Causes, Predictors, and Trends of Unplanned Readmissions after Elective Endovascular Embolization of Cerebral Aneurysms

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Background: 30- and 90-day readmissions (dRA) are being increasingly scrutinized as quality metrics for hospital and provider performances. Little information regarding risk factors for readmission after elective endovascular treatment (EVT) of an unruptured cerebral aneurysm (UCA) is available. *Methods:* The Nationwide Readmissions Database was used to identify patients who underwent elective endovascular embolization of an unruptured aneurysm between 2010 and 2014. The primary outcomes of interest were unplanned readmissions occurring within 30 or 90 days of discharge. Binary logistic regressions were used to identify variables related to patients' demographics, comorbidities, and index hospital admission that were associated with 30dRA and 90dRA. *Results:* A total of 8588 patients met the inclusion criteria for 30dRA analysis and 7289 patients were eligible for 90dRA analysis. The 5-year 30dRA and 90dRA readmission rates were 7.1% and 13.5%, respectively. The annual incidences of 30dRAs and 90dRAs between 2010 and 2014 decreased significantly (pooled odds ratio (OR) for 30dRA: .874, 95% confidence interval (CI) .765-.998; pooled OR for 90dRA: .841, 95% CI .755-.938). Patients in higher income quartiles experienced decreased odds of 30dRA and 90dRA. Non-routine disposition following the index admission and greater comorbidity burdens were associated with higher likelihoods of both 30dRA and 90dRA. The presence of pulmonary or cardiac complications was associated with increased odds of 90dRA. *Conclusion:* Readmission rates after elective EVT of UCAs decreased between 2010 and 2014. We identified several novel risk factors for both 30dRAs and 90dRAs that can be used to identify patients who are at highest risk of readmission.

Key Words: Aneurysm—endovascular—coiling—readmission

Introduction

Unruptured cerebral aneurysms (UCA) have a prevalence of 3.2% and are found more frequently in women.[1] They are commonly associated with smoking, hypertension, connective tissue disorders, and autosomal dominant polycystic kidney disease.[1,2] Rupture risk is associated with the size,[3] morphology,[4] and the location of the aneurysm.[5] Approximately 8-10 per 100,000 people or 30,000 North Americans each year suffer from aneurysmal subarachnoid hemorrhage, which carries a mortality rate of 40%-50%.[6,7] Endovascular treatment (EVT) has gained favor over microsurgical clipping as the initial treatment approach for both ruptured and unruptured aneurysms since the International Subarachnoid Aneurysm Trial was published.[8] The advantages of EVT include its minimally invasive nature and its ease of access to areas such as the vertebrobasilar system that are associated with high surgical morbidity.[9]

Significant attention has been placed on reducing unplanned 30- and 90-day readmission (30dRA, 90dRA) rates since the Affordable Care Act was passed in 2010. 30dRA and 90dRA have been employed as quality metrics to evaluate the performance of hospitals and providers.

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Hospitals can face financial penalization if their readmission rates are too high.[10] Since the implementation of the hospital readmission reduction program, both not-for-profit and proprietary hospitals have reduced readmission rates.[11] However, unplanned readmissions remain a significant economic burden. Furthermore, unplanned readmissions may limit the neurological and functional recoveries of patients who have recently undergone EVT.

The published data regarding 30- and 90dRA rates in patients who have undergone EVT is sparse. No studies have evaluated risk factors or indications for readmission after EVT. The current literature is limited to comparisons of readmission rates associated with EVT to microsurgical clipping,[12-16] and characterization of readmission rates in noncontemporary series.[15-17] Additionally, prior studies have not identified risk factors or reasons for readmission and have not included 30dRA or 90dRA as outcomes. The goal of this study was to use the Nationwide Readmissions Database (NRD) to analyze annual trends, causes, and predictors for 30dRAs and 90dRAs over a 5-year period in patients who underwent EVT for UCA. To the best of our knowledge, no study has used the NRD for this purpose before. We hypothesized that older patients with more comorbidities and those with nonroutine discharges from their index admissions were more likely to be readmitted. We also hypothesized that annual 30- and 90-dRA rates decreased in the same manner as nationally published trends for other diagnoses following the initiation of the hospital readmission reduction program.

Methods

Data Source

The NRD was used to identify patients for this study. It includes inpatient data obtained from hospital discharges in 27 states participating in the Healthcare Cost and Utilization Project (HCUP) from all types of payers (government, private, and uninsured patients). The database provides patient linkage numbers that allow users to track readmissions in the same state and calendar year for individual patients. Data includes up to 25 diagnoses and procedures per discharge provided as International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes. The NRD includes data from approximately 17 million discharges annually. All study personnel involved in data analysis completed the HCUP data use agreement. Institutional Review Board approval was not necessary because the study involved an existing, deidentified database.

