A systematic review of 30-day readmission after cranial neurosurgery

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OBJECTIVE The 30-day readmission rate has emerged as an important marker of the quality of in-hospital care in several fields of medicine. This review aims to summarize available research reporting readmission rates after cranial procedures and to establish an association with demographic, clinical, and system-related factors and clinical outcomes.

METHODS The authors conducted a systematic review of several databases; a manual search of the *Journal of Neurosurgery*, *Neurosurgery*, *Acta Neurochirurgica*, *Canadian Journal of Neurological Sciences*; and the cited references of the selected articles. Quality review was performed using the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria. Findings are reported according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

RESULTS A total of 1344 articles published between 1947 and 2015 were identified; 25 were considered potentially eligible, of which 12 met inclusion criteria. The 30-day readmission rates varied from 6.9% to 23.89%. Complications arising during or after neurosurgical procedures were a prime reason for readmission. Race, comorbidities, and longer hospital stay put patients at risk for readmission.

CONCLUSIONS Although readmission may be an important indicator for good care for the subset of acutely declining patients, neurosurgery should aim to reduce 30-day readmission rates with improved quality of care through systemic changes in the care of neurosurgical patients that promote preventive measures.

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KEY WORDS readmission; cranial neurosurgery; causes; outcomes; systematic review

IN recent years, readmission has become a predominant issue due to its burdens on the health care system, hospitals, insurers, and patients. It has been estimated that the yearly cost to Medicare of unplanned readmissions is \$17.4 billion.²⁴ In the US, reimbursement penalties have been instituted for early readmissions to improve quality of care under the Patient Protection and Affordable Care Act.² Considering the health and financial costs associated with readmission, it is not surprising that reducing readmission rates has been deemed a public health priority.^{23,27} In neurosurgery, the connection between the rates of readmission and performance level is unclear and considerable debate exists regarding this association.⁴³ A recent study from Health Canada concluded that readmission rates are important for measuring the quality and efficiency of

acute care.²³ However, some researchers argue that a drop in readmission among neurosurgery patients may not be a positive indicator of health care and that unlike other divisions of care, early readmission and intervention in neurosurgery can ultimately prevent complications, serious morbidities, and disease progression.²¹ Hence, high rates of 30-day readmission in neurosurgery are suggested to be a sign of prudent care that may indicate better outcomes and higher quality of care.⁴³

Recent studies report that primary diagnoses at readmission are related to surgery and that these complications are mostly preventable, according to the Agency for Healthcare Research and Quality.^{16,34} As a result, attempts have been made to identify causes and factors related to readmission rates and to introduce preventive measures to

ABBREVIATIONS CPT = current procedural terminology; DVT = deep venous thrombosis; LOS = length of stay; PE = pulmonary embolism; PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; STROBE = Strengthening the Reporting of Observational Studies in Epidemiology; VTE = venous thromboembolism.

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FIG. 1. Chart showing research strategy and terms used when searching through MEDLINE and EMBASE Classic.

reduce their impact, thereby improving patient care and reducing the cost to health care providers. In a number of other specialties, multifaceted interventions are now provided by health care professionals and have been shown to be effective in reducing readmission rates.^{23,29,39} However, these factors have yet to be summarized systematically for neurosurgical procedures and diagnoses. Such reports are crucial to understanding the causes of pathological entities that require cranial neurosurgery and subsequently developing strategies to prevent their occurrence.

In this review, our aims were 3-fold. First, we aimed to summarize available research on 30-day readmission rates after cranial procedures in neurosurgery. Our second goal was to identify demographically at-risk populations, and the clinical and system-related factors associated with readmission in neurosurgery. Last, potential strategies to reduce the identified readmission risk factors in neurosurgery were discussed.

Methods

A total of 1344 articles were obtained from a systematic search of English-language literature using MEDLINE (1946–June 2014) and EMBASE Classic (1947–June 2014); a manual search of the *Journal of Neurosurgery*, *Neurosurgery*, *Acta Neurochirurgica*, *Canadian Journal of Neurological Sciences*; the cited references of the selected articles; and the “search cited” feature of PubMed. The search was limited to randomized controlled trials and observational, retrospective, and follow-up studies involving only human cohorts. Search terms are summarized in Fig. 1.

