Predictors of 30-day hospital readmission after mechanical thrombectomy for acute ischemic stroke

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OBJECTIVE The 30-day readmission rate is of increasing interest to hospital administrators and physicians, as it is used to evaluate hospital performance and is associated with increased healthcare expenditures. The estimated yearly cost to Medicare of readmissions is \$17.4 billion. The Centers for Medicare and Medicaid Services therefore track unplanned 30-day readmissions and institute penalties against hospitals whose readmission rates exceed disease-specific national standards. One of the most important conditions with potential for improvement in cost-effective care is ischemic stroke, which affects 795,000 people in the United States and is a leading cause of death and disability. Recent widespread adoption of mechanical thrombectomy has revolutionized stroke care, requiring reassessment of readmission causes and costs in this population.

METHODS The authors retrospectively analyzed a prospectively maintained database of stroke patients and identified 561 patients who underwent mechanical thrombectomy between 2010 and 2019 at the authors' institution. Univariate and multivariate analyses were conducted to identify clinical variables and comorbidities related to 30-day readmissions in this patient population.

RESULTS Of the 561 patients, 85.6% (n = 480) survived their admission and were discharged from the hospital to home or rehabilitation, and 8.8% (n = 42/480) were readmitted within 30 days. The median time to readmission was 10.5 days (IQR 6.0–14.3). The most common reasons for readmission were infection (33.3%) and acute cardiac or cerebrovascular events (19% and 20%, respectively). Multivariate analysis showed that hypertension (p = 0.030; OR 2.72) and length of initial hospital stay (p = 0.040; OR 1.032) were significantly correlated with readmission within 30 days, while hemorrhagic conversion (grades 3 and 4) approached significance (p = 0.053; OR 2.23). Other factors, such as unfavorable outcome at discharge, history of coronary artery disease, and discharge destination, did not predict readmission.

CONCLUSIONS The study data demonstrate that hypertension, length of hospital stay, and hemorrhagic conversion were predictors of 30-day hospital readmission in stroke patients after mechanical thrombectomy. Infection was the most common cause of 30-day readmission, followed by cardiac and cerebrovascular diagnoses. These results therefore may serve to identify patients within the stroke population who require increased surveillance following discharge to reduce complications and unplanned readmissions.

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KEYWORDS mechanical thrombectomy; acute ischemic stroke; readmission; vascular disorders

THE 30-day hospital readmission rate is an outcome of increasing interest due to its use as a metric of quality of care as well as its association with increased healthcare expenditures. The estimated yearly cost of readmissions to Medicare is \$17.4 billion.¹ In an effort

to promote healthcare quality and sustainability, the Centers for Medicare and Medicaid Services track unplanned 30-day readmissions for various conditions and define national disease-specific standards. Hospitals that exceed these standards are held accountable with penalties. These

ABBREVIATIONS ACA = anterior cerebral artery; DVT = deep venous thrombosis; ICA = internal cerebral artery; LOS = length of stay; MCA = middle cerebral artery; mRS = modified Rankin Scale; mTICI = modified treatment in cerebral ischemia; NIHSS = National Institutes of Health Stroke Scale; NRD = Nationwide Readmission Database; PCA = posterior cerebral artery; PE = pulmonary embolism; tPA = tissue plasminogen activator; UTI = urinary tract infection.

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measures are implemented under the Readmission Prevention Program, which initially focused on common index diagnoses such as congestive heart failure, myocardial infarction, pneumonia, chronic obstructive pulmonary disease, and knee or hip arthroplasty. However, the program is under continuous expansion to include other conditions, such as stroke, which has been widely recognized as an economical and clinical burden, currently affecting 795,000 people annually in the United States, with a cost of \$40.1 billion.² With this impact on the healthcare system, readmission prevention programs targeting ischemic stroke have the potential to substantially lower healthcare costs and improve patients' quality of life.

Several recently published studies have investigated the reasons for and predictors of hospital readmission following ischemic stroke.^{3–6} However, the recent adoption of mechanical thrombectomy has radically altered the hospital course and functional outcome of patients with acute ischemic stroke.⁷ This paradigm shift has also impacted the 30-day readmission rates and reasons for readmission. The present study represents what is, to the authors' knowledge, the largest single-center experience to date with the goal of investigating the characteristics and readmission profiles of stroke patients who have undergone mechanical thrombectomy. Through retrospective analysis, the authors assess the readmission rate for this population as well as provide a detailed account of significant predictors of 30-day readmission.

