ORIGINAL RESEARCH

An investigation of the cost and benefit of mechanical thrombectomy for endovascular treatment of acute ischemic stroke

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ABSTRACT

Introduction The use of mechanical thrombectomy for the treatment of acute ischemic stroke has significantly advanced over the past 5 years, with few available data. The aim of this study was to analyze the cost and benefit of mechanical thrombectomy devices utilized during endovascular therapy of ischemic stroke patients.

Methods A retrospective chart review of patients that underwent intra-arterial stroke interventions was conducted. Clinical, angiographic, all devices used, procedural and postprocedural event and outcome data were collected. Thrombectomy devices were categorized as Penumbra aspiration system thrombectomy (group P) or stent retriever (group S). Statistical analysis of outcomes and costs for each group was performed.

Results 171 patients underwent mechanical thrombectomy. The Penumbra aspiration system was able to primarily achieve recanalization in 41.7% and the stent retriever in 70.4% of the time (p=0.006). The average cost was $11 159 and $16 022 (p=0.0002) in groups P and S, respectively. Average time to recanalization for group P was 85.1 min and for group S, 51.6 min (p<0.0001). Procedural complications were more frequent with the stent retriever (11.1% vs 9.0%; p=0.72) as were periprocedural significant complications (14.8 v 3%; p=0.04). Successful recanalization rates (Thrombolysis in Cerebral Infarction score 2b-3) were the same in groups P and S (78.5 vs. 77.8%). Similar rates of good neurologic outcomes were seen in group P (36.4%) and group S (50.0%) (p=0.19).

Conclusions For the treatment of acute stroke patients, the use of aspiration appears to be the most cost effective method to achieve acceptable recanalization rates and low complication rates. Stent retriever with local aspiration, despite higher costs and complication rates, yielded better overall outcome.

INTRODUCTION

The National Institutes of Health estimates that stroke, the fourth leading cause of death and the leading cause of disability in the USA, consumes health care resources of approximately US$70 billion threshold annually.1–4 Early vessel recanalization in acute ischemic stroke has been shown to strongly correlate with improved clinical outcome and reduced mortality.5–6 Thrombectomy devices have recently been shown to be safe and effective up to 8 h after the onset of symptoms.5–8

In addition to expanding the therapeutic time window for stroke treatment and broadening the treatment repertoire, mechanical approaches have been shown to produce higher recanalization rates than intravenous tissue plasminogen activator (tPA) or intra-arterial (IA) thrombolysis alone.5–9–12 The optimal treatment for acute ischemic stroke has continued to evolve and improve over the past decade, as evidenced by the evolution and iteration of mechanical stroke devices. However, limited data exist evaluating the practical application of these devices with regard to overall procedure device costs, time to vessel recanalization, and patient outcome.

The aim of this study was to highlight and analyze the cost and benefit of current stroke therapies; more specifically, the impact of various mechanical thrombectomy and adjutant devices utilized during endovascular therapy of ischemic stroke patients.

METHODS

Under an institutional review board approved protocol, a retrospective chart review from May 2008 to October 2012 was performed from the electronic medical records of the Medical University of South Carolina of all stroke patients who were treated with endovascular therapy. Patients were evaluated for candidacy for IA therapy based on CT perfusion imaging, irrespective of time of symptom onset, as published previously.13–14 The study evaluated the primary thrombectomy device(s) used in each case as well as any additional devices that aided in achieving recanalization. All procedural diagnostic and intervention related materials and devices were recorded along with cost data. A cost analysis was performed on the devices used in recanalization.

Documented patient characteristics included age, gender, National Institutes of Health Stroke Scale score at presentation, time to presentation from last known normal, and modified Rankin Scale score (mRS) at 90 days or closest follow-up period to 90 days. mRS data were obtained from the stroke neurology or neurointerventional clinic records. Radiological and angiographic imaging was reviewed to document location of the vascular occlusion, recanalization time, Thrombolysis in Cerebral Infarction (TICI) flow pre- and postprocedure, and procedural complications. Device efficacy was ultimately
evaluated based on restored flow postprocedure and occurrence of intraprocedural complications. Procedural related complications were documented and separated by device group. Clinically significant complications (including procedure related) such as symptomatic intracranial hemorrhage were also documented.