Studies that assessed readmission rates after the following procedures were included: craniotomy (for glioma and meningioma); transsphenoidal surgery (endoscopic pituitary, microscopic pituitary, transsphenoidal nonpituitary tumor); craniotomy for subdural hematoma; bur hole(s) for subdural hematoma; cerebral aneurysm repair by craniotomy and endovascular technique; ventriculoperitoneal shunt insertion and revision; endoscopic third ventriculostomy; surgical treatment of epilepsy by temporal lobectomy, amygdalohippocampectomy, hemispherectomy, callosotomy, and other procedures for seizures; or

other neurosurgical cranial procedures for brain tumors, traumatic brain injury, subdural hematomas, cerebral aneurysms, hydrocephalus, and epilepsy.

Articles of interest must have reported the number of patients returning to the hospital after a cranial procedure and their demographic data and/or reasons for readmission. The studies were required to perform comparative analyses between a readmitted and a nonreadmitted group or between a readmitted and the overall group. Excluded studies comprised those that reported readmission as reoperation, complications, mortality, morbidity, or as part of a composite outcome.

Based on the inclusion and exclusion criteria, 25 articles were retained for full-text examination, of which 12 were chosen to be included in this review. Figure 2 is a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, which illustrates the number of articles at each data acquisition level, the number of excluded articles, and the reasons for exclusion. Characteristics of study quality such as use of statistical analyses, generalizability, and external and internal validity were assessed by 2 of the authors (I.P. and M.L.) using STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria.⁴⁸ The Cohen’s kappa (κ) of 0.78 for the agreement between the 2 raters was high. The PRISMA guidelines were used to report the results.³⁰

Results

The 30-day readmission rates ranged from 6.0% to 23.89%. All of the selected studies assessed readmission rates and identified causes for readmission or for vulnerable populations.^{6,9,16,32,34,36,38,42,43,47,50,52} Table 1 provides details of characteristics of each study. All except one Australian study were conducted in the US.⁵⁰ All 12 studies were retrospective cohorts. Studies reported on data derived from time periods ranging from 1991 to 2013, and the sample size in each study varied from 100 to 18,506.

Seven studies^{9,32,34,36,38,42,52} used ICD-9 or current procedural terminology (CPT) codes to identify the appropriate neurosurgical diagnoses and/or procedures. Nine of the 12 selected studies^{12,16,32,34,38,38,42,43,52} reported the significance of factors associated with 30-day readmission,

FIG. 2. A PRISMA flow diagram showing the flow of information through the different phases of the systematic review.

whereas the 3 remaining studies^{6,47,50} stated reasons for readmission with no analysis of their significance. Analytical methods used to examine predictors of readmission included univariate analyses,^{9,16,34,36,42,43,52} multivariate logistic regression,^{9,16,32,36,38,42,52} and bivariate analyses using the Welch t-test and Pearson chi-square test.^{32,38} None of the articles reported power analyses to determine if their study had a sufficient sample size to detect an effect, if an effect was present.

Tables 2–4 present a summary of the characteristics of patients that have been shown to be predictive of readmission. There was strong consistency in several patient and procedural factors, such as age (see Table 2); however, results for sex and race were inconsistent between studies. Although 2 studies demonstrated that age was a significant factor in predicting readmission,^{32,34} the majority of the studies reported nonsignificant results.^{9,16,34,36,38} Sex was found to be a significant and important predicting factor in 2^{32,34} of the 6^{9,16,32,34,36,38} studies that examined it; males were more likely to be readmitted in the hospital after neurosurgery than females. Race was examined by 5 of

the 12 studies as a possible readmissions predictor. Marcus et al.³² found that African American and Hispanic patients were more likely to be readmitted. Nuño et al.³⁶ found that nonwhite patients were at greater risk for 30-day readmission after neurosurgery. Moghavem et al.³⁴ reported that black or Hispanic ethnicity were predictors of readmission after neoplasm surgery, and that black ethnicity was found to be a significant predictor of readmission for patients with vascular conditions. Two studies reported that race was not a significant predictor in hospital readmission after neurosurgery.^{9,16} Other patient and procedural factors that were found to be consistently nonsignificant in the studies we reviewed were household income,^{9,36} tumor size,^{16,36} procedure length,^{9,38,52} and extent of resection.^{16,36}

