BMJ Open

Cost-effective analysis of mechanical thrombectomy alone in the treatment of acute ischaemic stroke: a Markov modelling study

Mingyang Han,[1] Yongkai Qin,[1] Xin Tong,[2,3] Linjin Ji,[4] Songfeng Zhao ,[1] Lang Liu,[1] Jigang Chen,[2,3] Aihua Liu [2,3]

To cite: Han M, Qin Y, Tong X, *et al*. Cost-effective analysis of mechanical thrombectomy alone in the treatment of acute ischaemic stroke: a Markov modelling study. *BMJ Open* 2022;**12**:e059098. doi:10.1136/bmjopen-2021-059098

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-059098).

MH and YQ contributed equally.

Received 09 November 2021
Accepted 11 March 2022

[1]Department of Neurosurgery, Central South University Third Xiangya Hospital, Changsha, Hunan, China
[2]Beijing Neurosurgical Institute, Capital Medical University, Beijing, China
[3]Department of Interventional Neuroradiology, Beijing Tiantan Hospital, Beijing, China
[4]Department of Neurosurgery, First Affiliated Hospital of Nanchang University, Nanchang, Jiangxi, China

Correspondence to
Dr Aihua Liu; liuaihuadoctor@163.com and Dr Jigang Chen; chenjigang2015@126.com

ABSTRACT

Objective Recently, a randomised controlled trial (DIRECT-MT) demonstrated that mechanical thrombectomy (MT) was non-inferior to MT with intravenous alteplase as to the functional outcomes. This study aims to investigate whether MT alone is cost-effective compared with MT with alteplase in China.

Methods A Markov decision analytic model was built from the Chinese healthcare perspective using a lifetime horizon. Probabilities, costs and outcomes data were obtained from the DIRECT-MT trial and other most recent/comprehensive literature. Base case calculation was conducted to compare the costs and effectiveness between MT alone and MT with alteplase. One-way and probabilistic sensitivity analyses were performed to evaluate the robustness of the results.

Results MT alone had a lower cost and higher effectiveness compared with MT with alteplase. The probabilistic sensitivity analysis demonstrated that, over a lifetime horizon, MT alone had a 99.5% probability of being cost-effective under the willingness-to-pay threshold of 1× gross domestic product per capita in China based on data obtained from the DIRECT-MT trial. These results remained robust under one-way sensitivity analysis.

Conclusions MT alone was cost-effective compared with MT with alteplase in China. However, cautions are needed to extend this conclusion to regions outside of China.

Strengths and limitations of this study

- The cost-effectiveness of mechanical thrombectomy (MT) alone versus MT with alteplase has been evaluated for the first time from the perspective of Chinese healthcare.
- A decision analytic model was developed to compare the costs and effectiveness between MT alone and MT with alteplase.
- The complications of different treatment strategies such as bleeding or operation failure were not considered in the study.
- We assumed the patients with different levels of disability had the same rate of a recurrent stroke, which might not be true.
- The indirect costs such as lost work productivity were not included in this analysis.

INTRODUCTION

Stroke is a global health issue and continues to be the leading cause of mortality and disability throughout the world.[1] Mechanical thrombectomy (MT) has been demonstrated to be an effective treatment in the management of acute ischaemic stroke (AIS) caused by large vessel occlusion in the anterior cerebral circulation.[2 3] It has been compared with the intravenous administration of thrombolytic agent alteplase, which is the proven therapy for AIS.[4] Theoretically, alteplase can dissolve residual distal thrombi after MT and would contribute to reperfusion of the ischaemic area.[5–7] However, intravenous alteplase could lead to an increased risk of bleeding,[8] and partial lysis might lead to the fragmentation of target thrombus, drive them to distal vessels and complicate the MT.[9 10] Therefore, the dispute remains regarding the degree of benefits that could be gained by alteplase administration before and during thrombectomy.