Study Population

Patients at least 18 years of age with an index admission from 2010 to 2014 and a primary diagnosis of unruptured cerebral aneurysm (437.3) with a procedure code denoting endovascular embolization (39.72, 39.75, 39.76, or 39.79) were screened for inclusion in the study. We excluded patients who died during the index admission, were not admitted electively, and who experienced a planned readmission according to criteria published by the Center for Medicare and Medicaid Services.[18] We also excluded patients who were not residents of the same state as the hospital that they underwent endovascular intervention, because the NRD's patient linkage numbers are unique to each state. All patients with missing length of stay (LOS) data for the index admission were excluded because this would have precluded calculating an accurate duration to readmission. Finally, patients who were discharged in the month of December or October through December were excluded from the 30dRA and 90dRA analyses, respectively. We applied this exclusion because it is not possible to track individual patients across calendar years with the NRD.

Comorbidity Adjustment

The Charlson Comorbidity Index (CCI) was used to adjust for the severity of each patient's comorbidities. This was calculated using ICD-9-CM codes according to previously published methodology.[19]

Outcome Measures

Our primary outcomes of interest were 30dRA and 90dRA. Duration from discharge to readmission was calculated according to the method described by HCUP. Indications for readmission were classified according to the primary CCS diagnosis code associated with the admission. We also performed a subgroup analysis of patients who were admitted at any time interval following their index hospitalization discharge to identify factors associated with a nonroutine discharge following readmission. A nonroutine discharge was defined as any disposition other than home or self care. Disposition data is provided as a discrete variable in the NRD.

Statistical Analysis

Univariate and binary logistic regression analyses were performed to identify factors associated with 30dRA and 90dRA. The univariate analyses were performed using Chi-square and Mann-Whitney U tests for categorical and continuous variables, respectively. Variables that were associated with readmission in the univariate analysis with a P value less than .20 were included as covariates in the regression. We performed a similar analysis among patients who were readmitted to identify variables associated with nonroutine discharge after readmission. Cochran-Mantel-Haenszel test was used to obtain a pooled odds ratio (OR) for the

annual likelihood of readmission after 2010. Statistical analysis was performed with IBM SPSS Statistics 24.0 (IBM Corp., Armonk, NY).

Results

Summary of the Cohort

A total of 13,847 patients who underwent endovascular embolization for an unruptured cerebral aneurysm between 2010 and 2014 were screened for inclusion. After applying the exclusion criteria, there were 8588 patients for whom 30dRA analysis could be performed (Fig 1). Of these, 7289 patients were eligible for 90dRA analysis. The mean (±SD) age of the entire cohort was 58.9 years ± 12.2. As shown in Table 1, the majority of patients were female (78.8%), treated at hospitals in large metropolitan locations (66.8%) that were teaching institutions (90.2%), and had a CCI of 0 (60.8%) or 1 (24.2%). The 5-year 30dRA and 90dRA rates were 7.1% and 13.5%, respectively. The Kaplan-Meier curve for 30- and 90-dRAs among patients who experienced any readmission is shown in Figure 2.

Changes in Readmission Rates Over Time

The annual 30- and 90-dRA rates between 2010 and 2014 are shown in Figure 3. Compared to the index year (2010), the pooled OR of 30dRA from 2011 to 2014 was .874 (95% confidence interval (CI) .765-.998, P = .047). During the same time period, the pooled OR of 90dRA also decreased significantly (OR .841, 95% CI .755-.938, P = .002). The median LOS of readmission was 2 days (IQR 1-4).

Predictors of Readmission

After performing univariate analyses (Supplementary Table 1), binary logistic regression analyses were used to determine predictors of 30dRA and 90dRA. In the former (Table 2), the model was statistically significant ($X^2(24) = 510.469$, $P < .001$), the data fit the model well (Hosmer and Lemeshow P = .983), and the model classified 93.0% of cases correctly. Sex and insurance status were not associated with 30dRA. Compared to patients in the lowest income quartile, those who were in the second, third, or fourth quartiles all had decreased odds of 30dRA. A CCI of 3 or more was associated with 30dRA (OR 1.391, 95% CI 1.007-1.921). Stent placement was not associated with 30dRA (OR .558, 95% CI .289-1.078) but nonroutine disposition following the index admission was (OR 15.333, 95% CI 12.040-19.527).

In the corresponding 90dRA logistic regression (Table 3), the model was statistically significant ($X^2(24) = 669.809$, $P < .001$), the data fit the model well (Hosmer and Lemeshow P = .615), and the model classified 88.5% of cases correctly. Similar to the 30dRA analysis, second through fourth income quartiles were associated with decreased odds of 90dRA, while CCI greater than or equal to 3, and pulmonary or cardiac complications during the index hospitalization were associated with increased odds of 90dRA. Additionally, nonroutine discharge following the index admission was associated with 90dRA (OR 21.431, 95% CI 16.484-27.862).

