NIHSS score, poorer collateral circulation, heavier thrombus burden, and lower baseline ASPECTS (Table 1). No significant differences were observed in sex, age, hypertension, diabetes mellitus, intravenous tPA, MAP, time from symptom onset to groin puncture, or time of EVT between the groups. In the subgroup, significant differences were also not observed in sedation and mechanical ventilation. The baseline characteristics of the patients needing DC and those who did not are compared in Table 1.

Regression analysis

Univariate logistic regression revealed the following risk factors were related to the need for DC: sedation [OR, 2.88; 95% CI, 1.10–7.53] ($P = 0.031$), mechanical ventilation [OR, 4.55; 95% CI, 1.54–13.43] ($P = 0.006$), atrial fibrillation [OR, 2.38; 95% CI, 1.04–5.43] ($P = 0.040$), poorer collateral circulation [OR, 4.00; 95% CI, 1.52–10.56] ($P = 0.005$), higher baseline NIHSS score [OR, 1.23; 95% CI, 1.10–1.38; for each score] ($P < 0.001$), heavier thrombus burden [OR, 1.57; 95% CI, 1.24–1.99; for each score] ($P < 0.001$), baseline ASPECTS ≤ 8 [OR, 5.11; 95% CI, 2.16–12.09] ($P < 0.001$), and unsuccessful recanalization [OR, 5.33; 95% CI, 2.07–13.73] ($P = 0.001$) (Table 2). All of these factors were entered into a multivariate logistic regression analysis, and the results showed that higher baseline NIHSS score [OR, 1.17; 95% CI, 1.03–1.32; for each score] ($P = 0.014$), heavier thrombus burden [OR, 1.35; 95% CI, 1.02–1.79; for each score] ($P = 0.038$), baseline ASPECTS ≤ 8 [OR, 7.41; 95% CI, 2.43–22.66] ($P < 0.001$), and unsuccessful recanalization [OR, 7.49; 95% CI, 2.13–26.36] ($P = 0.002$) were independent predictors of needing DC after EVT (Table 3).

In the subgroup (mTICI ≥ 2b), univariate logistic regression revealed that atrial fibrillation [OR, 2.89; 95% CI, 1.03–8.06] ($P = 0.043$), poorer collateral circulation [OR, 5.00; 95% CI, 1.36–18.39] ($P = 0.015$), higher baseline NIHSS score

Table 1 Comparison of baseline demographic, clinical, and radiological characteristics between the patients with and without a need for DC after EVT

Characteristics	n = 138			mTICI ≥ 2b; n = 114		
	DC n = 30	No DC n = 108	P value	DC n = 18	No DC n = 96	P value
Sex male (%)	19 (63.3)	66 (61.1)	0.825[c]	13 (72.2)	61 (63.5)	0.479[c]
Age (SD)	63.4 (11.4)	64.3 (11.6)	0.609[d]	62.3 (8.9)	64.3 (12.0)	0.046[d]
Hypertension (%)	20 (66.7)	72 (66.7)	1.000[c]	11 (61.1)	60 (62.5)	0.911[c]
Diabetes mellitus (%)	9 (30.0)	28 (25.9)	0.656[c]	6 (33.3)	24 (25.0)	0.560[f]
Intravenous tPA (%)	12 (40.0)	50 (46.3)	0.540[c]	6 (33.3)	44 (45.8)	0.327[c]
MAP (SD)	112.6 (17.2)	112.2 (15.9)	0.622[d]	113.7 (18.3)	111.2 (15.8)	0.508[d]
EVT time (IQR)	2.33 (1.9–3.0)	2.08 (1.4–2.8)	0.113[e]	2.23 (1.8–2.6)	2.00 (1.4–2.7)	0.357[e]
Time to puncture (IQR)	4.37 (3.6–5.6)	4.79 (3.9–6.3)	0.140[e]	4.37 (3.6–5.6)	4.73 (3.9–6.4)	0.349[e]
Sedation	9 (30.0)	14 (13.0)	0.049[c]	3 (16.7)	10 (10.4)	0.429[f]
Mechanical ventilation	8 (26.7)	8 (7.4)	0.008[f]	2 (11.1)	4 (4.2)	0.240[f]
Atrial fibrillation (%)	15 (50.0)	32 (29.6)	0.037[c]	10 (55.6)	29 (30.2)	0.038[c]
ASTIN/SIR < 2 (%)	24 (80.0)	54 (50.0)	0.003[c]	15 (83.3)	48 (50.0)	0.009[c]
NIHSS score (IQR)	19 (17–21.25)	16 (12.25–19)	0.000[e]	19 (16.5–21.25)	16 (12.25–18.75)	0.001[e]
Thrombus burden (IQR)	4 (2–5.25)	2 (2–3)	0.000[e]	3.5 (2–5)	2 (2–3)	0.003[e]
ASPECTS (IQR)	8 (5.75–9.25)	9 (9–10)	0.000[e]	7.5 (5.75–9)	9 (9–10)	0.000[e]
mTICI < 2b (%)	12 (40.0)	12 (11.1)	0.000[c]	–	–	–
Death within 30 days	19 (63.3)	5 (4.6)	0.000[c]	12 (66.7)	5 (5.2)	0.000[f]