Methods

Patient Selection, Variables, and Outcomes

The study protocol was approved by the Thomas Jefferson University Institutional Review Board. We conducted a retrospective analysis and identified 561 stroke patients who underwent mechanical thrombectomy at Thomas Jefferson University Hospital between 2010 and 2019. We collected data on patient comorbidities and risk factors for stroke, including National Institutes of Health Stroke Scale (NIHSS) score on admission; intravenous tissue plasminogen activator (tPA) administration; revascularization outcome (modified treatment in cerebral ischemia [mTICI] score); posttreatment complications (i.e., postoperative intracerebral hemorrhage); hospitalization-associated complications (pneumonia, deep venous thrombosis [DVT], urinary tract infection [UTI]); total length of stay (LOS) and length of ICU stay; functional status at discharge measured by the modified Rankin Scale (mRS); disposition to home, a rehabilitation facility, or hospice; inpatient mortality; and readmission within 30 days. Posttreatment hemorrhage was scored based on the grading scale developed by Fiorelli and colleagues, in which small petechiae are defined as type 1, confluent petechiae as type 2, hemorrhage in 30% of the infarcted area with mild space-occupying effects as type 3, and hemorrhage in $\geq 30\%$ of the infarcted area with significant space-occupying effects as type 4.⁸ The primary outcome was all-cause 30-day hospital readmission, which was defined as the first admission within 30 days of discharge. Any planned readmissions for elective procedures, such as carotid endarterectomy or carotid artery stenting, were excluded from this analysis.

Statistical Analysis

Data are presented as means and ranges for continuous variables and as frequencies for categorical variables. Analyses were carried out using an unpaired t-test, chi-square test, or Fisher's exact test as appropriate. Univariable analysis was used to test covariates predictive of readmission. Factors found to be predictive of readmission in univariable analysis ($p < 0.20$) were entered into a multivariable logistic regression analysis. This p value threshold was selected to capture all of the potential relationships that might influence the multivariable logistic regression analysis. A p value ≤ 0.05 was considered statistically significant. The logistic regression analyses to determine predictors of 30-day readmission excluded patients who died during the index hospitalization or were discharged to hospice. Statistical analysis was carried out with IBM SPSS software (version 24.0, IBM Corp.).

Results

Patient Characteristics

Of the 561 patients who underwent mechanical thrombectomy, 44.7% were males and 55.3% were females and the mean age was 72.0 ± 15.5 years (range 16–106 years). The median hospital LOS was 7.0 days (IQR 4.0–11.0) and the median length of ICU stay was 3.0 days (IQR 2.0–5.0). The mean NIHSS score at admission was 15.7 ± 6.7 , and intravenous tPA was given to 45.5% of patients. Acute thrombosis involved the middle cerebral artery (MCA) in 66.1% of patients, the internal cerebral artery (ICA) in 13.9%, both the ICA and MCA in 10.2%, the vertebrobasilar circulation in 8.2%, the anterior cerebral artery (ACA) in 1.2%, and the posterior cerebral artery (PCA) in 0.4%. An mTICI score of 2B or 3 was achieved in 84.7% of the patients. Hemorrhage after mechanical thrombectomy was noted in 208 patients (37.2%), of whom 57 (10.2%) had grade 1 hemorrhage, 76 (13.6%) had grade 2, 24 (4.3%) had grade 3, and 51 had grade 4 (9.1%). Nineteen (3.4%) of the 561 patients required a decompressive hemicraniectomy during the index admission. Hospital-associated complications such as DVT, pneumonia, bacteremia, and UTI were seen in 8.7%, 14.3%, 13.3%, and 14.3% of patients, respectively. The inpatient mortality was 9.8% ($n = 55$). Of the remaining 506 patients, 19.2% were discharged to home, 75.7% were discharged to a rehabilitation facility, and 5.1% of the patients were discharged to a hospice facility. The hemorrhagic conversion rates in those eligible for readmission were grade 1 in 10.8% of patients, grade 2 in 13.3%, grade 3 in 4.2%, and grade 4 in 7.9% of patients. Further characteristics of the cohort can be found in Table 1.

