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REVIEW ARTICLE

Acute ischaemic stroke: a systematic review of the cost-effectiveness of emergency endovascular therapy using mechanical thrombectomy

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Abstract

Purpose Although good evidence exists regarding the clinical effectiveness of mechanical thrombectomy for people with acute ischaemic stroke, cost-effectiveness should also be considered. The aim of this study was to systematically review the evidence of cost-effectiveness of emergency endovascular therapy using mechanical thrombectomy in the management of acute ischaemic stroke.

Methods The search was carried out in PubMed, EMBASE, Cochrane Library, and a grey literature search. Studies were included if they compared the costs and consequences of mechanical thrombectomy added to usual medical care compared to usual care alone for people with acute ischaemic stroke in the anterior and/or posterior region. Study quality was assessed using two appraisal tools tailored to economic evaluations.

Findings Thirteen studies were identified including twelve cost-utility analyses and one cost-benefit analysis. Studies could be dichotomised into those that evaluated first-generation ($n = 4$) and second-generation ($n = 9$) mechanical thrombectomy devices. Six studies had low applicability, six had moderate applicability, and one had high applicability to other settings. All cost-utility studies reported incremental cost-effectiveness ratios that would be considered cost-effective under typical willingness-to-pay thresholds.

Conclusions If the outcomes of the trials underpinning the evidence of clinical effectiveness can be replicated, then mechanical thrombectomy is likely to be cost-effective by typical willingness-to-pay thresholds. This finding holds under the assumption that no investment is required to develop stroke centres to the standard required to provide a safe emergency endovascular service and that additional expenditure on timely patient transport is not required.

Keywords Cost-effectiveness · Cost-utility · Endovascular therapy · Ischaemic stroke · Mechanical thrombectomy · Systematic review

Introduction

Acute ischaemic stroke occurs as a result of an obstruction within a blood vessel supplying to the brain, disrupting the flow of blood to the brain causing a focal or global neurological deficit (affecting bodily functions or mental processes) lasting more than 24 h or causing death within 24 h [1]. Stroke is the second leading cause of death globally, and half of the 6.5 million stroke deaths each year are due to ischaemic stroke [2]. Ischaemic stroke also results in a substantial burden of disability.

Since publication of the National Institute of Neurological Disorders and Stroke (NINDS) study results in 1995 [3], intravenous tissue plasminogen activator (IV t-PA) became a key component in the treatment of acute ischaemic stroke and has become a standard medical care [4]. However, the effectiveness of IV t-PA is linked to how soon after stroke onset the intervention is provided and is associated with a relatively narrow treatment window of 4.5 h. The efficacy of intra-arterial thrombolysis (IAT) was suggested in a number of clinical trials, although PROACT II remains the only randomised controlled trial (RCT) of IAT versus IV t-PA

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which has demonstrated statistically significant clinical benefit in favour of IAT [5].

Endovascular therapy using mechanical thrombectomy devices aims to retrieve thrombi and rapidly restore blood flow in patients with acute ischaemic stroke. Based on their time of development and approval for use, these devices can be classified as 'first-' and 'second-generation' retrieval devices. Between 2013 and the end of 2016, ten RCTs reported results comparing mechanical thrombectomy plus routine medical care (including IV t-PA and or IAT if appropriate) to routine medical care, three based on first-generation and seven based on second-generation stent-retriever devices [6]. Although the results for the first three trials were equivocal, meta-analyses have shown that the use of second-generation devices within 6 to 12 h of stroke onset substantially increases the proportion of patients achieving functional independence 90 days after stroke [6].

An international, multi-society consensus document was published in 2016, outlining many of the requirements for institutions providing emergency endovascular procedures for acute stroke [7]. Endovascular therapy should be provided within comprehensive and advanced stroke centres which have advanced neuro-imaging capability, coordinated stroke care, specialised stroke teams, and a stroke unit to provide appropriate care and recovery after the hyperacute period [8]. The provision of mechanical thrombectomy can also have potentially important implications for long-term post-stroke care given the impact on functional independence.

While there may be good evidence regarding the clinical effectiveness of mechanical thrombectomy for people with acute ischaemic stroke, cost-effectiveness is also an important consideration. This is particularly relevant given the requirements associated with the provision of a safe endovascular therapy service. For budget-constrained health systems, it is imperative that interventions are not only clinically effective, but also efficient from an economic standpoint. The aim of this study was to systematically review the evidence of cost-effectiveness of mechanical thrombectomy.