DC, decompressive craniectomy; *EVT*, endovascular treatment; *SD*, standard deviation; *tPA*, tissue-type plasminogen activator; *IQR*, interquartile range; *MAP*, mean arterial pressure; *ASTIN/SIR*, American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology; *NIHSS*, National Institutes of Health Stroke Scale; *ASPECTS*, Alberta Stroke Program Early Computed Tomography Score; *mTICI*, modified thrombolysis in cerebral infarction

[c, d, e, f], compared by using chi-square test, Student's t test, Mann-Whitney U test, and Fisher's exact test, respectively

[OR, 1.20; 95% CI, 1.06–1.36; for each score] (P = 0.006), heavier thrombus burden [OR, 1.68; 95% CI, 1.21–2.33; for each score] (P = 0.002), and baseline ASPECTS ≤ 8 [OR, 6.73; 95% CI, 2.26–20.00] (P = 0.001) were associated with needing DC (Table 2). In the multivariate analysis, heavier thrombus burden [OR, 1.74; 95% CI, 1.21–2.49; for each score] (P = 0.003) and baseline ASPECTS ≤ 8 [OR, 7.58; 95% CI, 2.33–24.73] (P = 0.001) were the independent predictors of needing DC (Table 3).

ROC analysis

Based on the risk factors, a score was derived to accurately predict DC after EVT, with one point for baseline NIHSS ≥ 19, one point for thrombus burden ≥ 4, two points for baseline ASPECTS ≤ 8, and two points for unsuccessful recanalization. The range of the scores was 0–6. The area under the ROC curve of the predictive DC score was 0.85 [95% CI, 0.76–0.93] (P < 0.001) (Fig. 1). The sensitivity and specificity were 70.0% and 88.0%, respectively. Those who with scores of 0–2 had 8.7% (9/104) incidence of DC, and 55.2% (16/29) patients with scores of 3–4 needed DC. All (100%, 5/5) of the patients with scores of 5–6 needed DC (Table 4).

Discussion

Endovascular mechanical thrombectomy is an effective treatment for AIS caused by large artery occlusions in anterior circulation [5–9]. Timely artery recanalization saved the ischemic penumbra and reduced the final infarct volume, which greatly improved patients' functional outcomes and reduced mortality [5–9]. However, in clinical practice, we found that even though timely EVT was performed, some of the patients still experienced malignant MCA infarction and required surgical intervention. Therefore, the original intention for the study came from a common clinical question: given that EVT was performed, how many patients still require DC, and how can we predict whether a subsequent DC will be needed?

In this study, we observed that 21.7% of patients ultimately needed DC after EVT. We also found that unsuccessful recanalization was highly related to the need for subsequent surgical decompression treatment. Importantly, the data showed that 15.8% (18/114) of patients who needed subsequent DC had received successful recanalization, demonstrating that DC is still an essential treatment for some AIS patients despite achieving recanalization. In addition, patients with a higher baseline NIHSS score, baseline ASPECTS ≤ 8, and heavier