Outcomes

The all-cause 30-day readmission rate was 8.8% ($n = 42/480$) after excluding those who died during their hospital stay and those who were discharged to hospice. In these 42 patients, the occlusions during the initial admission were located in the MCA in 64.3% of patients (27/42), were tandem occlusions involving the ICA and MCA in 19.0%, were located in the ICA alone in 11.9%, and were located in the vertebrobasilar circulation in 4.8% of patients ($p = 0.542$). The median time to readmission was

TABLE 1. Baseline patient characteristics

Characteristic	Readmitted (n = 42)	Not Readmitted (n = 519)	p Value
Sex			0.118
Male	33.3%	45.9%	
Female	66.7%	54.1%	
Age, yrs	74.3 ± 12.5	71.8 ± 15.7	0.308
LOS, days			
Hospital, median (IQR)	7.0 (5.8–14.5)	6.0 (4.0–11.0)	0.045
ICU, median (IQR)	2.0 (2.0–7.0)	3.0 (2.0–5.0)	0.901
Comorbidities			
HTN	85.7%	69.4%	0.026
Diabetes mellitus	21.4%	21.5%	0.996
COPD	7.1%	6.6%	0.897
Coronary artery disease	19.0%	16.4%	0.665
Peripheral vascular disease	19.0%	8.7%	0.029
CHF	19.0%	12.3%	0.215
Hyperlipidemia	54.8%	39.0%	0.047
Stroke history	21.4%	13.0%	0.130
NIHSS at presentation	16.7 ± 6.7	15.0 ± 6.2	0.310
IV tPA	45.2%	46.6%	0.868
mTICI score			0.936
0	4.8%	3.7%	
1	0%	1.6%	
2A	7.1%	6.4%	
2B	14.3%	16.7%	
3	73.8%	71.7%	
Hemorrhagic conversion (grades 3 & 4)	21.4%	11.2%	0.052

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; HTN = hypertension; IV = intravenous.

Values are presented as percentage of patients or mean ± SD unless otherwise indicated.

10.5 days after discharge (IQR 6.0–14.3). The mean LOS during the readmission was 6.0 days (IQR 3.0–10.3). The most common reason for readmission was infection, including pneumonia, UTI, and sepsis (n = 14, 33.3%). Other readmissions were attributable to acute cardiac events in 8 patients (19%) and cerebrovascular events in 7 patients (16.7%) (Table 2). Three patients were readmitted with DVT/pulmonary embolism (PE; 7.1%). One patient (2.4%) was readmitted due to groin hematoma and was found to have a pseudoaneurysm at the access site (Table 2). Discharge to home versus a rehabilitation facility did not significantly affect 30-day readmission (p = 0.080). The median index LOS was 7.0 days (IQR 5.8–14.5) in the patients who were later readmitted and 6.0 days (IQR 4.0–11.0) in those who were not readmitted (p = 0.045).

Decompressive hemicraniectomy (DHC) was necessary in 19 of the 480 patients during the index admission. Of these 19 patients, 16 (84.2%) were discharged to home or rehabilitation, and 3 (18.8%) of those 16 were readmitted within 30 days (2 for infection, 1 for chest pain),

TABLE 2. Patient readmission data

Reason for Readmission	No. of Patients (%)	Time to Readmission, Median (IQR)	Readmission LOS, Median (IQR)
Infection (pneumonia, UTI, sepsis)	14 (33.3%)	8.0 (4.5–12.3)	6.5 (3.0–9.8)
Cerebrovascular event	7 (16.7%)	13.0 (10.0–17.0)	6.0 (6.0–19.0)
New infarct	6 (14.3%)		
ICH	1 (2.4%)		
Cardiovascular event (Afib w/ RVR, HTN urgency, CHF exacerbation)	8 (19.1%)	13.0 (6.8–21.5)	4.0 (3.0–9.5)
DVT or PE	3 (7.1%)	7.0 (1.0–7.0)	10.0 (6.0–10.0)
Other (seizures, GI bleed, rehab limitations)	9 (21.4%)	12.0 (1.0–13.5)	6.0 (3.0–16.0)
Pseudoaneurysm	1 (2.4%)	4	7

Afib = atrial fibrillation; GI = gastrointestinal; ICH = intracerebral hemorrhage; rehab = rehabilitation; RVR = rapid ventricular response.

Time and LOS values presented in days.

whereas only 39 (8.4%) of the 480 patients without a DHC had a 30-day readmission (p = 0.157).