Several comorbidities were found to predict readmission after neurosurgery (Table 3). Three studies found that having chronic obstructive pulmonary disease, diabetes mellitus, or congestive heart failure were risk factors for hospital readmission.^{32,34,38} Interestingly, Moghavem et al.³⁴ and Rambachan et al.³⁸ showed that alcohol abuse was not a significant predictor of hospital readmission af-

TABLE 1. Study characteristics of 12 retrospective cohort studies of 30-day readmission after cranial neurosurgery

Authors & Year	Data Source (study period)	Study Location	No. of Hospitals/ No. of Patients	Diagnosis	Procedure	Study Outcome/ Comparator Group	30-Day Readmission Rate (%)	STROBE Average Score	Analytical Model
Buchanan et al., 2014	Database, Dept of Neurosurgery at UCLA Ronald Reagan Medical Center & UCLA Santa Monica Hospital (May 2009–May 2012)	US	2/5569	Brain tumor, CSF shunt malfunction, hydrocephalus, spinal pathology, spinal tumor, subdural hematoma, trigeminal neuralgia, calvarial defect, other	Craniotomy, shunt insertion/revision, other	Readmission	6.9	14.5	NA
Chern et al., 2014	NA (May 1, 2009–April 30, 2013)	US	1/1755	Hydrocephalus (not explicitly stated)	Shunt insertion/revision (CPT 62190–62258, excluding 62200 & 62201)	Readmission	16.5	17	Univariate analysis using Fisher's exact test; binary logistic regression; multivariate logistic regression*
Dickinson et al., 2015	Cedars-Sinai Medical Center (January 2003–December 2011)	US	1/362	Glioblastoma	Craniotomy	Readmission	7.5	18.5	Univariate comparisons using Wilcoxon rank-sum test, chi-square test, & Fisher's exact test; Kaplan-Meier estimation method; Cox proportional hazards model; multivariate logistic regression*
Marcus et al., 2014	CA OSHPD longitudinal inpatient-discharge administrative database (1995–2010)	US	Multiple (no. not specified)/18,506	Malignant brain tumor (ICD-9-CM 191.0–191.5, 191.8, 198.9)	Lobectomy (ICD-9-CM 01.53), excision or destruction of tissue or lesion of brain (01.59), or open brain biopsy (01.14)	Readmission	13.2	16.5	Bivariate analysis using Welch t-test & Pearson chi-square test; multivariate logistic regression*
Moghavem et al., 2015	AHRQ State Inpatient Databases for CA, FL, & NY (2010–2011)	US	Multiple (all nonfederal hospitals in CA, FL, & NY)/7016	Neoplasm, seizure, vascular, & trauma diagnoses using (ICD-9-CM: 160.0; 170.0; 191*; 192.1; 194*; 198*; 200.20; 200.50; 202.80; 202.81; 209.79; 213.0; 215.0; 225*; 227*; 237*; 239.6; 253*; 255*; 345; 349.2; 430*–434*; 437*; 438.20; 438.89; 747.81; 996.1; 800*–803*; 851*–853*)	Any cranial neurosurgical procedure (ICD-9-CM: 01; 01.0–01.6; 02; 02.0–02.02.2; 02.9; 04.01)	Readmission	Neoplasm: 17.27, seizure: 13.89, vascular: 23.89, trauma: 19.82	18	Univariate analysis using Fisher's exact test; logistic regression models*