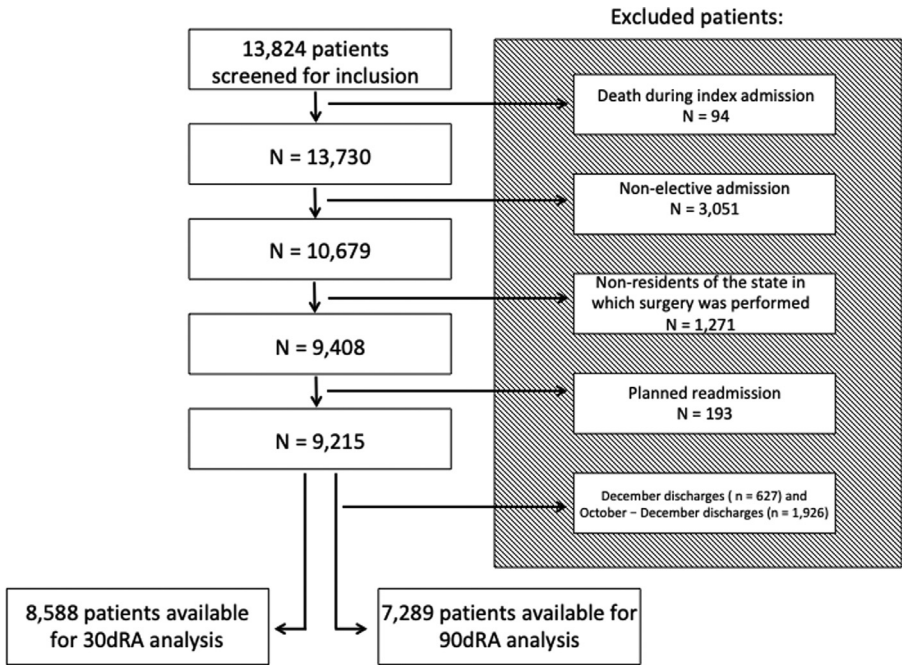

Figure 1. *Development of the patient cohort (30dRA: 30-day readmission; 90dRA: 90-day readmission).*

Table 1. *Demographic, comorbidity, and index hospitalization data for the cohorts used in the 30-day and 90-day readmission analyses*

	30-day readmissions N (%)	90-day readmissions N (%)
Total number of cases	8588	7289
Age group, years		
18-35	315 (3.7)	271 (3.7)
36-65	5526 (64.3)	4732 (64.9)
>65	2747 (32.0)	2286 (31.4)
Sex		
Male	1817 (21.2)	1543 (21.2)
Female	6771 (78.8)	5746 (78.8)
Primary expected payer		
Medicare	3458 (40.4)	2906 (40.0)
Medicaid	884 (10.3)	780 (10.7)
Private	3684 (43.0)	3133 (43.1)
Self-pay	129 (1.5)	114 (1.6)
No charge	38 (0.4)	31 (.4)
Other	373 (4.4)	306 (4.2)
Income quartile		
First	1897 (22.5)	1598 (22.3)
Second	1918 (22.7)	1640 (22.9)
Third	2292 (27.2)	1939 (27.1)
Fourth	2334 (27.7)	1977 (27.6)
Size of hospital		
Small	478 (5.6)	401 (5.5)
Medium	1110 (12.9)	946 (13.0)
Large	7000 (81.5)	5942 (81.5)
Hospital location		
Large metropolitan	5735 (66.8)	4881 (67.0)
Small metropolitan	2838 (33.0)	2395 (32.9)
Micropolitan	15 (.2)	13 (.2)
Hospital teaching status		
Metropolitan nonteaching	826 (9.6)	698 (9.6)
Metropolitan teaching	7747 (90.2)	6578 (90.2)
Nonmetropolitan	15 (.2)	13 (0.2)
Hospital volume (top 10%)		
Low	5624 (65.5)	4752 (65.2)
High	2964 (35.5)	2537 (34.8)
Charlson comorbidity index		
0	5220 (60.8)	4412 (60.5)
1	2079 (24.2)	1758 (24.1)
2	718 (8.4)	619 (8.5)
≥3	571 (6.6)	500 (6.9)
Ischemic stroke during hospitalization		
None	8370 (97.5)	7107 (97.5)
Present	218 (2.5)	182 (2.5)
Subarachnoid hemorrhage or intracerebral hemorrhage during hospitalization		
None	8470 (98.6)	7184 (98.6)
Present	118 (1.4)	105 (1.4)
Urinary tract infection		
None	8404 (97.9)	7135 (97.9)
Present	184 (2.1)	154 (2.1)
Pneumonia		
None	8544 (99.5)	7252 (99.5)
Present	44 (.5)	37 (0.5)
Sepsis		
None	8569 (99.8)	7274 (99.8)
Present	19 (.2)	15 (.2)
Venous thromboembolism		
None	8560 (99.7)	7264 (99.7)
Present	28 (.3)	25 (.3)
Acute kidney injury		
None	8545 (99.5)	7250 (99.5)
Present	43 (.5)	39 (.5)
Disposition from index hospitalization		
Routine	8072 (94.0)	6848 (93.9)
Nonroutine	516 (6.0)	441 (6.1)

Indications for Readmission

Table 4 lists the most common indications for 30dRA and 90dRA. The most common primary diagnosis associated with both 30- and 90-dRAs were the same as the index hospitalization (437.3, unruptured cerebral aneurysm). Ischemic events were the second most common diagnoses for both 30dRA (.9%) and 90dRA (1.0%). Only .3% of 30- and 90-dRAs were associated with a primary diagnosis of intracerebral hemorrhage. Figure 4 displays the median intervals to readmission stratified by CCS categorization of the readmission diagnosis for both 30- and 90-dRAs.