Table 2 Univariate regression analysis of predictors for requiring DC after EVT

Variable	*n* = 138			mTICI ≥ 2b; *n* = 114		
	OR	95% CI	*P* value	OR	95% CI	*P* value
Male	1.10	0.48–2.54	0.825	1.50	0.49–4.54	0.481
Age	0.99	0.96–1.03	0.684	0.99	0.94–1.03	0.516
Hypertension	1.00	0.42–2.36	1.000	0.94	0.34–2.65	0.911
Diabetes mellitus	1.21	0.50–2.95	0.676	1.50	0.51–4.43	0.463
Intravenous tPA	0.77	0.34–1.76	0.540	0.59	0.21–1.70	0.330
MAP	1.00	0.98–1.03	0.888	1.01	0.98–1.04	0.536
EVT time	1.03	0.82–1.29	0.806	0.98	0.71–1.34	0.875
Time to puncture	0.86	0.72–1.03	0.094	0.90	0.73–1.09	0.253
Sedation	2.88	1.10–7.53	0.031	1.72	0.42–7.00	0.448
Mechanical ventilation	4.55	1.54–13.43	0.006	2.88	0.49–17.02	0.244
Atrial fibrillation	2.38	1.04–5.43	0.040	2.89	1.03–8.06	0.043
ASTIN/SIR < 2	4.00	1.52–10.56	0.005	5.00	1.36–18.39	0.015
NIHSS score	1.23	1.10–1.38	0.000	1.20	1.06–1.36	0.006
Thrombus burden	1.57	1.24–1.99	0.000	1.68	1.21–2.33	0.002
ASPECTS ≤ 8	5.11	2.16–12.09	0.000	6.73	2.26–20.00	0.001
mTICI < 2b	5.33	2.07–13.73	0.001	–	–	–

DC, decompressive craniectomy; *EVT*, endovascular treatment; *OR*, odds ratio; *CI*, confidence interval; *tPA*, tissue-type plasminogen activator; *MAP*, mean arterial pressure; *ASTIN/SIR*, American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology; *NIHSS*, National Institutes of Health Stroke Scale; *ASPECTS*, Alberta Stroke Program Early Computed Tomography Score; *mTICI*, modified thrombolysis in cerebral infarction

thrombus burden on DSA were prone to needing subsequent DC (Table 3). Interestingly, the analysis did not indicate any relationship between the time from symptom onset to groin puncture and the risk of needing DC.

Not surprisingly, unsuccessful recanalization was the strongest predictor of requiring DC. The risk for requiring DC was 7.5 times greater for patients without successful recanalization than for those with successful recanalization. Achieving recanalization is crucial for rescuing penumbra tissue and avoiding malignant MCA infarction [13]. Unsuccessful recanalization means unsuccessful reperfusion, and large infarctions are irreversible. Unfortunately, reports have shown that more than 27% subjects could not achieve recanalization [11]. In this study, 108 of the 138 (82.6%) patients achieved recanalization, which is consistent with previous reports [9, 11]. Kondziella et al. emphasized that DC is still a well-established therapeutic option for those who failed to achieve recanalization of the occluded artery [13].

A higher baseline NIHSS score was another independent risk factor for DC. A higher baseline NIHSS score reflects the severity of ischemic stroke onset [14]. Hao et al. found that patients with hemorrhagic transformation after EVT had a higher baseline NIHSS score [10]. In addition, previous studies showed that severe clinical deficits such as an NIHSS score > 20 with dominant and ≥ 15 with nondominant hemisphere stroke were risk factors for fatal space-occupying edema caused by ischemic stroke [13]. Hemorrhagic transformation and cerebral edema are complications of AIS, which both

Table 3 Multivariate regression analysis of predictors for requiring DC after EVT

Variable	*n* = 138			mTICI ≥ 2b; *n* = 114		
	OR	95% CI	*P* value	OR	95% CI	*P* value
NIHSS score	1.17	1.03–1.32	0.014	–	–	–
Thrombus burden	1.35	1.02–1.79	0.038	1.74	1.21–2.49	0.003
ASPECTS ≤ 8	7.41	2.43–22.66	0.000	7.58	2.33–24.73	0.001
mTICI < 2b	7.49	2.13–26.36	0.002	–	–	–

DC, decompressive craniectomy; *EVT*, endovascular treatment; *OR*, odds ratio; *CI*, confidence interval; *NIHSS*, National Institutes of Health Stroke Scale; *ASPECTS*, Alberta Stroke Program Early Computed Tomography Score; *mTICI*, modified thrombolysis in cerebral infarction