Cases were segregated into two mechanical thrombectomy technological paradigms: Penumbra aspiration and stent retriever devices. Penumbra aspiration catheters alone achieved primary recanalization in 41.7% of cases and the remainder required other devices to fully recanalize. Stent retriever devices (Solitaire, Trevo or Penumbra 3D separator) were successful as the primary device in recanalization in 70.1% (p=0.006) of cases, with the remainder requiring aspiration thrombectomy, stents, or balloon maceration. Thrombus location was documented for each of the 171 cases; 88.3% of all cases investigated involved anterior circulation occlusion while 11.7% of cases involved posterior circulation. Occlusion of the middle cerebral artery was the most common location (74.9%) followed by the internal carotid artery (12.9%) and basilar artery (9.9%). Of note, all but one posterior circulation occlusions were treated by aspiration thrombectomy (group P).

Outcomes
Successful recanalization, defined as a TICI score of 2b or 3, was nearly identical for both groups, with 78.5% for group P and 77.8% for group S (p=0.9). For complete recanalization alone, there was a significant difference, with group S achieving TICI 3 in 59.3% of cases compared with 28.5% for group P (p=0.002) (figure 1). There was a statistically significant difference in time required to revascularize (groin access to restoration of flow in the occluded vessel), 85.1 min for group P and 51.6 min for group S (p=<0.0001). Procedural complications occurred in 9.0% of group P and 11.1% of group S cases (p=0.72). Clinical outcomes were not available for 13 patients. Clinically significant complications were seen in 3.5% for group P and 14.8% for group S (p=0.04). Clinical outcomes with good neurologic function at 90 days, as defined by mRS ≤ 2, were not significantly different (36.4% in group P and 50.0% in group S) (p=0.19). However, the number of patients achieving mRS 0 was significantly greater in group S (26.9%) than in group P (8.3%) (p=0.01) (figure 2). When overall clinical outcomes were correlated with recanalization, there was significant improvement in rates of good neurologic outcomes (mRS 0–2) and rates of poor neurologic outcomes or death (mRS 5,6) in those where recanalization was successful (figure 3).

Cost analysis
The mean cost across the groups was $11,926.45, with a minimum procedural cost of $3296.00 and a maximum cost of...
DISCUSSION

This study found that utilization of direct aspiration to revascularize occluded vessels in patients with acute ischemic stroke could be done with a significantly lower cost with similar acceptable degrees of recanalization (TICI 2b and 3). However, the time to achieve revascularization was significantly longer and was only successful as the primary device to achieve recanalization 41.7% of the time. Superior (mRS 0) neurologic outcomes as well as the proportion of patients achieving complete recanalization (TICI 3) were significantly higher in those patients treated with stent retrievers, with local aspiration. Although clinically significant complications were significantly higher with the stent retriever group, good neurologic outcomes remained high within this group.

Angiographic imaging data were used to assess postprocedural flow restoration for the cases. The group using the Penumbra aspiration system was successful as the primary device that achieved revascularization, the cost was $8727.06. Group S had a mean cost of $16 021.53, with values ranging from $9601.85 to $35 724.00. In cases where a stent retriever was successful as the primary device that achieved revascularization, the cost was $14 483.41.

Procedural complications were similar among the groups but clinically significant complications were significantly less in group P. In the stent retriever group, 14.8% of cases experienced a clinically significant complication during or after the procedure. These included symptomatic intracranial hemorrhage, vessel dissection, or perforation. One possible explanation for the complication rate in this group likely relates to the stent-like mechanism where the device exhibits outward radial force to create a channel through the thrombus and displace the thrombus along the vessel wall. During removal of the device there is subsequent traction of the device against the wall of the vessel. This has been shown to result in increased frequency of endothelial and vessel injury.18 This could also be related to the method utilized for device removal, although the method we employ using direct stent retriever retraction into a large aspiration catheter at the proximal edge of the clot should intuitively minimize vascular traction injury. The small sample size of group S should be noted also, and a more accurate representation of complications with respect to the group would be provided with a larger number of cases.