Bellwald *et al*[11] compared MT alone and MT with alteplase from a pooled analysis of two prospective registries. The results showed that there were no differences in 3 month outcomes in patients with large-vessel occlusion anterior circulation stroke. Another similar study by Coutinho *et al*[12] also proved that alteplase before MT did not appear to provide a clinical benefit over MT alone. Furthermore, a recently published randomised clinical trial DIRECT-MT involving 41 academic tertiary care centres in China compared the functional outcomes of patients treated by MT alone with MT preceded by intravenous alteplase administered within 4.5 hours after symptom onset.[13] Results showed that for patients with AIS

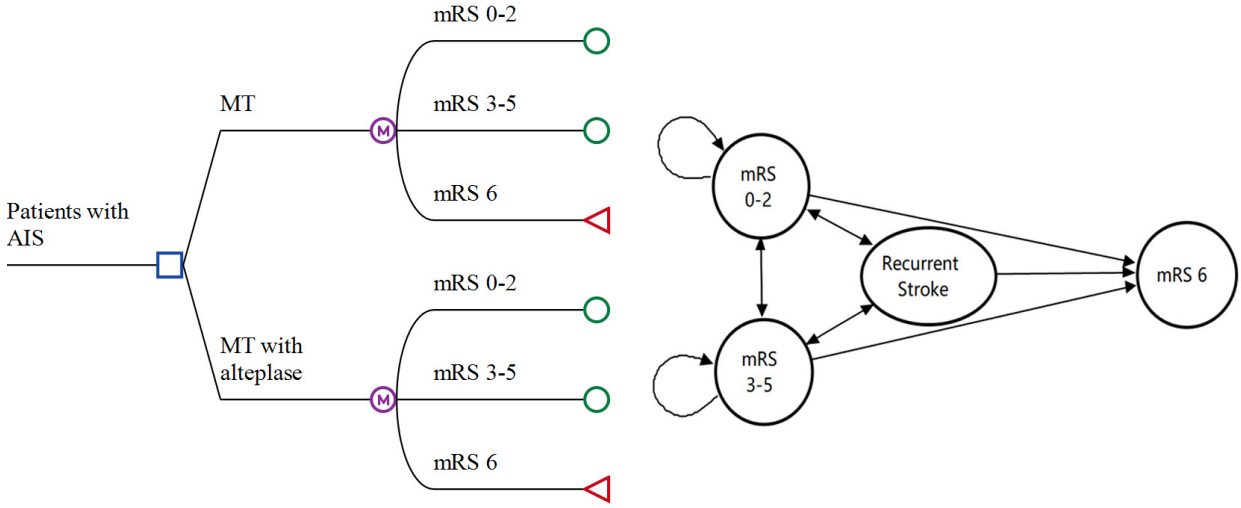

Figure 1 Structure of the decision tree model (left) and Markov model (right). AIS, acute ischaemic stroke; mRS, modified Rankin Score; MT, mechanical thrombectomy.

from large-vessel occlusion, mechanical thrombectomy was non-inferior to thrombectomy with alteplase. These studies together proved that MT alone was a reliable treatment for AIS caused by large-vessel occlusion.

The economic factor is one of the major concerns for patients to choose appropriate treatment options, especially in some low-income and middle-income countries like China. We aimed to evaluate the cost-effectiveness of MT alone versus MT with alteplase for the treatment of AIS from a healthcare perspective in China.

METHODS

Model overview

The study was conducted according to the Consolidated Health Economic Evaluation Reporting Standards reporting guidelines (online supplemental table 1). A short-run decision tree model (3-month time horizon) with a long-run (30 years) Markov state-transition model was designed in Treeage Pro Suite 2020 (Cambridge, Massachusetts, USA) to compare the costs and effectiveness between MT alone and MT with alteplase (figure 1). The target patient population was as same as that from the DIRECT-MT trial. Included patients were adults (≥18 years of age) who had an occlusion of the intracranial segment of the internal carotid artery or the first or proximal second segment of the middle cerebral artery and were available for treatment within 4.5 hours after symptom onset. The median age of patients was 69 years.

In the first 3 months, patients entered the model to receive either MT alone or MT with alteplase and then they moved to one of three possible health states defined by the modified Rankin scale (mRS) including good outcome (mRS 0–2); poor outcome (mRS 3–5); or death (mRS 6). Patients who survived (mRS 0–2 and mRS 6) at the end of the first 3 months would enter the long-run Markov state-transition model to evaluate costs and health outcomes in a lifetime horizon. This model used 3 months as a cycle and would repeat until all patients died theoretically (120 cycles seemed adequate for this purpose when all patients would reach 99 years old).