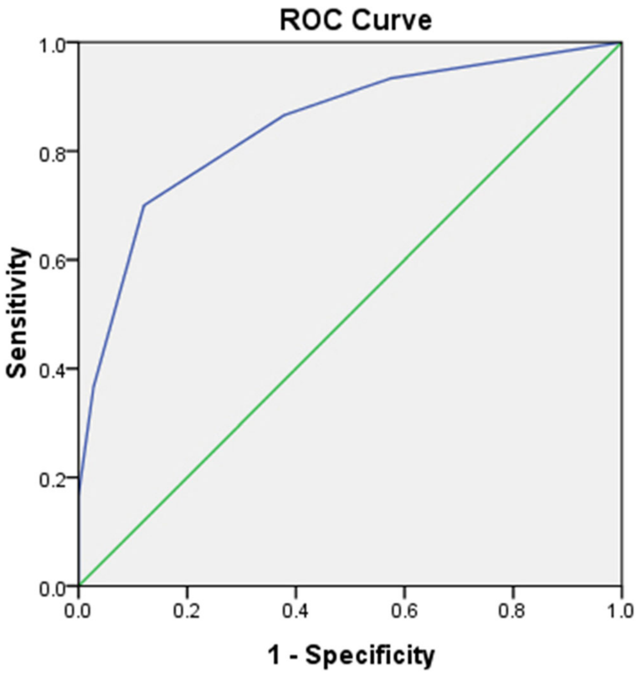

Fig. 1 A ROC analysis of the score for predicting DC after EVT. The area under the ROC curve of the predictive score was 0.85 [95% CI, 0.76–0.93] ($P < 0.001$). The sensitivity and specificity were 70.0% and 88.0%, respectively

contributed to the mass effect. Reports have shown that these two conditions have a similar mechanism [18]. Additionally, the two conditions regularly coexist and are often treated together. Hence, analyzing these two conditions together is reasonable and necessary for clinical practice. Our study further demonstrated that patients with a higher baseline NIHSS score at symptom onset were more likely to need DC even if they had received EVT. In addition, heavy thrombus burden was also found to be a predictor for subsequent DC. Studies have reported that patients with ICA occlusion or a thrombus length greater than 8 mm have a lower recanalization rate and unfavorable outcomes [19]. Furthermore, heavy thrombus burden may result in difficult recanalization of the artery. A previous study showed that > 3 passes of the retriever increase the risk of intracerebral hemorrhage [10]. Flottmann et al. reported that more passes of the retriever may lead to good recanalization rates, but clinical outcomes did not improve [20]. Similarly, reports showed that MCA infarction

Table 4 Incidence of needing DC after EVT based on the predictive score

	Predictive DC score						
	0	1	2	3	4	5	6
Total	48	23	33	20	9	2	3
Need for DC	2	2	5	10	6	2	3
Percentage (%)	4.2	8.7	15.2	50.0	66.7	100	100

with involvement of the ACA increases the risk of space-occupying infarction and represents the need for compressive craniectomy [13, 21]. Finally, a baseline ASPECTS ≤ 8 was also highly related to the need for DC, showing a 7-fold increase in odds compared with ASPECTS > 8. A lower baseline ASPECTS usually represents a large volume of unreversed infarction in the early phase [12]. A previous study also demonstrated that lower ASPECTS predicts hemorrhagic transformation [10]. Moreover, a lower baseline ASPECTS may also indicate an absence of poor collateral circulation, which increases the risk of needing DC.

Patients who need DC are associated with a poor outcome. The DESTINY study showed that DC performed within 48 h greatly reduced mortality after 30 days of follow-up [3]. However, it left 53% patients with poor outcomes after follow-up for at least 6 months, and no significant difference in functional outcomes was observed between the DC and conservative treatment groups [3]. A meta-analysis of the DESTINY, DECIMAL, and HAMLET trials showed that DC also reduced poor outcomes [22]. Vahedi et al. found that up to 43% of patients achieved functional outcomes [23]. Another study further validated that timely DC increased survival and good outcomes and, importantly, decreased survival with disabilities [4]. All these results showed that early DC after malignant MCA infarction was positively meaningful and remains one of the most crucial comprehensive treatment strategies for severe ischemic stroke. In the cohort, 30 of the 138 (21.7%) patients required DC after EVT, and even though only 11 of the 30 patients underwent DC, the results showed that DC greatly reduced mortality ($P = 0.047$). Unfortunately, most of the patients showed poor functional outcomes at the 30-day follow-up, as all of these patients underwent DC after clinical deterioration marked by pupillary change, which was greatly associated with poor outcomes.