As shown in Table 4, the most common procedure performed during 30dRAs and 90dRAs was cerebral angiography (7.3% and 8.0%, respectively). The incidence of repeat aneurysm embolization was 5.4% within 30 days and 6.0% within 90 days. The incidence of craniotomy for aneurysm clipping was .7% within 30 days and .8% within 90 days.

Predictors of Nonroutine Discharge Following Readmission

We also performed a binary logistic regression analysis to identify predictors of non-routine discharge following readmission (Table 5). The model was statistically significant ($X^2(23) = 286.113$, $P < .001$), the data fit the model well (Hosmer and Lemeshow $P = .588$), and the model classified 95.7% of cases correctly. Privately insured patients had decreased odds of nonroutine disposition compared to those with Medicare (OR .500, 95% CI .361-.692). Patients with a CCI greater than or equal to 3, hemorrhagic complication following endovascular embolization, and urinary tract infection during the index admission had greater odds of nonroutine disposition. Additionally, those

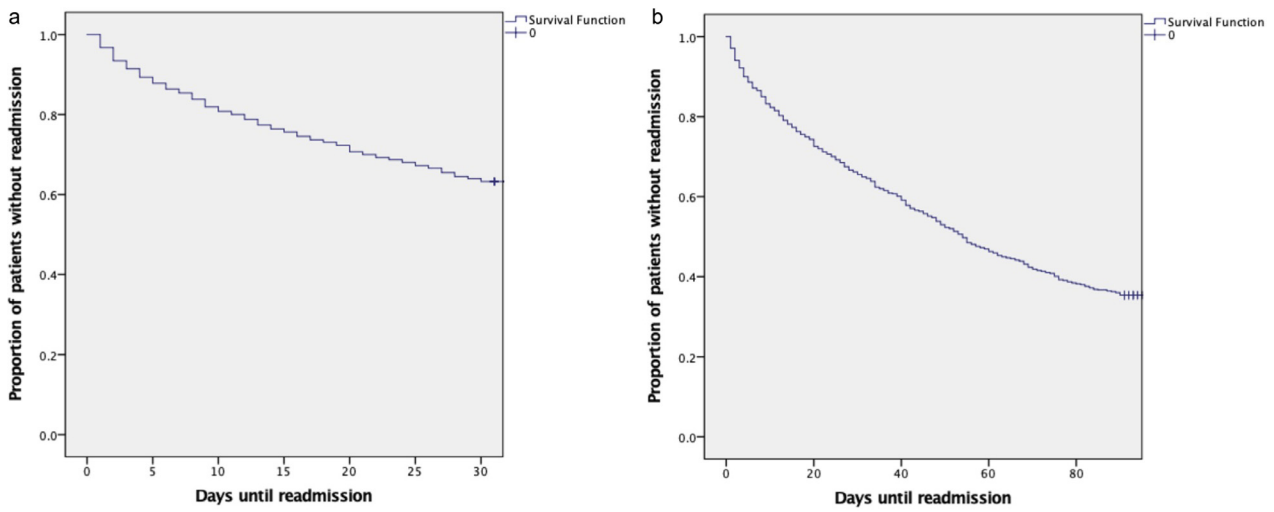

Figure 2. *Kaplan-Meier curves demonstrating the durations to 30dRA (a) and 90dRA (b) among all patients who experienced readmission.*

who had a nonroutine disposition from their index admission were 4 times more likely to experience a nonroutine discharge following readmission than those who did not.

Discussion

Cerebral aneurysms are relatively common and cause significant morbidity and mortality upon rupture.[1] Although the endovascular approach has become the