Transition probabilities

Clinical parameters were derived from the published literature (table 1). The proportions of patients in different mRS states at the end of 3 months were obtained directly from the DIRECT-MT trial.[13] We used these proportions in the base-case calculation and one-way and probabilistic sensitivity analyses. We assumed that patients could move between mRS 0–2 and mRS 3–5 only during the first year due to rehabilitation or deterioration.[14 15] After the first year, patients would remain in their current state, experience a recurrent stroke or die due to nonstroke-related causes every 3 months. Patients having a recurrent stroke were managed based on their initial treatment during the first stroke. For the independent patient, the probabilities of remaining in mRS 0–2, deteriorating to mRS 3–5 or dying were the same as the probabilities after the first stroke. For dependent patients, they could either remain in the same state or die.[14 15] We assumed that patients in the independent and dependent states had the same risk of recurrence and increased by 1.03-fold per life-year.[16]

We obtained the age-specific nonstroke death rates from the most recent published census of China and adjusted the rates according to the causes of death in 2018 reported in the China Health Statistics Yearbook 2019.[17 18] Patients in an independent state (mRS 0–2) were assumed to have the same risk of death as the general population.[19–21] However, previous studies indicated that patients in a dependent state (mRS 3–5) have increased mortality compared with independent patients, and the age-specific non-stroke death rates for dependent patients were adjusted by 1.68-fold.[19–21]

Costs and effectiveness

Only direct costs were considered in this study. Total costs included both out-of-pocket costs and reimbursements and were converted to the 2018 Chinese yuan renminbi

Table 1 List of input variables

Input variables	Mean value	Distribution	Distribution parameters	Reference
Proportions of patients in different mRS states at the end of 3 months according to different studies				
MT alone				DIRECT- MT[13]
mRS 0–2	0.365	Dirichlet	0–1	
mRS 3–5	0.457	Dirichlet	0–1	
mRS 6	0.178	Dirichlet	0–1	
MT+alteplase				
mRS 0–2	0.369	Dirichlet	0–1	
mRS 3–5	0.442	Dirichlet	0–1	
mRS 6	0.189	Dirichlet	0–1	
MT alone				Bellwald *et al*[11]
mRS 0–2	0.441	Dirichlet	0–1	
mRS 3–5	0.289	Dirichlet	0–1	
mRS 6	0.27	Dirichlet	0–1	
MT+alteplase				
mRS 0–2	0.41	Dirichlet	0–1	
mRS 3–5	0.317	Dirichlet	0–1	
mRS 6	0.273	Dirichlet	0–1	
MT alone				Coutinho *et al*[12]
mRS 0–2	0.477	Dirichlet	0–1	
mRS 3–5	0.401	Dirichlet	0–1	
mRS 6	0.122	Dirichlet	0–1	
MT+alteplase				
mRS 0–2	0.577	Dirichlet	0–1	
mRS 3–5	0.343	Dirichlet	0–1	
mRS 6	0.081	Dirichlet	0–1	
Probabilities				
Recurrent rate of stroke	0.067	Beta	SD: 0.003 Range: 0.057–0.077	27
RR of stroke recurrence per life-year	1.03	Lognormal	SD: 0.003 Range: 1.02–1.04	16
RR of non-stroke death for mRS 3–5	1.68	Lognormal	SD: 0.058 Range: 1.49–1.92	19 21
mRS 0–2 to mRS 0–2 in first year	0.955	Dirichlet	0–1	15
mRS 0–2 to mRS 3–5 in first year	0.024	Dirichlet	0–1	
mRS 3–5 to mRS 0–2 in first year	0.03	Dirichlet	0–1	
mRS 3–5 to mRS 3–5 in first year	0.946	Dirichlet	0–1	
Costs (CNY)				
MT treatment costs	72901	Gamma	SD: 3959 Range: 62704–84276	22
Alteplase treatment costs	13399	Gamma	SD: 255 Range: 12651–14178	22
One-time hospitalisation costs for mRS 0–2	10882	Gamma	SD: 173 Range: 10478–11517	20
One-time hospitalisation costs for mRS 3–5	13510	Gamma	SD: 225 Range: 13016–14376	20
One-time hospitalisation costs for mRS 6	11887	Gamma	SD: 201 Range: 11415–12621	20
Annual posthospitalisation costs for mRS 0–2	8852	Gamma	SD: 93 Range: 8577–9132	22