Patient mRS scores for functional status were calculated at discharge. The average mRS score among surviving patients who were discharged (n = 506) was 3.2 ± 1.4. When those patients discharged to hospice were excluded, the average mRS score was 3.1 ± 1.4 (n = 480). The average mRS score of those who were readmitted was 3.5 ± 1.3 and of those who were not readmitted it was 3.07 ± 1.43 (p = 0.079). The mRS score of those readmitted with infection (n = 14) was 3.9 ± 1.4, 64.3% of whom were discharged with an unfavorable score (4–6). Patients who were readmitted with a cardiovascular diagnosis (n = 8) had a mean mRS score of 3.6 ± 1.2, with 75% of these patients having an unfavorable score at discharge, and those readmitted with an ischemic or hemorrhagic stroke (n = 8) had a mean mRS score of 3.4 ± 1.4, 50% of whom had an unfavorable score at discharge.

Multivariable logistic regression analysis was performed after excluding those patients who died prior to discharge and those who went to hospice (n = 26). Hypertension (p = 0.030; OR 2.72) and initial hospital LOS (p = 0.040; OR 1.032) were significantly correlated with readmission within 30 days (Table 3), while hemorrhagic conversion (grades 3 and 4) approached significance (p = 0.053; OR 2.23).

Discussion

There still remains a paucity of data on readmission metrics for patients with ischemic stroke who have undergone mechanical thrombectomy. As neurointerventionalists are increasingly required throughout the country to oversee the care of these newly adopted patients, it is imperative that we attain a better understanding of the nuances of their care.

TABLE 3. Predictors of 30-day readmission

Predictor	OR	95% CI	p Value
HTN	2.72	1.10–6.73	0.030
LOS	1.032	1.001–1.064	0.040
Hemorrhagic conversion (grades 3 & 4)	2.23	0.99–5.02	0.053

Lichtman et al. provided an early estimate of readmission of the elderly stroke population before the advent of mechanical thrombectomy.⁹ The authors analyzed a national database from 2005 to 2006 with patients older than 65 years and found a 30-day readmission rate of 14.4%.⁹ A recent study by Vahidy et al., using the 2013 Nationwide Readmission Database (NRD), found a readmission rate of 12.1% across all treatment modalities, including mechanical recanalization.¹⁰ As mechanical thrombectomy has fundamentally changed the hospital course and functional outcomes of patients with stroke, we focused our analysis specifically on patients who received mechanical thrombectomy in order to investigate risk factors for readmission specific to this population, as this procedure imparts different risks for readmission than those for medically managed patients.

The 30-day readmission rate of 8.8% in our sample is lower than that found in these previous studies. The most common reasons for readmission in our series were related to sepsis, UTI, pneumonia, or other infection (33.3%). These results are similar to those of a retrospective analysis of a Norwegian stroke registry conducted by Bjerkreim et al.,¹¹ in which infections accounted for the majority of early readmissions within 90 days of discharge. In a study involving 2657 stroke patients, Lin et al. found infections to be the most frequent reason for readmission.¹² Similarly, in a systematic review, Rao et al. found infections to be the second most common reason for readmission, preceded only by recurrent stroke.¹³ The high proportion of urinary and respiratory tract infections within 30 days of discharge brings into question whether these were acquired during the index hospitalization and insufficiently treated prior to discharge. Alternatively, it may also reflect the increased susceptibility of stroke patients to infection due to depressed mental status, dysphagia, and immobilization.¹⁴ Our study found no difference in the rate of readmission between patients who were discharged to home versus a rehabilitation facility. However, early mobility and attention to hygiene are imperative regardless of the setting. Close follow-up with the primary care physician would allow for preemptive addressing of many of these risk factors in the outpatient setting and thus avoiding readmissions.

More recently, a national study by Ramchand et al. investigated readmission outcomes within 30 and 90 days in stroke patients who underwent mechanical thrombectomy. Using the NRD, they studied 4850 cases and showed the 30- and 90-day readmission rates to be 12.5% and 20.7%, respectively.¹⁵ Additionally, Ramchand et al. identified certain factors, such as longer initial LOS, discharge to inpatient postacute care facilities, and female sex to be associated with a higher likelihood of readmission. Similar