Studies have shown that patients with age ≤ 60 who underwent DC before clinical deterioration had more chances of better outcomes [24]. Age is an unmodifiable factor among patients. However, surgical opportunity is a highly modifiable factor. Obviously, the key for improving patient functional outcomes is to identify whether a patient needs DC before showing the signs of tentorial herniation. However, DC is not necessary for every stroke patient [25], especially those with brain atrophy. If the operation indication is simply evaluated by the territories of infarction, an early surgery may be performed on patients who could have originally had good recovery [4]. If surgery is performed after neurologic deterioration, patients may miss the best time for treatment. In addition, the extensive performance of EVT reduces the number of patients who need DC [26] and makes it more difficult to identify which patients need DC in the early phase. In this observational study, we found that a higher NIHSS score at symptom onset, ASPECTS ≤ 8 on baseline CT, heavier thrombus burden, and failure to achieve recanalization were independent predictors for requiring DC following EVT. We further found that patients with scores of 0–2 had an 8.7% (9/104) incidence of DC, and 55.2% (16/29) of patients with scores of 3–4 needed DC. All (5/5) of the patients with scores of 5–6 needed DC after EVT (Table 4). Hence, we suggest that patients with scores of 3–4 should be closely monitored in an intensive care unit, with frequent neurofunctional examinations and CT scans. Intracranial pressure (ICP) monitoring is recommended for those with radiographic evidence of ≥ 2/3 MCA territories ischemic infarction, and DC should be recommended to those with unmanageable ICP hypertension (sustained greater than 20 mmHg after strong dehydration treatment). For patients with scores of 5–6, in consideration of all of those patients needing DC and the median time of clinical deterioration of 28.1 h (IQR, 11.28–37.5) after EVT, it is suggested that those patients receive a repeat CT scan within 10 h after EVT, and once evidence of early phase large ischemic infarction appears, DC should be performed, especially for those younger than 60 years who have a greater chance of achieving a good functional outcome.

Obvious limitations of this study are the small sample size and the fact that patient outcomes were assessed only at 30 days. In addition, as a retrospective study, selection bias cannot be ignored. Furthermore, DC after EVT was conservative at our center; therefore, in all patients, DC was performed only after neurologic deterioration. Thus, prospective studies with larger sample sizes are needed to further confirm these risk factors and validate whether DC after EVT before neurological deterioration could improve functional outcomes in patients with these risk factors.

Conclusion

DC remains an essential treatment for some AIS patients regardless of whether they have received successful recanalization. A higher baseline NIHSS score, lower baseline ASPECTS, heavier thrombus burden on DSA, and failure to achieve recanalization were independent risk factors for subsequent DC after EVT. In addition, DC could reduce mortality for malignant MCA infarction after EVT.

Funding information This paper was supported by the Clinical Research Program of Shantou Central Hospital.

Compliance with ethical standards

Competing interests The authors declare that they have no conflicts of interest.

Ethical approval This study was approved by the Ethics Committee of Shantou Central Hospital (2019-001).

Informed consent Obtained.