Continued

Table 1 Continued

Input variables	Mean value	Distribution	Distribution parameters	Reference
Annual posthospitalisation costs for mRS 3–5	13604	Gamma	SD: 253 Range: 12861–14379	22
Utility				
mRS 0–2	0.76	Beta	SD: 0.022 Range: 0.69–0.82	23
mRS 3–5	0.21	Beta	SD: 0.015 Range: 0.17–0.26	23
mRS 6	0	Beta		23
Recurrent stroke	0.20	Beta	SD: 0.017 Range: 0.16–0.26	23

CNY, Chinese yuan renminbi; mRS, modified Rankin Score; MT, mechanical thrombectomy; RR, relative risk.

(CNY) with the medical care component of the consumer price index. The costs for treatment, one-time hospitalisation and annual posthospitalisation care were extracted from Chinese-based studies and adjusted from the years of publication.[20 22]

Quality-adjusted life-years (QALYs) were measured to determine health outcomes by multiplying the length of patient-years within a particular health state by the corresponding utility scores. Utilities were assigned to each of the four possible health states (mRS 0–2, mRS 3–5, mRS 6 and recurrent stroke) based on a study by Wang *et al*[23] that evaluated the utility values using the European Quality of Life Scale and the Chinese preference weights. Utilities varied according to a beta distribution because they were flexible and ranged between 0 and 1. All costs and utilities were discounted by 3% annually.[24]

Statistical analysis

Base case calculation was performed using the mean value of each parameter. We calculated the incremental cost-effectiveness ratio (ICER) as the incremental cost per additional QALY gained. There is no standard willingness-to-pay (WTP) threshold in China and the 1–3×gross domestic product (GDP) per capita was recommended by the Macroeconomics and Health of the WHO.[25] A strategy was considered to be cost-effective if the ICER was less than the three times of GDP and to be highly cost-effective if the ICER was less than the GDP. The WTP threshold corresponded to CNY66 006/QALY to CNY198 018/QALY in the year 2018.[17]

The sensitivity analysis is based on the ICER obtained considering the DIRECT-MT data. One-way sensitivity analyses were conducted to assess the robustness of the conclusion against the key variables identified by varying one parameter while keeping the other fixed. Probabilistic sensitivity analysis was conducted with a Monte Carlo simulation (10000 iterations). All parameters were sampled simultaneously from their prespecified distributions to evaluate the impact of uncertainty. The gamma distribution was assigned to all the cost parameters since they are rightward skewed with a lower boundary of zero. The log-normal distribution was assigned to the relative risk of stroke recurrence per-year and of non-stroke death for mRS 3–5 as it reflects the ratio nature of relative risk. The beta distribution is a continuous probability distribution defined on the interval of 0–1 and can be used to reflect the probability of an event. If more than two mutually exclusive events occurred, the Dirichlet distribution was usually assigned.[26]

The two aforementioned studies also reported the proportions of patients in different health states at the end of 3 months.[11 12] We compared the results based on these two studies with those based on the DIRECT-MT trial to see if our conclusion would remain unchanged.

Patient and public involvement

Patients and/or the public were not involved in the study.

RESULTS

Base case calculation

According to the DIRECT-MT trial, MT alone was found to have an expected cost of CNY724 721 with an expected utility of 4.073 in 30 years, compared with MT with alteplase, which had a higher expected cost of CNY837 477 with lower expected QALYs of 4.064. MT alone was associated with an additional cost of −112756 and an additional QALY gain of 0.1 and therefore dominates MT with alteplase.

Sensitivity analysis

The results of one-way sensitivity analysis were presented in the tornado diagram (figure 2). The ICER was particularly sensitive to the utility of mRS 3–5, utility of recurrent stroke, relative risk of nonstroke death for mRS 3–5 and utility of mRS 0–2. All the ICERs indicated that MT alone was the dominant strategy compared with MT with alteplase when these parameters varied in their ranges.

MT alone was dominant in both the short and long term. The detailed mean, SD and 95% CI were presented in table 2. Compared with MT with alteplase, MT alone was cost-effective in 99.5% of cases with the WTP threshold of CNY66 006/QALY over the long-run model (figure 3).