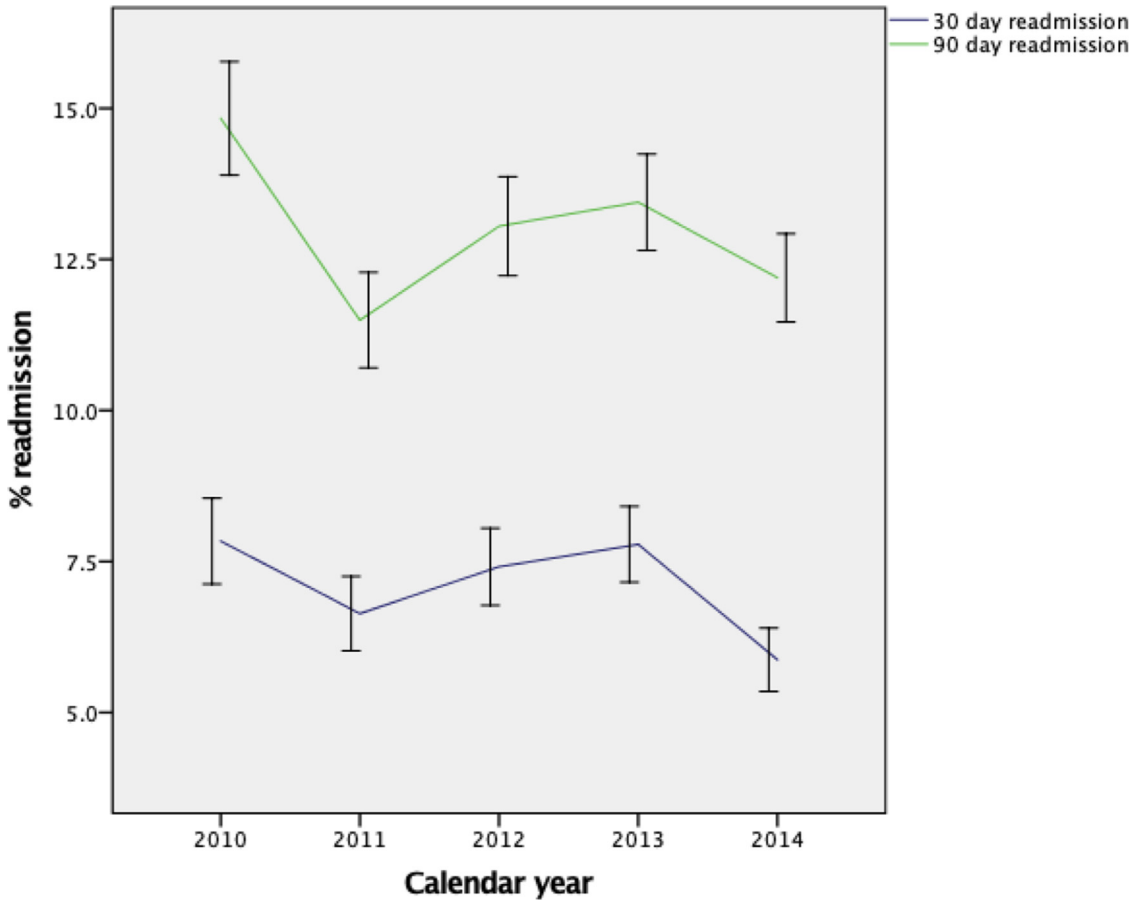

Figure 3. *30- and 90-day readmission rates each year between 2010 and 2014 for the entire cohort. The pooled ORs of 30dRA and 90dRA were .874 (95% CI .765-.998, P = .047) and .841 (95% CI .755-.938, P = .002), respectively. Abbreviations: OR, odds ratio.*

Table 2. *Multivariate analysis of putative predictors for unplanned 30-day readmission*

	Odds ratio	95% confidence interval	*P*
Sex			
Male	Ref	-	-
Female	.829	.671-1.023	.081
Primary expected payer			
Medicare	Ref	-	-
Medicaid	.805	.580-1.119	.197
Private	1.056	.863-1.292	.597
Self-pay	1.315	.673-2.566	.423
No charge	.386	.051-2.932	.358
Other	1.039	.664 − 1.624	.868
Income quartile			
First	Ref	-	-
Second	.588	.453-.764	<.001
Third	.672	.527-.856	.001
Fourth	.622	.485-.797	<.001
Hospital bed size			
Small	Ref	-	-
Medium	.947	.620-1.446	.800
Large	.744	.514-1.077	.117
Charlson comorbidity index			
0	Ref	-	-
1	1.056	.848-1.315	.624
2	1.065	.774-1.467	.698
≥3	1.391	1.007-1.921	.045
Stent placement			
Not performed	Ref	-	
Performed	.558	.289-1.078	.083
Hemorrhagic complication			
None	Ref	-	-
Present	.744	.370-1.495	.406
Medical complication			
Urinary tract infection	.782	.449-1.363	.386
Pneumonia	1.024	.382-2.744	.962
Sepsis	2.054	.527-7.997	.300
Venous thromboembolism	2.043	.661-6.312	.215
Acute kidney injury	.812	.287-2.297	.694
Pulmonary or cardiac	1.428	.848-2.403	.180
Length of stay			
1 day	Ref	-	-
>1 day	1.070	.885-1.295	.484
Disposition from index hospitalization			
Routine	Ref	-	-
Nonroutine	15.333	12.040-19.527	<.001

Table 3. *Multivariate analysis of putative predictors for unplanned 90-day readmission*