Methods

The systematic literature review was conducted following the PRISMA guidelines [9].

Inclusion criteria

Eligible studies compared the costs and consequences of mechanical thrombectomy added to routine care compared to routine care alone for people with acute ischaemic stroke in the anterior and/or posterior region. Studies had to report the cost-effectiveness of the intervention. The studies could be randomised controlled trials (RCTs), observational studies, or economic modelling studies. Studies only published as abstracts were excluded as study quality could not be appropriately appraised.

Search strategy

The search was carried out in PubMed, EMBASE, and the Cochrane Library. Search terms and filters for economic evaluations were applied (see supplementary appendix for search terms). A search of the main health technology assessment (HTA) agency websites and Google was also used to identify grey literature. In addition, systematic reviews of the clinical effectiveness of mechanical thrombectomy were hand-searched for primary studies that included cost or economic outcomes. The search period was from January 1, 2005, to December 31, 2016, and restricted to English language publications.

Data extraction and quality assurance

Preliminary screening of all returned results was carried out by a single person to eliminate studies that were clearly not relevant. Assessment of study eligibility and identification of multiple reports from single studies, data extraction, and quality assessment were carried out for each study independently by two reviewers. Any disagreements were resolved by discussion and mutual agreement between the two reviewers.

Study quality was assessed using the Consensus on Health Economic Criteria (CHEC) list [10]. For studies that incorporated an economic model, the relevance and credibility of the studies were assessed using a questionnaire from the International Society for Pharmacoeconomics and Outcomes Research (ISPOR) [11]. Study applicability was graded as high, moderate, or low. A 'moderate' grading indicated that the study was subject to bias, but the findings were likely to be broadly accurate and applicable to other settings. A 'low' grading identified studies at significant risk of bias and the results were therefore unlikely to be accurate, or it was unlikely that the results would be applicable to other settings.

For comparability, the costs reported in each study were inflated to 2016 values using the local consumer price index for health and converted to US dollars using the purchasing power parity exchange rate [12]. Cost-based results are reported as per the original studies followed by the 2016 US dollar equivalents in parentheses.

Due to the differences in unit costs and methods of economic evaluation, a narrative review approach was used.

Results

The initial search identified 1,909 unique articles, with 33 potentially relevant based on the title and abstract. Fourteen

publications representing 13 eligible studies were subsequently identified (Fig. 1). The studies included twelve cost-utility analyses and one cost-benefit analysis (i.e., where clinical outcomes are valued in monetary terms). Eight studies were based in North America and the remaining five were European-based. Details of the excluded articles are given in the supplementary appendix.

Four studies evaluated first-generation devices in the absence of RCT data to support estimates of clinical effectiveness [13–16], with three presented as exploratory analyses due to the substantial uncertainty around the clinical effectiveness of endovascular treatment requiring RCT evidence to confirm results.

Study findings

Three early evaluations were US-based and used data from the Multi-MERCI trial [13–15]. All three studies took a societal perspective, applied a discount rate of 3% to costs and benefits, and used a 20-year or lifetime time horizon. The comparator differed across the three studies, variously defined as follows: standard therapy with anti-platelet agents and supportive care, but excluding the use of thrombolytics such as tPA; best medical therapy outside the 3-h window for IV t-PA; and IV t-PA alone. Long-term outcomes were modelled based on successful recanalisation and incidence of symptomatic intra-cerebral haemorrhage (SICH). The estimated incremental cost-effectiveness ratios (ICERs) ranged from $9,386 ($11,587) to $16,001 ($19,753) per quality-adjusted life year (QALY).

A Dutch study from 2013 was the last evaluation published based on evidence from first-generation devices [16]. The comparator was IV t-PA alone. The assessment took a payer perspective and used time horizons of 6 months and lifetime. Parameter values for the economic model came from a variety of sources, including expert opinion for some of the key outcomes. The ICERs were €31,687 ($47,577) per QALY at 6 months and €1,922 ($2,886) per QALY at lifetime.

Subsequent studies used data from one or more of the first five RCTs of second-generation stent-retriever mechanical thrombectomy devices published between 2013 and 2015.

Two US studies used modified Rankin Score (mRS) outcome data from the MR CLEAN trial [17, 20]. The first, by Leppert et al., was a cost-utility analysis comparing mechanical thrombectomy plus intra-arterial therapy (IAT) to IV t-PA alone for patients who received thrombolysis within 4.5 h of symptom onset and IAT within 6 h [17]. Based on a payer perspective, a discount rate of 3% and a 30-year time horizon, the ICER for IAT was $14,137 ($15,798) per QALY. A cost-benefit analysis by Mangla et al. compared mechanical thrombectomy with IV t-PA alone [20]. A QALY was valued at $129,090 ($133,981), discounting was not applied, and there was no assessment of uncertainty.