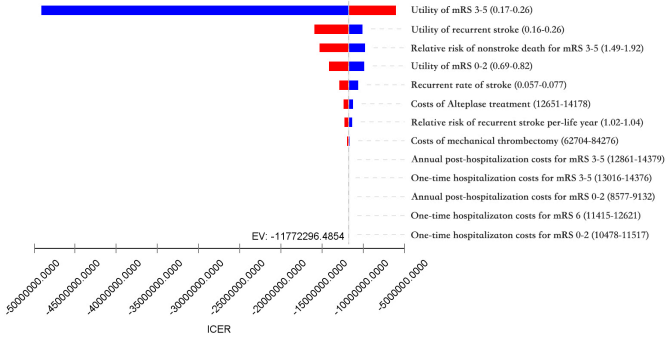

Figure 2 Tornado diagram depicting results of one-way sensitivity analyses. Effects of parameters variations on the ICER of mechanical thrombectomy alone versus mechanical thrombectomy with alteplase were presented. EV, expected value; ICER, incremental cost-effectiveness ratio; mRS, modified Rankin Score

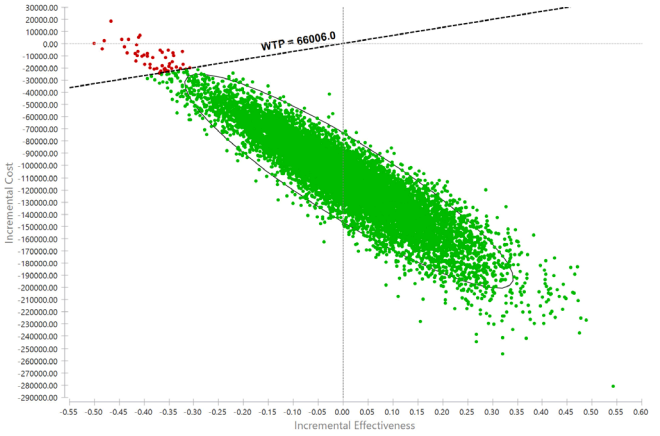

Figure 3 Probabilistic sensitivity analysis over the long-run model (30 years horizon). Incremental cost-effectiveness scatters plot of mechanical thrombectomy alone versus mechanical thrombectomy with alteplase. The dotted line represents a WTP threshold of CNY66 006/QALY. Each dot represents a simulation run (10 000 iterations). CNY, Chinese yuan renminbi; QALY, quality-adjusted life-year; WTP, willingness-to-pay.

Comparison of results based on different trials

According to the study of Bellwald *et al*, MT alone was associated with an additional QALY of 0.170 at an additional cost of CNY−148 177 when compared with MT plus alteplase, and MT alone was dominant. On the contrary, based on the trial of Coutinho *et al*, MT alone had an extra cost of CNY70 877 at an additional QALY of −0.765 when compared with MT plus alteplase, and MT plus alteplase was dominant (table 3). The cost-effectiveness plane for the probabilistic sensitivity analysis based on the three trials showing the distribution of costs and effects was presented in figure 4. The results showed that MT alone was dominant based on the data from the DIRECT-MT and Bellwald *et al* and was dominated based on the data from Coutinho *et al* when compared with MT plus alteplase.

DISCUSSION

In this study, we compared the costs and effects of MT alone to MT with alteplase for the treatment of AIS due to large vessel occlusion in the anterior cerebral circulation. Our results indicate that, based on the DIRECT-MT trial, MT alone meets the standard criteria to be cost-effective from the Chinese healthcare perspective in the base case scenario. MT alone was also cost-effective against MT with alteplase over a 3-month, 1-year and lifetime horizon (30 year). The robustness of this conclusion was further demonstrated by the one-way and probabilistic sensitivity analyses with different input parameters varying in their potential ranges. We also used the data of the first 3-month outcomes from another two studies in the base-case calculation. According to the trial of Bellwald *et al*, MT alone was associated with a lower cost and higher effectiveness than MT with alteplase, indicating that it was dominant. However, using the transition probabilities from Coutinho *et al*, an opposite result was observed and MT alone was dominated as compared with the alternative (table 2). This is because that MT plus alteplase was associated with a much higher proportion of favourable outcomes when compared with MT alone (mRS 0–2, 0.577 vs 0.477) even though the difference was not statistically significant.