	Odds ratio	95% confidence interval	*P*
Age group, years			
18-35	Ref	-	-
36-65	.924	.624-1.369	.695
>65	.827	.533-1.282	.395
Primary expected payer			
Medicare	Ref	-	-
Medicaid	.757	.560-1.023	.070
Private	.985	.793-1.223	.890
Self-pay	1.111	.622-1.983	.723
No charge	.376	.081-1.738	.210
Other	.906	.605-1.358	.633
Income quartile			
First	Ref	-	-
Second	.786	.635-.973	.027
Third	.730	.593-.899	.003
Fourth	.743	.604-.916	.005
Charlson comorbidity index			
0	Ref	-	-
1	1.031	.860-1.236	.743
2	1.144	.877-1.493	.320
≥3	1.374	1.034-1.825	.029
Stent placement			
Not performed	Ref	-	-
Performed	.680	.409-1.130	.137
Ischemic complication			
None	Ref	-	-
Present	.646	.388-1.075	.092
Hemorrhagic complication			
None	Ref	-	-
Present	.935	.510-1.714	.828
Medical complication			
Urinary tract infection	.841	.502-1.409	.510
Pneumonia	.850	.307-2.356	.755
Sepsis	.840	.176-4.008	.827
Venous thromboembolism	1.919	.661-5.567	.230
Acute kidney injury	1.304	.532-3.195	.562
Pulmonary or cardiac	1.637	1.038-2.582	.034
Length of stay			
1 day	Ref	-	-
>1 day	1.066	.910-1.248	.428
Disposition from index hospitalization			
Routine	Ref	-	-
Nonroutine	21.431	16.484-27.862	<.001

preferred initial treatment option for aneurysms of many locations and configurations, it is not without potential complication. The most feared risks of EVT include intraoperative aneurysm rupture and thromboembolism. Postoperative complications include rupture, stroke, and aneurysm recurrence.[20] National readmission rates following elective EVT have not been described. Likewise, annual trends in readmission rates as well as risk factors and reasons for readmission are unknown. Using nationally representative data derived from endovascular embolizations of UCAs performed between 2010 and 2014, we identified 30dRA and 90dRA rates of 7.1% and 13.5%, respectively. We also identified multiple predictors of unplanned readmission. It is important to track national readmission rates for neurosurgical procedures in order to identify potential sources of increasing healthcare costs. Furthermore, individual hospitals and providers can use these figures

Table 4. *Ten most common diagnoses and procedures for 30 and 90-day readmissions in order of decreasing frequency*

30-day readmissions			90-day readmissions		
Diagnosis	N	%	Diagnosis	N	%
Cerebral aneurysm, unruptured	528	6.1	Cerebral aneurysm, unruptured	491	6.7
Infarction due to cerebral artery occlusion	80	.9	Infarction due to cerebral artery occlusion	71	1.0
Cerebrovascular anomaly	38	.4	Cerebrovascular anomaly	37	.5
Headache	31	.4	Headache	26	.4
Transient cerebral ischemia	29	.3	Transient cerebral ischemia	25	.3
Iatrogenic cerebrovascular infarction or hemorrhage	27	.3	Urinary tract infection	25	.3
Urinary tract infection	26	.3	Sepsis	23	.3
Sepsis	25	.3	Iatrogenic cerebrovascular infarction or hemorrhage	23	.3
Nontraumatic intracerebral hemorrhage	23	.3	Carotid artery occlusion	21	.3
Carotid artery occlusion	21	.2	Nontraumatic intracerebral hemorrhage	20	.3
Procedure	N	%	Procedure	N	%
Cerebral arteriogram	629	7.3	Cerebral artriogram	585	8.0
Cerebral endovascular embolization	465	5.4	Cerebral endovascular embolization	435	6.0
Packed cell transfusion	120	1.4	Packed cell transfusion	111	1.5
Procedure on single vessel (peripheral)	73	.9	Procedure on single vessel (peripheral)	67	.9
Clipping of aneurysm	62	.7	Clipping of aneurysm	58	.8
Endotracheal intubation	57	.7	Endotracheal intubation	54	.7
Femoral arteriogram	54	.6	Femoral arteriogram	47	.6
Placement of vascular stent	46	.5	Placement of vascular stent	42	.6
Arterial catheterization	43	.5	Arterial catheterization	38	.5
Mechanical ventilation	41	.5	Mechanical ventilation	37	.5