to our study results, sepsis and recurrent cerebrovascular events were found to be the most commonly cited reasons for readmission. While our study focused on 30-day readmission due to its use as a metric for hospital performance measures and reimbursement, the increase in readmission rates within 90 days detailed in the study by Ramchand et al. suggests that this timeframe may also warrant further investigation in the future. Despite the large patient population used by Ramchand et al. in their study, important clinical information was not included in their analysis. NIHSS score at presentation, mTICI score, and hemorrhage rate were not available through the NRD, all of which are clinically relevant factors. The ICD-based data collection used in their study runs the risk of missing relevant clinical information.¹⁵ Our study demonstrated that hemorrhage was strongly associated with 30-day readmission. Postprocedure hemorrhage significantly affects patient management, as it influences decisions regarding antiplatelet medication, hypertonic saline administration, ICU LOS, and possible surgical intervention (i.e., craniectomy). The rate of significant hemorrhagic conversion (13.1% for grades 3 and 4) was substantial and significantly impacted the patient hospital course. This rate is higher than the rates reported in the major trials because our study included all patients from 2010 on. The technology available and the surgical expertise have varied significantly during the 10 years included in our study.⁷ Additionally, our study provides real-life experience and thus differs from randomized controlled trials with strict selection criteria. Furthermore, Shkirkova et al. also studied 2111 patients from 2010 to 2014 through the NRD and reported a 90-day readmission rate of 25.3%.¹⁶ The variability in the rates in these studies is likely due to the use of a national registry that includes institutions with varying mechanical thrombectomy expertise, critical care resources, and rehabilitation/outpatient clinic networks. The 3 most common causes of readmission were septicemia (5.9%), atrial fibrillation (4.8%), and recurrent stroke (4.8%). Lastly, in a retrospective study of mechanical thrombectomy in the elderly, Andrews et al. showed a 30-day readmission rate of 8.3% in those younger than 80 years, 8.1% in those aged 80–90 years, and 14.3% in those older than 90 years.¹⁷

Hypertension was also significantly correlated with 30-day readmission in our multivariable analysis, reflecting the high degree of cardiovascular pathology in this patient population. A substantial proportion of the readmitted patients (19%) presented with atrial fibrillation with a rapid ventricular rate, decompensated congestive heart failure exacerbation, or cardiac-related chest pain. This finding highlights the importance of a thorough cardiac workup and adequate follow-up planning prior to discharge, possibly through collaboration with neurointensivists, neurohospitalists, and cardiologists, to address the patients' medical comorbidities. Another risk factor that is relevant even though our data were not statistically significant in the multivariable analysis is the development of DVT, which significantly complicates a patient's hospital course because anticoagulation is often avoided in the acute setting after a stroke. Most of these patients undergo filter placement in the inferior vena cava, which does not limit the progression of the thrombus. Patients can become

symptomatic after discharge and therefore return to the hospital. Close outpatient follow-up of clot progression with ultrasound is required to initiate anticoagulation treatment once patients are cleared from a neurosurgical standpoint.

Study Limitations

Our study has limitations that need to be taken into consideration. Our analysis includes only readmissions at our institution, excluding patients who presented to emergency departments at other institutions. Even though many patients who present to a different hospital of the region are transferred to our institution if they require an inpatient admission, we do not have data to quantify this. Additionally, the retrospective nature of the study design can limit our ability to further characterize the relationship between the variables studied. The small number of readmissions prevents us from performing a logistic regression analysis of those readmitted to better understand the predictors of each cause of readmission. Infection was the most common cause of readmission in our study; however, we are unable to determine the specific predictors of readmission due to infection.

Conclusions

Hospital administrators and physicians have a mutual interest in reducing 30-day readmissions to improve long-term patient outcomes and hospital performance, as well as to curtail reimbursement penalties. Infection was the most common cause of 30-day readmission, followed by cardiac and cerebrovascular diagnoses. We identified hypertension, hospital LOS, and postprocedural hemorrhage as strong predictors of 30-day readmission in stroke patients who underwent mechanical thrombectomy. The location of the occlusion and the need for decompressive hemicraniectomy were not correlated with readmission. We hope that our findings will help in identifying high-risk patients who require closer monitoring during inpatient hospitalization and increased outpatient follow-up after discharge to reduce unplanned 30-day readmissions.

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Disclosures

Dr. Tjoumakaris reports being a consultant for Medtronic and MicroVention.

Author Contributions

Conception and design: Gooch, Jabbour, Tjoumakaris, Sharan, Rosenwasser. Acquisition of data: Al Saiegh, Valcarcel, Andrews, Fitchett, Nauheim, Moskal. Analysis and interpretation of data: Mouchtouris, Al Saiegh, Andrews. Drafting the article: Mouchtouris, Al Saiegh, Valcarcel, Fitchett, Moskal. Critically revising the article: Gooch, Herial, Jabbour, Sharan. Reviewed submitted version of manuscript: Gooch, Herial, Tjoumakaris. Statistical analysis: Mouchtouris, Nauheim. Administrative/technical/material support: Jabbour, Tjoumakaris, Rosenwasser. Study supervision: Gooch.

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