Effectiveness and economic factors are the major concerns in the reimbursement decision process and market access. Although the cost of thrombectomy is higher than intravenous alteplase, it might lead to savings

Table 2 Short-term and long-term costs and effectiveness

Time	Strategy	Cost (95% CI)	QALYs (95% CI)	Incremental costs	Incremental QALYs	ICER
3 months	MT+alteplase	151 917 (147 681 to 156 370)	0.093 (0.089 to 0.098)			Reference
	MT alone	140 350 (136 522 to 144 260)	0.093 (0.089 to 0.098)	−11567	0.00	Dominant
1 year	MT+alteplase	157 777 (153 297 to 162 337)	0.275 (0.260 to 0.290)			Reference
	MT alone	146 175 (142 102 to 150 303)	0.276 (0.262 to 0.290)	−11602	0.001	Dominant
30 years	MT+alteplase	836 851 (734 048 to 950 338)	4.067 (3.824 to 4.324)			Reference
	MT alone	724 610 (638 442 to 818 892)	4.075 (3.835 to 4.328)	−112241	0.008	Dominant

ICER, incremental cost-effectiveness ratio; MT, mechanical thrombectomy; QALYs, quality-adjusted life-years.

Table 3 Comparison of base-case results based on different trials

Strategy	Cost	QALYs	Incremental costs	Incremental QALYs	ICER	Source
MT+alteplase*	837 477	4.064			Reference	Direct-MT[13]
MT alone	724 721	4.073	−112 756	0.010	Dominant	
MT+alteplase*	829 180	4.016			Reference	Bellwald, *et al*[11]
MT alone	681 003	4.186	−148 177	0.170	Dominant	
MT+alteplase	496 029	5.614			Reference	Coutinho, *et al*[12]
MT alone*	566 906	4.848	70 877	−0.765	Dominated	

*Dominated strategy.
ICER, incremental cost-effectiveness ratio; MT, mechanical thrombectomy; QALYs, quality-adjusted life-years.

downstream in stroke treatment and care pathway due to the better outcomes. Studies have investigated the difference of alteplase alone with and without MT from an economic point of view. For example, Ganesalingam *et al*[15] compared the cost-effectiveness of intravenous alteplase alone versus MT with alteplase as bridging therapy in eligible patients from the UK. Their results showed that MT was more expensive than alteplase, but it improved QALY for patients. The ICER was under the WTP threshold over a 20-year period and MT was thus considered cost-effective in the UK.[15]

To the best of our knowledge, this is the first study that investigates the cost-effectiveness of MT alone and MT with alteplase for the treatment of AIS patients in China. One potential reason for this might be that no high-quality randomised controlled trials comparing the treatment effects between MT with and without alteplase have been published until the DIRECT-MT trial. Conducting a cost-effectiveness analysis based on randomised clinical research would improve the study quality and render a more reliable conclusion. Though the MT alone was not cost-effective compared with MT with alteplase according to the study of Coutinho *et al*, this study did not target the Chinese population and thus might lead to a different conclusion under the Chinses healthcare perspective.

One of the strengths of this study was that we derived all the data for the model from the Chinese resources. It might provide a reference for medical workers and policy-makers to commit to cost-effective practice. However, we acknowledge there are some limitations in our study that need to be considered when interpreting the results. First, the complications of different treatment strategies such as bleeding or operation failure were not considered in the study; however, considering that patients receiving MT with alteplase might have higher complication rates than MT alone, resulting in higher cost and lower quality. The conclusion would remain the same. Second, we assumed the patients with different levels of disability had the same rate of a recurrent stroke while this rate might be higher among the more disabled; however, this is not unprecedented in other similar studies, and sensitivity analysis showed that the model was not sensitive to the recurrence rate. Third, patients with a recurrent stroke were assumed to have the same treatment as the initial stroke, and the mortality remained to be as same as the initial treatment. This group of patients might have higher mortality rates after the first stroke. Last, we conducted this study from the Chinese healthcare perspective and the indirect costs like lost work productivity were not included in this analysis because these costs were difficult to estimate.