Five evaluations used clinical effectiveness estimates pooled across five RCTs of mechanical thrombectomy: MR CLEAN, ESCAPE, EXTEND-IA, SWIFT PRIME, and REVASCAT [18, 19, 21, 23, 25]. The five studies all compared the intervention plus IV t-PA with IV t-PA alone, and none of the economic studies specified treatment windows in relation to symptom onset. A UK study, adopting a payer

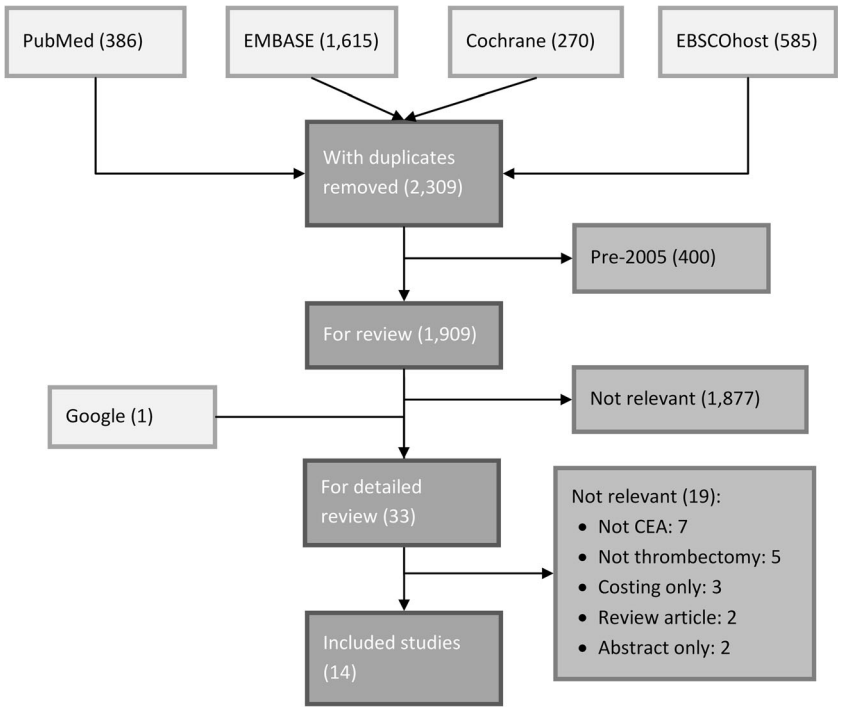

Fig. 1 PRISMA flowchart diagram of search results

perspective over a 20-year time horizon, estimated an ICER of $11,651 ($10,998) per QALY [18]. An evaluation by Health Quality Ontario estimated an ICER of CA$11,990 ($9,972) based on a 5-year time horizon and a discount rate of 5% [21]. Two Swedish evaluations were also published, both adopting a 20-year or lifetime time horizon. The first to be published, by Thurman et al., took a societal perspective and did not include discounting [19]. The ICER for mechanical thrombectomy was estimated at SEK45,000 ($5,005) per QALY. The second study, by Aronsson et al., found that mechanical thrombectomy dominated usual care, that is, it was more effective and less costly than IV t-PA alone [23]. A 2016 German study combined pooled individual-level data from the five RCTs with US cost data from a previously published analysis [25]. An economic model was used to project outcomes to 30 years for patients aged 68 years at the start of the model. The study estimated an ICER of $3,110 ($3,228) per QALY in the base case and also investigated various patient subgroups based on severity of stroke, time to treatment, and location of occlusion. For all patient subgroups, the ICER was below $50,000 per QALY or treatment dominated routine care.

Finally, two studies used outcome data from the SWIFT PRIME study to estimate the cost-effectiveness of combined stent-retriever thrombectomy and IV t-PA compared with IV t-PA alone [24, 26]. In a UK study, patients were assumed to receive the intervention within 6 h of symptom onset [24]. In addition to lifetime, time horizons of 1, 2, and 5 years were also used. The intervention dominated IV t-PA alone at time horizons of 2 and 5 years and lifetime. At a time horizon of 1 year, the ICER was £369 ($563) per QALY. A second study used data from the SWIFT PRIME trial to inform costs and outcomes and then appended a model component to estimate longer-term costs and outcomes to patient life expectancy [26]. It was assumed that mRS outcomes and utility values would not change after 90 days except due to mortality. The intervention was found to dominate usual care (Table 1).