References

1. Hacke W, Schwab S, Horn M, Spranger M, DeGeorgia M, von Kummer R (1996) 'Malignant' middle cerebral artery infarction: clinical course and prognostic signs. Arch Neurol 53(4):309–315
2. Gupta R, Connolly ES, Mayer S, Elkind MS (2004) Hemicraniectomy for massive middle cerebral artery territory infarction: a systematic review. Stroke 35(2):539–543
3. Juttler E, Schwab S, Schmiedek P et al (2007) Decompressive surgery for the treatment of malignant infarction of the middle cerebral artery (DESTINY): a randomized, controlled trial. Stroke 38(9): 2518–2525
4. Lin T-K, Chen S-M, Huang Y-C, Chen P-Y, Chen M-C, Tsai H-C, Lee T-H, Chen K-T, Lee M-H, Yang J-T, Huang K-L (2016) The outcome predictors of malignant large infarction and the functional outcome of survivors following decompressive craniectomy. World Neurosurg 93:133–138
5. Berkhemer OA, Fransen PS, Beumer D, van den Berg L, Lingsma HF, Yoo AJ, Schonewille WJ, Vos JA, Nederkoorn PJ, Wermer MJ, van Walderveen M, Staals J, Hofmeijer J, van Oostayen J, Lycklama à Nijeholt GJ, Boiten J, Brouwer PA, Emmer BJ, de Bruijn SF, van Dijk L, Kappelle LJ, Lo RH, van Dijk E, de Vries J, de Kort PL, van Rooij W, van den Berg J, van Hasselt B, Aerden LA, Dallinga RJ, Visser MC, Bot JC, Vroomen PC, Eshghi O, Schreuder TH, Heijboer RJ, Keizer K, Tielbeek AV, den Hertog H, Gerrits DG, van den Berg-Vos R, Karas GB, Steyerberg EW, Flach HZ, Marquering HA, Sprengers ME, Jenniskens SF, Beenen LF, van den Berg R, Koudstaal PJ, van Zwam W, Roos YB, van der Lugt A, van Oostenbrugge R, Majoie CB, Dippel DW, MR CLEAN Investigators (2015) A randomized trial of intraarterial treatment for acute ischemic stroke. N Engl J Med 372:11–20
6. Campbell BC, Mitchell PJ, Kleinig TJ, Dewey HM, Churilov L, Yassi N, Yan B, Dowling RJ, Parsons MW, Oxley TJ, Wu TY, Brooks M, Simpson MA, Miteff F, Levi CR, Krause M, Harrington TJ, Faulder KC, Steinfort BS, Priglinger M, Ang T, Scroop R, Barber PA, McGuinness B, Wijeratne T, Phan TG, Chong W, Chandra RV, Bladin CF, Badve M, Rice H, de Villiers L, Ma H, Desmond PM, Donnan GA, Davis SM, EXTEND-IA Investigators (2015) Endovascular therapy for ischemic stroke with perfusion-imaging selection. N Engl J Med 372(11):1009–1018
7. Goyal M, Demchuk AM, Menon BK, Eesa M, Rempel JL, Thornton J, Roy D, Jovin TG, Willinsky RA, Sapkota BL, Dowlatshahi D, Frei DF, Kamal NR, Montanera WJ, Poppe AY, Ryckborst KJ, Silver FL, Shuaib A, Tampieri D, Williams D, Bang OY, Baxter BW, Burns PA, Choe H, Heo JH, Holmstedt CA, Jankowitz B, Kelly M, Linares G, Mandzia JL, Shankar J, Sohn SI, Swartz RH, Barber PA, Coutts SB, Smith EE, Morrish WF, Weill A, Subramaniam S, Mitha AP, Wong JH, Lowerison MW, Sajobi TT, Hill MD (2015) Randomized assessment of rapid endo-vascular treatment of ischemic stroke. N Engl J Med 372:1019–1030
8. Jovin TG, Chamorro A, Cobo E, de Miquel MA, Molina CA, Rovira A, San Román L, Serena J, Abilleira S, Ribó M, Millán M, Urra X, Cardona P, López-Cancio E, Tomasello A, Castaño C, Blasco J, Aja L, Dorado L, Quesada H, Rubiera M, Hernandez-Pérez M, Goyal M, Demchuk AM, von Kummer R, Gallofré M, Dávalos A (2015) Thrombectomy within 8 hours after symptom onset in ischemic stroke. N Engl J Med 372(24):2296–2306
9. Saver JL, Goyal M, Bonafe A, Diener HC, Levy EI, Pereira VM, Albers GW, Cognard C, Cohen DJ, Hacke W, Jansen O, Jovin TG, Mattle HP, Nogueira RG, Siddiqui AH, Yavagal DR, Baxter BW, Devlin TG, Lopes DK, Reddy VK, du Mesnil de Rochemont R, Singer OC, Jahan R (2015) Stent-retriever thrombectomy after intravenous t-PA vs. t-PA alone in stroke. N Engl J Med 372(24): 2285–2295