CONCLUSIONS

Based on the data from the DIRECT-MT trial, the current study demonstrates that MT alone to treat AIS caused by large vessel occlusion in the anterior cerebral circulation is cost-effective compared with MT with alteplase from the Chinese healthcare perspective. However, cautions

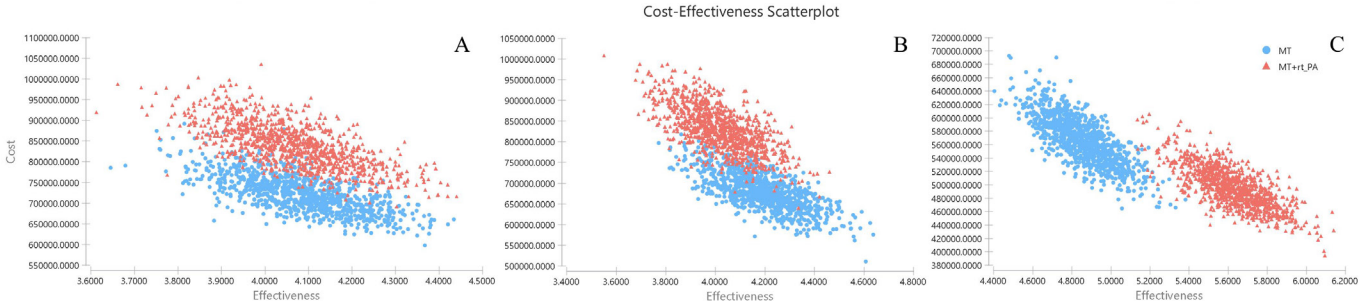

Figure 4 Cost-effectiveness plane according to probabilistic sensitivity analysis over the long-run model (30 years horizon) based on different trials. (A) The result was based on the DIRECT-MT trial. (B) The result was based on the trial of Bellwald *et al*. (C) The result was based on the trial of Coutinho *et al*.[12]

are needed to extend this conclusion to regions outside of China.

Acknowledgements We would like to express our gratitude to Yuesong Pan, an expert who has 6 years of performing cost-effectiveness, for his work in reviewing and validating the model structure, data source, statistical analyses and results. We would also like to thank Yuesong Pan and Zhifei Wang for giving options about the value of clinical parameters.

Contributors AL, JC, MH and YQ conceived the study and participated in its design and coordination. MH, XT, LJ, SZ and LL performed the data collection. AL, JC, MH and YQ performed the statistical analyses and interpretation and drafted the manuscript. All authors read and approved the final manuscript. AL and JC accept full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

Funding This study is funded by the Beijing Science and Technology Planning Project (No. Z181100009618035).

Disclaimer The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This was a modelling study and ethical approval from the institutional review board was waived because no real human subjects were involved.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. Data are available on reasonable request from the corresponding author.

ORCID iDs
Songfeng Zhao http://orcid.org/0000-0003-3071-9115
Aihua Liu http://orcid.org/0000-0002-6391-805X