Applicability of the included studies

Six studies were considered of low applicability [14–16, 19, 20, 26], six were of moderate applicability [13, 17, 18, 23–25], and one was graded as highly applicable [21]. Low applicability was associated with serious methodological issues (for example, a failure to apply discounting) and concerns over data sources (for example, data on recanalisation rates for the intervention and comparator coming from different sources). Studies graded as moderate applicability failed to adequately describe data sources or included data from a single trial where outcomes from multiple trials were available.

A lack of clear reporting was common across studies, creating ambiguity over parameters including included costs and the proportion of patients in the intervention arm receiving mechanical thrombectomy (Fig. 2).

The majority of studies used probabilistic models with parameter values defined as distributions. The impact of parameter uncertainty on the estimated cost-effectiveness could be explored through one-way and multivariate sensitivity analysis. Parameters for which uncertainty consistently had a marked impact on the estimate of cost-effectiveness were the thrombectomy procedure cost, long-term care cost, and the average age of patients. Mechanical thrombectomy was more cost-effective when the procedure cost was lower, when the long-term care cost was higher, and when patients were younger at the time of stroke. However, within sensitivity analyses, the intervention was generally found to be considered cost-effective or cost saving.

For evaluations of second-generation devices, clinical outcomes were expressed in terms of mRS at 90 days. Subsequent quality of life was estimated based on mRS at 90 days with some studies allowing for recurrent stroke and an associated potential for further reduced mRS. Quality of life was estimated by applying utilities to each mRS score, and the utility values used varied substantially across studies (Fig. 3). Two studies used weights that were high for mRS scores of 0 and 1, but low for scores of 4 and 5 relative to the remaining studies [20, 24]. The choice of utility weights in those two studies resulted in a greater benefit for mechanical thrombectomy relative to the other studies. The Canadian study dichotomised survival into two health states: functional independence and functional dependence [21]. Within those two categories, there is likely to be substantial heterogeneity in costs and utilities.

Discussion

Based on a systematic review, thirteen studies were identified that estimated the cost-utility or cost-benefit of mechanical thrombectomy relative to standard care. Studies could be dichotomised into evaluations of first- and second-generation devices. The clinical effectiveness of second-generation devices is supported by data from multiple RCTs and is considered the best level of evidence. The applicability of the economic evaluations to other healthcare systems was mixed, but was generally poor or moderate.

Applicability of studies

One study was identified, by Health Quality Ontario, which included a detailed and comprehensive economic evaluation and considered highly applicable to Ireland [21, 22]. The study found mechanical thrombectomy plus IV t-PA to be cost-effective relative to IV t-PA alone. Detailed sensitivity analysis suggests that other than by adopting a 1-year time

Table 1 Characteristics of economic evaluations of mechanical thrombectomy

Author (year)	Country	Technology	Comparator	Evaluation type	Quality
Patil et al. (2009) [13]	USA	Merci retriever	Standard medical therapy with no thrombolytics	Cost-utility	Moderate
Nguyen-Huynh and Johnston (2011) [14]	USA	Merci retriever	Best medical therapy outside the 3-h IV t-PA window	Cost-utility	Low
Kim et al. (2011) [15]	USA	Merci retriever	IV t-PA alone within 3-h IV t-PA window	Cost-utility	Low
Bouvy et al. (2013) [16]	Netherlands	Stent retrievers	IV t-PA alone and conservative medical therapy	Cost-utility	Low
Leppert et al. (2015) [17]	USA	CE-marked devices	IV t-PA alone	Cost-utility	Moderate
Ganesalingam et al. (2015) [18]	UK	Stent retrievers	IV t-PA alone	Cost-utility	Moderate
Thurman et al. (2015) [19]	Sweden	New-generation devices	IV t-PA alone	Cost-utility	Low
Mangla et al. (2016) [20]	USA	CE-marked devices	IV t-PA alone	Cost-benefit	Low
Ontario (2016) [21, 22]	Canada	New-generation devices	IV t-PA alone	Cost-utility	High
Aronsson et al. (2016) [23]	Sweden	Stent retrievers	IV t-PA alone	Cost-utility	Moderate
Lobotesis et al. (2016) [24]	UK	CE-marked devices	IV t-PA alone	Cost-utility	Moderate
Kunz et al. (2016) [25]	USA	New-generation devices	IV t-PA alone	Cost-utility	Moderate
Shireman et al. (2017) [26]	USA	Solitaire stent retriever	IV t-PA alone	Cost-utility	Low