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Authors & Year	Data Source (study period)	Study Location	No. of Hospitals/ No. of Patients	Diagnosis	Procedure	Study Outcome/ Comparator Group	30-Day Readmission Rate (%)	STROBE Average Score	Analytical Model
Nuño et al., 2014	NCI SEER Medicare-linked database (January 1991–December 2007)	US	Multiple (no. not specified)/2774	NA	Biopsy, resection (ICD-9-CM: 1.11–1.15, 1.18, 1.19; 1.23–1.25, 1.31, 1.32, 1.39; 1.51–1.53, 1.59, 1.60)	Readmission	15.8	18	Univariate analysis using Wilcoxon rank-sum test, chi-square test, & Fisher's exact test; multivariate logistic regression; Cox proportional hazards model*
Ram-bachan et al., 2014	American College of Surgeons NSQIP (2011)	US	Multiple (no. not specified)/8456	NA	Carotid endarterectomy (CPT 35301, ICD-9 433.1, 433.10, 433.11)	Unplanned readmission	6.0	18	Bivariate analysis; c-statistics; Hosmer-Lemeshow statistics; multivariate logistic regression*
Sarda et al., 2014	Children's Healthcare of Atlanta (May 1, 2009–April 30, 2013)	US	1/2924	NA	Any nonshunt neurosurgical procedures (i.e., CPT 62190–62258 were excluded)	Readmission	10.4	17	Univariate analysis (data not published); multivariate logistic regression*
Shah et al., 2013	Barnes-Jewish Hospital (April 30, 2009–September 26, 2010)	US	1/3552	NA	NA	Readmission	11.5	16	Univariate analysis using Microsoft Excel, chi-square test, & Fisher's exact test*
Vaziri et al., 2014	UFL Neurosurgery Service (January 1–March 31, 2012)	US	1/626	NA	NA	Readmission	14	13	NA
Wilson et al., 1999	SSFR Programme of the Austin and Repatriation Medical Centre (October 1992–September 1996)	Australia	1/100	Epilepsy	Anterior temporal lobectomy	Readmission	21	12.5	NA
Wrubel et al., 2014	Children's Healthcare of Atlanta (2012)	US	1/1358	ICD-9 348.0, 348.4, 756.0, V53.09, 996.63, 345.41, 996.2, 331.4, 742.59, V57.89, & other	Cranial procedure (CPT text search "craniotomy," "craniectomy," "cranioplasty"); shunt-related procedure (CPT 62190 & 62258, CPT text search "shunt"); other	Return to system w/in 30 days	10.9	15	Univariate analysis; multivariate logistic regression*

AHRQ = Agency for Healthcare Research and Quality; CM = clinical modification; NA = not available; NCI = National Cancer Institute; NSQIP = National Surgical Quality Improvement Program; OSHPD = Office of Statewide Health Planning and Development; SEER = Surveillance, Epidemiology, and End Results; SSFR = Seizure Surgery Follow-up and Rehabilitation; UCLA = University of California, Los Angeles; UFL = University of Florida.

* p value < 0.05 considered significant.

TABLE 2. Contributions of patient characteristics (patient and procedural factors)

Authors & Year	Patient Factors							Procedural Factors			
	Age	Sex	Race	Marital Status	Residence Location	Household Income	Tumor Size	Type	Major/Minor	Length	EOR
Buchanan et al., 2014	X	X	O	O	O	O	O	X	X	O	O
Chern et al., 2014	NS	O	NS	O	O	NS	O	NS	O	NS	O
Dickinson et al., 2015	NS	NS	NS	O	O	O	NS	O	O	O	NS
Marcus et al., 2014	S	S	S	O	O	O	O	O	O	O	O
Moghavem et al., 2015*	NS ^{a,c} , S ^{b,d}	S ^{a-c} , NS ^d	S ^{a,c} , NS ^{b,d}	O ^{a-d}	NS ^{a,b} , S ^{c,d}	O ^{a-d}	O ^{a-d}	O ^{a-d}	O ^{a-d}	O ^{a-d}	O ^{a-d}
Nuño et al., 2014	NS	NS	S	NS	O	NS	NS	O	O	O	NS
Rambachan et al., 2014	NS	NS	O	O	O	O	O	O	O	NS	O
Sarda et al., 2014	O	O	O	O	O	O	O	X	S	O	O
Shah et al., 2013	X	X	X	O	O	O	O	O	O	O	O
Vaziri et al., 2014	O	O	O	O	O	O	O	O	O	O	O
Wilson et al., 1999	X	X	O	X	O	O	O	O	O	O	O
Wrubel et al., 2014	NS	O	O	O	O	O	O	S	O	NS	O

EOR = extent of resection; NS = not statistically significant; O = the variable was not assessed or considered in the model; S = the variable was found to be statistically significant; X = the variable was considered in the model but statistical significance was not reported or was unclear.