REFERENCES

1 Johnson CO, Nguyen MH, Roth GA, *et al*. Global, regional, and national burden of stroke, 1990-2016: a systematic analysis for the global burden of disease study 2016. *Lancet Neurol* 2019;18:439–58.
2 Goyal M, Demchuk AM, Menon BK, *et al*. Randomized assessment of rapid endovascular treatment of ischemic stroke. *N Engl J Med* 2015;372:1019–30.
3 Jovin TG, Chamorro A, Cobo E, *et al*. Thrombectomy within 8 hours after symptom onset in ischemic stroke. *N Engl J Med* 2015;372:2296–306.
4 Grotta JC, Kothari M, Welch K. Tissue plasminogen activator for acute ischemic stroke. The National Institute of neurological disorders and stroke rt-PA stroke Study Group. *N Engl J Med* 1995;333:1581–8.
5 Desilles J-P, Loyau S, Syvannarath V, *et al*. Alteplase reduces downstream microvascular thrombosis and improves the benefit of large artery recanalization in stroke. *Stroke* 2015;46:3241–8.
6 Seners P, Turc G, Maïer B, *et al*. Incidence and predictors of early recanalization after intravenous thrombolysis: a systematic review and meta-analysis. *Stroke* 2016;47:2409–12.
7 Tsivgoulis G, Katsanos AH, Schellinger PD, *et al*. Successful reperfusion with intravenous thrombolysis preceding mechanical thrombectomy in large-vessel occlusions. *Stroke* 2018;49:232–5.
8 Wardlaw JM, Murray V, Berge E, *et al*. Thrombolysis for acute ischaemic stroke. *Cochrane Database Syst Rev* 2014;113.
9 Kaesmacher J, Boeckh-Behrens T, Simon S, *et al*. Risk of thrombus fragmentation during endovascular stroke treatment. *AJNR Am J Neuroradiol* 2017;38:991–8.
10 Alves HC, Treurniet KM, Jansen IGH, *et al*. Thrombus migration paradox in patients with acute ischemic stroke. *Stroke* 2019;50:3156–63.
11 Bellwald S, Weber R, Dobrocky T, *et al*. Direct mechanical intervention versus bridging therapy in stroke patients eligible for intravenous thrombolysis: a pooled analysis of 2 registries. *Stroke* 2017;48:3282–8.
12 Coutinho JM, Liebeskind DS, Slater L-A, *et al*. Combined intravenous thrombolysis and thrombectomy vs thrombectomy alone for acute ischemic stroke: a pooled analysis of the swift and StAR studies. *JAMA Neurol* 2017;74:268–74.
13 Yang P, Zhang Y, Zhang L, *et al*. Endovascular thrombectomy with or without intravenous alteplase in acute stroke. *N Engl J Med Overseas Ed* 2020;382:1981–93.
14 Peultier A-C, Redekop WK, Allen M, *et al*. Exploring the cost-effectiveness of mechanical thrombectomy beyond 6 hours following advanced imaging in the United Kingdom. *Stroke* 2019;50:3220–7.
15 Ganesalingam J, Pizzo E, Morris S, *et al*. Cost-utility analysis of mechanical thrombectomy using stent retrievers in acute ischemic stroke. *Stroke* 2015;46:2591–8.
16 Pennlert J, Eriksson M, Carlberg B, *et al*. Long-term risk and predictors of recurrent stroke beyond the acute phase. *Stroke* 2014;45:1839–41.
17 National Health Commission of the People's Republic of China. *China health statistics yearbook 2019*. Beijing: Peking Union Medical College Press, 2019.
18 National Bureau of Statistics of China. The 2010 population census of the peaple's republic of china (in Chinese). Available: http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm [Accessed 25 Feb 2016].
19 Slot KB, Berge E, Sandercock P, *et al*. Causes of death by level of dependency at 6 months after ischemic stroke in 3 large cohorts. *Stroke* 2009;40:1585–9.
20 Pan Y, Zhang L, Li Z, *et al*. Cost-effectiveness of a multifaceted quality improvement intervention for acute ischemic stroke in China. *Stroke* 2020;51:1265–71.
21 Samsa GP, Reutter RA, Parmigiani G, *et al*. Performing cost-effectiveness analysis by integrating randomized trial data with a comprehensive decision model: application to treatment of acute ischemic stroke. *J Clin Epidemiol* 1999;52:259–71.
22 Pan Y, Cai X, Huo X, *et al*. Cost-effectiveness of mechanical thrombectomy within 6 hours of acute ischaemic stroke in China. *BMJ Open* 2018;8:e018951.
23 Wang Y-L, Pan Y-S, Zhao X-Q, *et al*. Recurrent stroke was associated with poor quality of life in patients with transient ischemic attack or minor stroke: finding from the chance trial. *CNS Neurosci Ther* 2014;20:1029–35.
24 Pan Y, Wang A, Liu G, *et al*. Cost-effectiveness of clopidogrel-aspirin versus aspirin alone for acute transient ischemic attack and minor stroke. *J Am Heart Assoc* 2014;3:000912.
25 Commission on Macroeconomics and Health of World Health Organization. Choosing interventions that are cost effective (WHO-CHOICE). Available: http://www.who.int/choice/costs/CER_thresholds/en/ [Accessed 17 Oct 2012].
26 Gray AM, Clarke PM, Wolstenholme JL. *Applied methods of cost-effectiveness analysis in healthcare*. OUP Oxford, 2010.
27 Wang Y, Li Z, Zhao X, *et al*. Effect of a multifaceted quality improvement intervention on hospital personnel adherence to performance measures in patients with acute ischemic stroke in China: a randomized clinical trial. *JAMA* 2018;320:245–54.