ICER, incremental cost-effectiveness ratio; *QALY*, quality-adjusted life year; *IV t-PA*, intravenous tissue plasminogen activator; *CE*, Conformité Européene

horizon, mechanical thrombectomy is likely to be considered cost-effective relative to a willingness-to-pay threshold of CAN$20,000 per QALY. The findings of the Ontario study in terms of cost-effectiveness are similar to the other identified studies, providing reassurance about the consistency of cost-effectiveness evidence. There is no universal willingness-to-pay threshold below which interventions are considered cost-effective, and many countries have no stated willingness-to-

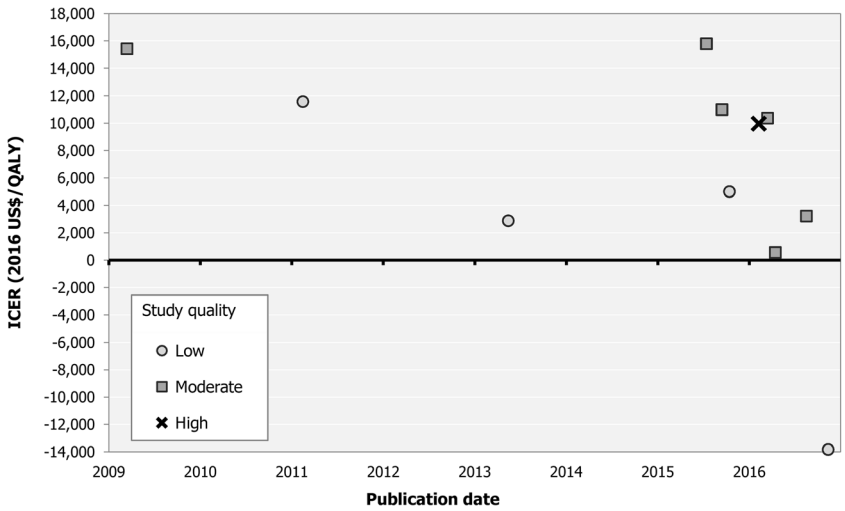

Fig. 2 Estimated incremental cost-effectiveness ratio by year published and study quality. ICER, incremental cost-effectiveness ratio

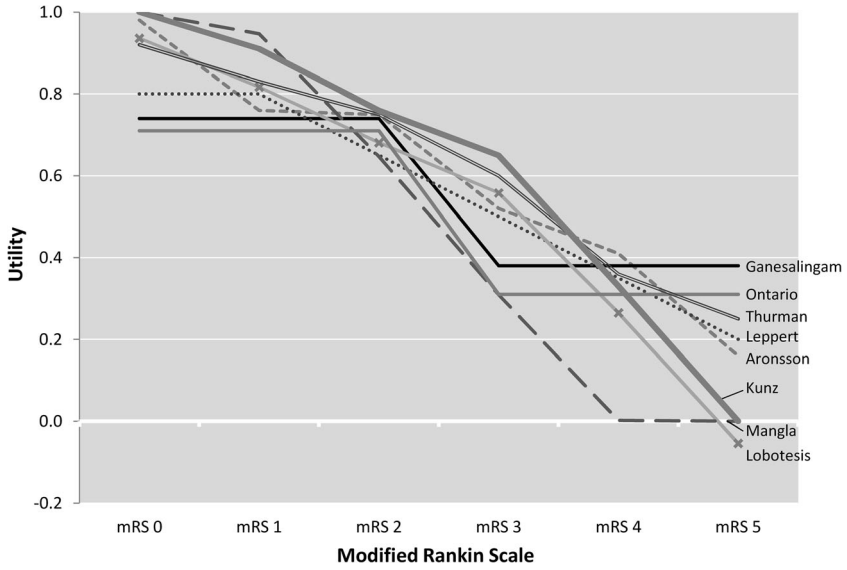

Fig. 3 Utilities by modified Rankin Score

pay threshold. However, the published ICERs for mechanical thrombectomy are in a range that could be considered cost-effective in most high-income countries [27].