10. Hao YG, Yang D, Wang HM et al (2017) Predictors for symptomatic intracranial hemorrhage after endovascular treatment of acute ischemic stroke. Stroke 48(5):1203–1207
11. Mokin M, Abou-Chebl A, Castonguay AC, Nogueira RG, English JD, Farid H, Gupta R, Martin C, Holloway WE, Haussen DC, Mueller-Kronast N, Zaidat OO (2019) Real-world stent retriever thrombectomy for acute ischemic stroke beyond 6 hours of onset: analysis of the NASA and TRACK registries. J Neurointerv Surg 11(4):334–337
12. Park JS, Lee JM, Kwak HS, Chung GH (2019) Predictive value of CT angiography source image ASPECTS in patients with anterior circulation acute ischemic stroke after endovascular treatment: ultimate infarct size and clinical outcome. J Neurointerv Surg 11(4): 342–346
13. Kondziella D, Cortsen M, Eskesen V, Hansen K, Holtmannspötter M, Højgaard J, Stavngaard T, Søndergaard H, Wagner A, Welling KL (2013) Update on acute endovascular and surgical stroke treatment. Acta Neurol Scand 127(1):1–9
14. Brott T, Adams HP Jr, Olinger CP et al (1989) Measurements of acute cerebral infarction: a clinical examination scale. Stroke 20: 864–870
15. Barber PA, Demchuk AM, Zhang J, Buchan AM (2000) Validity and reliability of a quantitative computed tomography score in predicting outcome of hyperacute stroke before thrombolytic therapy. Aspects study group. Alberta stroke programme early CT score. Lancet 355:1670–1674
16. Zaidat OO, Yoo AJ, Khatri P et al (2013) Cerebral angiographic revascularization grading (CARG) collaborators; STIR revascularization working group; STIR thrombolysis in cerebral infarction (TICI) task force: recommendations on angiographic revascularization grading standards for acute ischemic stroke: a consensus statement. Stroke 44:2650–2663
17. Puetz V, Dzialowski I, Hill MD et al (2008) Intracranial thrombus extent predicts clinical outcome, final infarct size and hemorrhagic transformation in ischemic stroke: the clot burden score. Stroke 3: 230–236
18. Castro P, Azevedo E, Serrador J, Rocha I, Sorond F (2017) Hemorrhagic transformation and cerebral edema in acute ischemic stroke: link to cerebral autoregulation. J Neurol Sci 372:256–261
19. Riedel CH, Zimmermann P, Jensen-Kondering U, Stingele R, Deuschl G, Jansen O (2011) Successful recanalization by intravenous thrombolysis in acute anterior stroke depends on thrombus length. Stroke 42:1775–1777
20. Flottmann F, Leischner H, Broocks G et al (2018) Recanalization rate per retrieval attempt in mechanical thrombectomy for acute ischemic stroke. Stroke 49:2523–2525
21. Kamran S, Salam A, Akhtar N, D'Soza A, Shuaib A (2019) Predictors of decompressive hemicraniectomy in malignant middle cerebral artery stroke. Neurosurg Rev 42(1):175–181
22. Hofmeijer J, Kappelle LJ, Algra A et al (2009) Surgical decompression for space-occupying cerebral infarction (the hemicraniectomy after middle cerebral artery infarction with life-threatening edema trial [HAMLET]): a multicentre, open, randomised trial. Lancet Neurol 8:326–333
23. Vahedi K, Hofmeijer J, Juettler E, Vicaut E, George B, Algra A, Amelink GJ, Schmiedeck P, Schwab S, Rothwell PM, Bousser MG, van der Worp HB, Hacke W, DECIMAL, DESTINY, and HAMLET investigators (2007) Early decompressive surgery in malignant infarction of the middle cerebral artery: a pooled analysis of three randomised controlled trials. Lancet Neurol 6:215–222
24. Chen C-C, Cho D-Y, Tsai S-C (2007) Outcome and prognostic factors of decompressive hemicraniectomy in malignant middle cerebral artery infarction. J Chin Med Assoc 70(2):56–60
25. Frank JI, Schumm LP, Wroblewski K, Chyatte D, Rosengart AJ, Kordeck C, Thisted RA, HeADDFIRST Trialists, Bernardini G, Andrefsky J, Krieger D, Elkind M, Coplin W, Graffagnino C, Biller J, Wang D, Cruz-Flores S, Brock D, Demchuk A, Verro P, Frank J, Woo D, Suarez J, Pettigrew C, LaMonte M (2014) Hemicraniectomy and durotomy upon deterioration from infarction-related swelling trial. Stroke 45(3):781–787
26. Beez T, Steiger HJ (2018) Impact of randomized controlled trials on neurosurgical practice in decompressive craniectomy for ischemic stroke. Neurosurg Rev 42(1):133–137