The group using Penumbra aspiration only (group P) displayed both the lowest mean cost with similar variability in cost (SD of $6028.67 compared with $6544.67 for group S). This was predominantly related to a complex anatomical or target lesion that required a multitude of additional devices besides the Penumbra to revascularize. Further, this occurred in a relatively large number (≥60%) of aspiration cases. The device in group S had a higher mean cost at $16 021.53. The cost range on these procedures was similar to those with the Penumbra. This is most likely related to the higher primary device success rate and requirement for fewer or cheaper adjunctive devices in the case of failure. Again, a much larger sample size is needed in order to fully elucidate the cost data for this group.

The technique we employ, using an aspiration catheter at the level of the clot for removal of the stent retriever rather than a proximal balloon guide catheter, does contribute to the cost as the aspiration catheter has a cost of $15 500 compared with the balloon guide catheter of $895. However, this difference in cost does not result in a significant alteration of the overall procedure cost. The technique of local aspiration during stent retriever removal was driven by the theoretical benefits of reduced embolism to new territory that has been as high as 9% in the SWIFT (Solitaire with the Intention for Thrombectomy) trial.16 Further, in the event of failure to recanalize with a stent retriever, the large bore local aspiration catheter can then be used for direct aspiration.
thrombectomy or function as a conduit to deliver other assist devices, such as balloons or stents. This increases the speed with which devices can be exchanged as the carotid siphon does not need to be navigated with each new device. Distal intracranial access also likely improves safety, as the amount of vessel displacement during stent retriever removal is minimized and the likelihood of guide catheter complications is lower.\(^{20}\)

Several limitations in both device cost and efficacy exist in this study. First, all patients that underwent endovascular stroke therapy were considered for this study, regardless of time of symptom onset. However, our outcomes have been previously published and are within the acceptable range reported in the literature.\(^{13}\)

The broad applicability of these study results are limited by the single center retrospective design. Most devices used in the cases were subject to unit cost inflation from 2009 to 2010 and, as a result and for the purposes of this study, the device cost was standardized using 2012 price values. Devices that were used in 2009 but did not continue into later years were assigned the unit cost according to the inventory in 2009. Intra-arterial tPA also experienced a significant shift in price as a result of a change in packaging. Prior to October 2009, tPA was dispensed in 50 mg vials and the unit cost, over $2000, was charged regardless of how little or how much was used. After that date, 2 mg vials became available at a unit cost of $87.00. For the purposes of this study, the cost of tPA was standardized from 2009 to 2012 at $87.00 per 2 mg used. Most importantly, the sample size of the newer technology stent retriever group was relatively small. However, the standardized approach with this technique and high success rate with the primary device is not likely to change the overall cost due to the low probability of using a second device. There is a greater possibility that there could be a change in group S; however, this group already had significantly higher costs compared with the other groups. A larger group S would be more likely to positively affect our clinical and angiographic outcomes beyond the already reported improved outcomes, although these values remain within those reported in the literature.

In conclusion, for treatment of acute stroke patients, the use of aspiration as an initial approach is a significantly less expensive method to achieve acceptable recanalization rates with low complication rates; however, this technique alone is often unsuccessful. Stent retriever cases, while having a notably higher rate of complete recanalization, does cost significantly more and was associated with a higher clinically significant complication rate, although improved overall outcomes. This suggests that the most cost effective approach to a large vessel occlusion might be to attempt a brief direct aspiration with a large bore catheter (without the separator) first and if this fails then proceed with other devices, such as a stent retriever.

**Contributors** Each author listed should receive authorship credit based on material contribution to this article, revision of this article and final approval of this article for submission to this journal.

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**Socioeconomics**

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