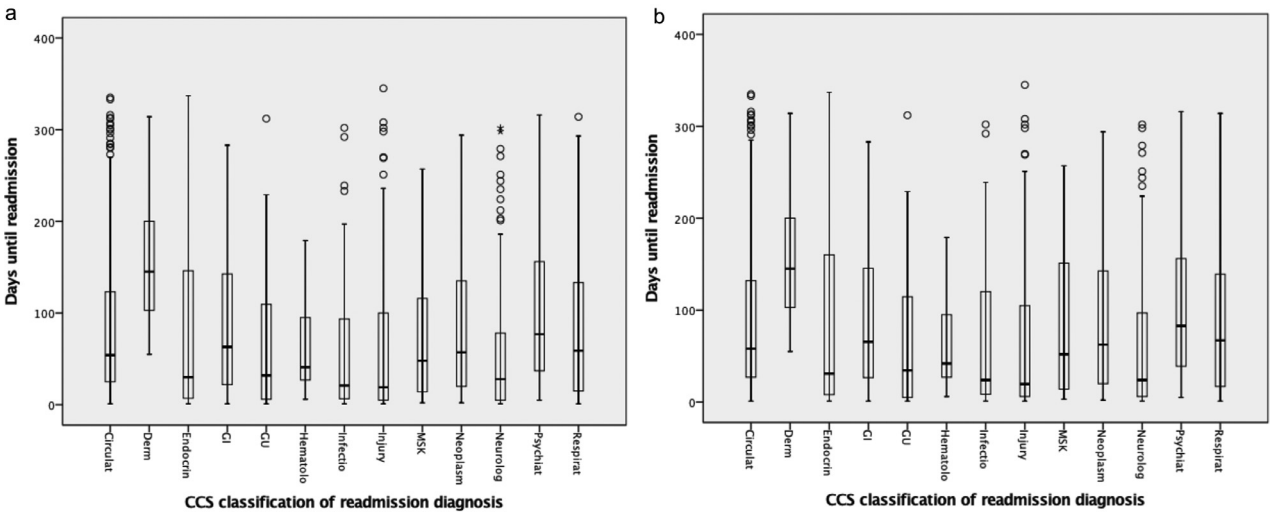

Figure 4. *Median times, interquartile ranges, and 95% confidence intervals for time to 30dRA (a) and 90dRA (b) categorized by Clinical Classifications Software system of the primary readmission diagnosis.*

as metrics to evaluate their performances. Finally, predictors of readmission can be used to direct resource utilization for predischarge planning and postdischarge surveillance to prevent readmission.

Our reported 30dRA rate of 7.1% is lower than that reported in Jalbert et al's study of Medicare beneficiaries in which 10.9% experienced a 30dRA.[15] Our 30dRA rate is also lower than that published by Bekelis et al, who identified 14.1% and 14.4% 30dRA rates in patients treated by operating neurosurgeons who were trained in either solely endovascular or both endovascular and open techniques, respectively.[21] Both of these studies were performed in Medicare beneficiaries, thereby increasing the age and potentially the medical complexity of their cohorts. In Bekelis et al's study using the New York Statewide Planning and Research Cooperative System of all age groups undergoing EVT, the 30dRA rate was 6.33%, which is comparable to our results.[14] Similar to our

Table 5. *Predictors of non-routine discharge following readmission*

	Odds ratio	95% confidence interval	*P*
Age group, years			
18-35	Ref	-	-
36-65	1.363	.595-3.121	.465
>65	1.596	.673-3.782	.289
Primary expected payer			
Medicare	Ref	-	-
Medicaid	.725	.473-1.112	.140
Private	.500	.361-.692	<.001
Self-pay	.656	.234-1.835	
No charge	.608	.082-4.532	.422
Other	.691	.477-1.264	.628
Charlson comorbidity index			
0	Ref	-	-
1	.966	.731-1.276	.808
2	1.351	.952-1.915	.092
≥3	1.897	1.354-2.658	<.001
Ischemic stroke during hospitalization			
Not performed	Ref	-	-
Performed	.843	.516-1.378	.496
Subarachnoid hemorrhage or intracerebral hemorrhage during hospitalization			
None	Ref	-	-
Present	2.066	1.168-3.653	.013
Medical complication			
Urinary tract infection	1.668	1.042-2.669	.033
Pneumonia	1.985	.854-4.616	.111
Sepsis	.607	.173-2.136	.437
Venous thromboembolism	1.070	.318-3.601	.913
Acute kidney injury	1.672	.724-3.863	.229
Pulmonary or cardiac	1.350	.807-2.258	.252
Length of stay			
1 day	Ref	-	-
>1 day	1.017	.796-1.299	.895
Disposition from index hospitalization			
Routine	Ref	-	-
Nonroutine	4.227	3.093-5.777	<.001

results, Jalbert et al noted a significant decrease in the incidence of 30dRAs from 13.3% in 2000 to 10.9% in 2010.[15] The factors influencing decreases in 30dRA and 90dRA rates are likely multifactorial. Endovascular embolization has become more sophisticated, with improved occlusion rates associated with iterative technologies and increased experience with the use of adjuncts to coiling such as balloon and stent assistance. Likewise, increased surgical experience with these technologies has also improved their safety. Of note, the 30dRA and 90dRA rates of 7.1% and 13.5%, respectively in this study are slightly lower than those of unruptured aneurysm clipping (9.1% and 14.9%, respectively) in a previous publication that used the NRD during the same study period.[22]

Identifying predictors of readmission is important so that resources for postdischarge surveillance and follow-up are allocated appropriately. We hypothesized that age would be associated with a higher likelihood of readmission, however this was not the case. Similarly, we suspected that Medicare beneficiaries would be more likely to be readmitted. Medicaid beneficiaries had lower incidences of 30dRA and 90dRA after index hospitalization compared to Medicare beneficiaries, but this did not reach statistical significance. We found that patients who were in the second, third, or fourth income quartiles were less likely to be readmitted within 30 or 90 days than those in the first quartile. Patients with higher income could have had an improved baseline level of health, increased access to superior rehabilitation, and closer outpatient follow-up. As we hypothesized, patients with greater comorbidity burdens were at higher risk of being readmitted. This is consistent with the findings of O'Neill et al who found that patients with a CCI greater than 4 were more likely to experience a poor outcome after discharge following both EVT and microsurgical clipping for UCAs.[23] Interestingly, stent placement did not influence the risk of 30- or 90-dRA. Although the use of adjunct devices during coiling has been associated with higher complication rates, previous studies have suggested that it also yields greater occlusion rates.[24] Previously, hospitals with a high endovascular volume have been associated with decreased lengths of stay, fewer nonroutine discharges, and lower costs.[16] In contrast, we did not identify any difference between readmission rates for the highest volume institutions compared to the rest. It is possible that systems-based factors relating to discharge planning and quality of follow-up have a greater influence on readmission rates. Additionally, high volume institutions may treat a greater proportion of patients who travel from out of state for treatment. These patients were excluded from our analysis due to limitations of the NRD.