Provided that the treatment times observed in the RCTs can be replicated and assuming availability of comprehensive stroke care, it is possible that mechanical thrombectomy would be cost-effective in settings other than those included in the cost-effectiveness analyses. This is not a criticism of the studies *per se*, as they are likely to be applicable within their own setting and thus be informative for local decision-making albeit with limitations. The published evaluations excluded capital investment in equipment and costs associated with patient transfer to avail this procedure. Depending on the existing network of stroke services and population distribution in a country, additional investment may be required to match the outcomes observed in the trials and this may impact negatively on the cost-effectiveness of the intervention conditional on the long-term savings. The incidence of stroke is decreasing in high-income countries and increasing in low- and middle-income countries [28]. The conditions necessary for adequately resourced emergency endovascular services are less likely in low- and middle-income countries, and achieving the outcomes observed in the trials may be challenging.

Four studies adopted a societal perspective when considering costs, and a fifth, the Canadian HTA, reported results based on both payer and societal perspectives. A societal perspective is considered appropriate when substantial costs fall on the individual and are not paid by the State. Adopting a payer perspective can promote the adoption of interventions that shift costs from the health service onto the patient. In the case of stroke, it can be anticipated that there may be marked societal impacts for families of those experiencing stroke in terms of both an economic burden and provision of care and support. The studies reporting a societal perspective had a higher average ICER than those reporting a payer perspective. The Canadian HTA reported both a payer and a societal perspective. They found that the intervention dominated usual care when a societal perspective was taken, whereas it was more costly and more effective when a payer perspective was adopted. Capturing the spectrum of societal impacts is typically challenging and may often be in the absence of good-quality data.

Sources of potential bias in results

The studies could be classed as first- and second-generation device evaluations. First-generation device assessments derived outcome data from the Multi-MERCI trial or expert opinion. Multi-MERCI was a single-arm trial of thrombectomy and did not collect information on the relevant comparator. Economic studies using the Multi-MERCI trial data estimated outcomes for the comparator using alternative sources, potentially introducing substantial bias. The assessments of second-generation stent-retriever devices used data from one or more of five RCTs of mechanical thrombectomy published between 2013 and 2015. In 2009, the recommended window for administering tPA changed from 3 to 4 h and a half hours after symptom onset following publication of the ECASS trial. The majority of the RCT evidence was based on a 4.5-h window for thrombolysis with tPA, whereas the Multi-MERCI trial was based on a 3-h window. Studies based on second-generation devices were less likely to be affected by bias in the estimates of clinical effectiveness and are more likely to have external validity.

The definition of the comparator varied, although across second-generation device evaluations, the comparator was consistently the best medical therapy including IV t-PA where

appropriate. In most cases, trial patients were restricted to those eligible for IV t-PA within the recommended timeframe.

Cost-effectiveness is the ratio of incremental costs to incremental benefits. In a cost-utility analysis, the benefits are a combination of the quality and quantity of life as measured by the number of years lived with a given quality of life. The estimates of quality of life varied between studies. Six separate studies were cited for utility data, although each economic evaluation identified a single source for utility weights without adequate of clear justification for choosing one study over the others. Given the variation observed, a pooled estimate would perhaps have been more appropriate and provided a better basis for encompassing the uncertainty in the underlying data, or else use of sensitivity analyses to explore the impact of selecting different data sources. Furthermore, it was generally unclear whether analyses took into account the underlying mean quality of life in the patient cohort [29]. Average population quality of life decreases with increasing age. As the average quality of life is less than one, inclusion of underlying quality of life would reduce the expected benefits and therefore impact on the interpretation of cost-effectiveness.

Endovascular therapy is typically used in only a proportion of cases, as successful recanalisation may be achieved through IV t-PA alone. Some studies noted the proportion of patients that would receive mechanical thrombectomy as part of endovascular therapy. In terms of costs, most of the studies did not clearly state whether costs took into account that not all patients would require mechanical thrombectomy. One study explicitly accounted for the fact that more than one device would be used for some patients. Given the cost associated with the device, it is important that an accurate estimate of the number of devices used is incorporated into the model. Assuming all patients require thrombectomy would overestimate costs whereas assuming one device per procedure would underestimate costs.

Strengths and limitations

The present review is limited by the restriction to English-language publications for which full papers were available, which may have introduced a bias. However, the impact is likely to have been low, given that the reports of the mechanical thrombectomy trials have all been published in English and we included a search of HTA agency websites. Unlike a systematic review of clinical effectiveness, where meta-analytic methods facilitate estimates of small study bias or potential publication bias, such an approach is not feasible in this instance due to the complex nature of the outcome measure. In the context of cost-effectiveness analysis, it is unclear what publication bias might mean. The analogue for a non-significant treatment effect would be that it is unclear whether the intervention is cost-effective, which may not be a barrier to publication.

The majority of cost-effectiveness analyses modelled longer-term outcomes based on functional status at 90 days as reported in the clinical trials. Decision-makers require longer-term cost and outcome data to support developing policies that have consequences over a period that is longer than described by the trial data. While an advantage of simulation models is that longer-term outcomes can be extrapolated, the accuracy of those estimates is dependent on the quality of the data used and the structural assumptions used in the model. In the absence of long-term follow-up data from the published trials, it is not possible to validate the models against observed outcomes and the accuracy must be inferred from the face validity of the underlying model assumptions. Some of the trials have included longer-term follow-up in subsequent publications, and it will be important for future research to evaluate whether benefits observed at 90 days are sustained as predicted in the economic models.

The evidence base for the clinical effectiveness of mechanical thrombectomy is evolving as additional trials are published with differing settings, such as the patient inclusion/exclusion criteria and the treatment window for endovascular therapy. Despite these changes, the estimated effectiveness in terms of functional outcomes has been reasonably consistent across trials of second-generation devices. The trials were powered to detect changes in functional outcomes but not on other outcomes, such as mortality. Mechanical thrombectomy may therefore have a clinically significant impact on other outcomes, but these are not being incorporated into models because of a lack of statistical significance. For this reason, sensitivity analyses on outcomes other than functional independence play an important role in exploring the results of economic evaluations of mechanical thrombectomy.

Study quality was evaluated using two tools, both based on item-by-item checklists. We used the two tools to determine the extent to which the findings were credible based on the methodology, data, and presentation. Although the conversion of the assessments into a low-/moderate-/high-quality rating was arguably subject to a degree of subjectivity, it enabled us to focus on the studies that provided the best level of evidence. None of the tools available for appraising economic evaluations are designed to enable a simple identification of high-quality studies. Rather, they facilitate identification of deficits in the studies that assist in interpreting the findings and their applicability to other contexts. Some reviews have reported the number of criteria fulfilled by a study as a measure of quality, assuming that all criteria are equally important—an assumption that is unlikely to hold. We have noted the Canadian HTA as being high quality, although some of the assumptions underpinning the analysis study may be questioned. For example, the data used to estimate transition probabilities after the initial 90-day post-stroke period (e.g.,

probability of losing functional independence) were derived from data that may be primarily based on patients with moderate stroke and may therefore be biased in relation to cases of severe stroke. It should be noted that the study included sensitivity analyses and that when the model inputs were varied, the intervention remained cost-effective in most scenarios.

Conclusions

We identified thirteen studies evaluating the cost-effectiveness of mechanical thrombectomy. There is sufficient evidence to suggest that if the outcomes of the RCTs underpinning the evidence of clinical effectiveness can be replicated, then mechanical thrombectomy is likely to be cost-effective by typical willingness-to-pay thresholds. The extent to which trial conditions can be emulated in practice is context-specific and dependent on the structure of existing endovascular therapy facilities and the ability to transfer patients to those centres in a timely manner. In the event that investment is required to develop stroke centres to the standard required to provide a safe endovascular service, the published estimates of cost-effectiveness may not be applicable.

Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

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References

1. Kernan WN, Ovbiagele B, Black HR et al (2014) Guidelines for the prevention of stroke in patients with stroke and transient ischemic attack: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke 45(7): 2160–2236
2. Feigin VL, Krishnamurthi R, Parmar P et al (2015) Update on the global burden of ischaemic and haemorrhagic stroke in 1990-2013: the GBD 2013 study. Neuroepidemiology 45(3):161–176
3. Marler JR, Brott T, Broderick J et al (1995) Tissue-plasminogen activator for acute ischemic stroke. N Engl J Med 333(24):1581–1587
4. Ellis JA, Youngerman BE, Higashida RT et al (2011) Endovascular treatment strategies for acute ischemic stroke. Int J Stroke 6(6):511–522
5. O'Carroll CB, Rubin MN, Chong BW (2015) What is the role for intra-arterial therapy in acute stroke intervention? Neurohospitalist 5(3):122–132
6. Glynn RW, Teljeur C, Harbison J, et al. (2018) A systematic review of the clinical effectiveness of emergency endovascular therapy using mechanical thrombectomy in acute ischaemic stroke: implications for service delivery. Ir J Med Sci. https://doi.org/10.1007/s11845-018-1899-6
7. Lavine SD, Cockroft K, Hoh B et al (2016) Training guidelines for endovascular stroke intervention: an international multi-society consensus document. Neuroradiology 58(6):537–541
8. Casaubon LK, Boulanger JM, Blacquiere D et al (2015) Canadian stroke best practice recommendations: hyperacute stroke care guidelines, Update 2015. Int J Stroke 10(6):924–940
9. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med 151(4):264–269
10. Evers S, Goossens M, de Vet H et al (2005) Criteria list for assessment of methodological quality of economic evaluations: Consensus on Health Economic Criteria. Int J Techno lAssess Health Care 21(2):240–245
11. Jaime Caro J, Eddy DM, Kan H et al (2014) Questionnaire to assess relevance and credibility of modeling studies for informing health care decision making: an ISPOR-AMCP-NPC Good Practice Task Force report. Value Health 17(2):174–182
12. OECD. (2016) Purchasing Power Parities (PPP) Statistics, Available from: http://stats.oecd.org/Index.aspx?DataSetCode=PPPGDP. Accessed 15 June 2017
13. Patil CG, Long EF, Lansberg MG (2009) Cost-effectiveness analysis of mechanical thrombectomy in acute ischemic stroke. J Neurosurg 110(3):508–513
14. Nguyen-Huynh MN, Johnston SC (2011) Is mechanical clot removal or disruption a cost-effective treatment for acute stroke? AJNR Am J Neuroradiol 32(2):244–249
15. Kim AS, Nguyen-Huynh M, Johnston SC (2011) A cost-utility analysis of mechanical thrombectomy as an adjunct to intravenous tissue-type plasminogen activator for acute large-vessel ischemic stroke. Stroke 42(7):2013–2018
16. Bouvy JC, Fransen PS, Baeten SA et al (2013) Cost-effectiveness of two endovascular treatment strategies vs intravenous thrombolysis. Acta Neurol Scand 127(5):351–359
17. Leppert MH, Campbell JD, Simpson JR, Burke JF (2015) Cost-effectiveness of intra-arterial treatment as an adjunct to intravenous tissue-type plasminogen activator for acute ischemic stroke. Stroke 46:1870–1876
18. Ganesalingam J, Pizzo E, Morris S et al (2015) Cost-utility analysis of mechanical thrombectomy using stent retrievers in acute ischemic stroke. Stroke 46(9):2591–2598
19. Thurman J, Södergård B, Eckard N et al (2015) Cost-effectiveness analysis of thrombectomy for treatment of acute severe ischemic stroke. Swedish Dental and Pharmaceutical Benefits Agency, Stockholm Contract No.: 01009/2015
20. Mangla S, O'Connell K, Kumari D, Shahrzad M (2016) Novel model of direct and indirect cost-benefit analysis of mechanical embolectomy over IV tPA for large vessel occlusions: a real-world dollar analysis based on improvements in mRS. J Neurointerv Surg 8(12):1312–1316
21. Health Quality Ontario (2016) Mechanical thrombectomy in patients with acute ischemic stroke: a health technology assessment. Ontario Health Technol Assess Series 16(4):1–79
22. Xie X, Lambrinos A, Chan B et al (2016) Mechanical thrombectomy in patients with acute ischemic stroke: a cost-utility analysis. CMAJ Open 4(2):E316–EE25
23. Aronsson M, Persson J, Blomstrand C et al (2016) Cost-effectiveness of endovascular thrombectomy in patients with acute ischemic stroke. Neurology 86(11):1053–1059
24. Lobotesis K, Veltkamp R, Carpenter IH et al (2016) Cost-effectiveness of stent-retriever thrombectomy in combination with IV t-PA compared with IV t-PA alone for acute ischemic stroke in the UK. J Med Econ 19:1–37
25. Kunz WG, Hunink MGM, Sommer WH et al (2016) Cost-effectiveness of endovascular stroke therapy. Stroke 47(11):2797–2804

26. Shireman TI, Wang K, Saver JL et al (2017) Cost-effectiveness of Solitaire stent retriever thrombectomy for acute ischemic stroke results from the SWIFT-PRIME Trial. Stroke 48(2):379–387
27. Woods B, Revill P, Sculpher M, Claxton K (2016) Country-level cost-effectiveness thresholds: initial estimates and the need for further research. Value Health 19(8):929–935
28. Feigin VL, Forouzanfar MH, Krishnamurthi R et al (2014) Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. Lancet 383(9913):245–254
29. Ara R, Brazier JE (2011) Using health state utility values from the general population to approximate baselines in decision analytic models when condition-specific data are not available. Value Health 14(4):539–545