It should be noted that the factors associated with readmission in this study are primarily nonmodifiable. However, knowledge of these associations can be used to apply interventions aimed at preventing unplanned readmissions. Previously described methods for reducing 30dRAs are multifaceted and implement a variety of personnel at different stages in the transition from the hospital to the community.[25] These include educational interventions, telephone follow-up after discharge with assessments of patient needs or concerns, telemonitoring with remote technology that transmits objective health information to providers, home visits, comprehensive discharge planning by a dedicated advanced practice nurse, and close outpatient follow-up with a dedicated transition of care clinic.[26] Many of these approaches are resource-intensive, making their implementation for all discharges prohibitively costly and time consuming. Their use in low risk patients would also be unnecessary. This underscores

the importance of identifying patients with risk factors for 30dRA or 90dRA so that the aforementioned interventions could be applied efficiently.

Nonroutine discharge rates to both acute and chronic facilitates after EVT of cerebral aneurysms decreased significantly from 1996 to 2010.[11-16,21] In this study, predictors of nonroutine discharge after readmission were similar to those for readmission. These included CCI greater than or equal to 3, hemorrhagic complications following the embolization, and urinary tract infections. As expected, patients who experienced nonroutine discharges after index hospitalization were significantly more likely to have a nonroutine discharge following readmission.

Indications for 30dRA and 90dRA were similar. The most common primary diagnosis associated with 30- and 90-dRAs in our study was the same as the index hospitalization (unruptured cerebral aneurysm), suggesting that readmissions were related to sequelae of the embolization procedure. Unfortunately, this diagnosis does not provide details regarding the exact reason for readmission and likely encompasses a variety of potential complications relating to endovascular intervention. The next most common cause for readmission was cerebral ischemia, which is a known complication of endovascular embolization and may be more prevalent with the use of adjunctive devices.[24] In a separate study that used the NRD, a larger proportion of patients who underwent microsurgical clipping of UCAs experienced readmission for cerebral ischemia (30dRA: 4.9%, 90dRA: 4.3%).[22] In the present study, the median LOS of readmission was short (2 days), suggesting that when complications of the index procedure accounted for readmission, they were likely minor. Bekelis et al was the only other study to describe the reasons for readmission after EVT, however, they did not report the frequency associated with each diagnosis, and their data included patients who were treated with clipping as well as EVT.[13] The most common reasons for 90dRAs in their study were headaches, seizures, malaise or fatigue, chest pain, and fever.

Limitations of our study should be noted. One of the shortcomings of administrative datasets is that they often only allow for broad generalizations regarding patients' treatments. We relied on ICD-9-CM codes in order to characterize in-hospital complications and readmission diagnoses. ICD-9-CM codes are susceptible to coding inaccuracies and do not provide the granularity achievable with clinical datasets. For example, details about aneurysm location, size, morphology, and prior treatment, which are known to influence surgical outcomes, were not available. We also did not have access to operative data that could have affected outcomes such as the presence of intraoperative complications and operative time. In addition, although we had access to hospital volume, we did not have data regarding surgeon experience, which is known to affect outcomes for EVT.[15] Finally, newer modalities for aneurysm occlusion such as flow diversion and placement of intrasaccular devices are not associated with unique ICD-9-CM codes, which prevented us from analyzing these techniques individually.

Despite these limitations, our study has several strengths. Our cohort is the largest to study outcomes after elective aneurysm embolization and is the first to use the NRD for this purpose. The NRD accounts for a wide variety of surgical and clinical practices across the United States, which provides our results strong generalizability. It is also the first study to evaluate the risk factors for readmission as well as the diagnoses associated with readmission. We also provide the first analysis of both 30- and 90-dRAs in a single cohort of patients undergoing EVT. Although considerable focus has been placed on characterizing and preventing 30dRAs, a large proportion of readmissions occur after this time period and may influence functional and neurologic recovery, making 90dRA a clinically important outcome.

Conclusion

The 30- and 90dRA rates following EVT for UCA from 2010 to 2014 were 7.1% and 13.5%, respectively. Annual readmission rates decreased during this time. Factors associated with a higher likelihood of readmission included lower income, greater comorbidity burden, and nonroutine discharge from the index admission.

Conflict of Interest

The authors have no relevant financial or personal conflicts of interest to disclose.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jstrokecerebrovasdis.2019.104396.

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