* Reported 4 separate sets of data—for patients with neoplasm (a), seizure (b), vascular condition (c), and trauma (d).

ter neurosurgery. There was no consistency in the findings for hypertension and obesity as significant predictors of readmission. Marcus et al.³² and Moghavem et al.³⁴ found that these 2 comorbidities were positively correlated with readmission rates; however, results reported by Rambachan et al.³⁸ showed no such correlation.

Six studies examined length of stay (LOS) at index admission as a predictor for hospital readmission (Table 4). Five of these found it to be a significant predictor.^{9,32,36,42,52} Specifically, 4 of the 5 studies showed a positive correlation between LOS and readmission rates.^{9,32,36,42} In addition, the significance of discharge disposition was demonstrated by Dickinson et al.¹⁶ and Nuño et al.³⁶ Furthermore, Chern et al.⁹ reported that being a Medicaid payee was a risk factor

for hospital readmission. Marcus et al.³² found that having Medi-Cal insurance increased the risk of readmission when compared with having private insurance. Moghavem et al.³⁴ found that being a Medicare or Medicaid payee as a patient with a neoplasm or a vascular condition was a significant predictor for hospital readmission compared with being a private insurance payee. Three other studies, however, found that insurance coverage was not a significant predictor.^{34,43,42} Additionally, Chern et al.⁹ and Sarda et al.⁴² found that index admission through the emergency department and neonatal ICU increased the likelihood of being readmitted. Moghavem et al.³⁴ found admission type at index admission to be a significant predictor for hospital readmission among patients with neoplasm and seizure di-

TABLE 3. Contributions of patient characteristics (comorbidities)

Authors & Year	Comorbidities								
	Hypertension	Tobacco Use Disorder/Smoking	COPD	Diabetes Mellitus	Obesity & Overweight	CHF	Renal Disease/Failure	Liver Disease	Alcohol Abuse
Buchanan et al., 2014	O	O	O	O	O	O	O	O	O
Chern et al., 2014	O	O	O	O	O	O	O	O	O
Dickinson et al., 2015	O	O	O	O	O	O	O	O	O
Marcus et al., 2014	S	NS	S	S	S	S	NS	S	O
Moghavem et al., 2015*	NS ^{a-c} , S ^d	O ^{a-d}	NS ^{a,c} , O ^b , S ^d	S ^{a,c} , NS ^{b,d}	O ^{a,b,d} , S ^c	S ^{a,c,d} , NS ^b	O ^{a,b,d} , S ^c	NS ^{a,c,d} , O ^b	O ^{a-c} , NS ^d
Nuño et al., 2014	O	O	O	O	O	O	O	O	O
Rambachan et al., 2014	NS	NS	S	S	NS	S	O	O	NS
Sarda et al., 2014	O	O	O	O	O	O	O	O	O
Shah et al., 2013	O	O	O	O	O	O	O	O	O
Vaziri et al., 2014	O	O	O	O	O	O	O	O	O
Wilson et al., 1999	O	O	O	O	O	O	O	O	O
Wrubel et al., 2014	O	O	O	O	O	O	O	O	O

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; NS = not statistically significant; O = the variable was not assessed or considered in the model; S = the variable was found to be statistically significant.

* Reported 4 separate sets of data—for patients with neoplasm (a), seizure (b), vascular condition (c), and trauma (d).

TABLE 4. Contributions of patient characteristics (health system factors)

Authors & Year	Health System Factors				
	Expected Primary Payer	Admission Type at Index Admission	LOS (index admission)	LOS (readmission)	Discharge Disposition
Buchanan et al., 2014	O	X	X	O	O
Chern et al., 2014	S	S	S	O	O
Dickinson et al., 2015	O	NS	NS	O	S
Marcus et al., 2014	S	O	S	O	O
Moghavem et al., 2015*	S ^{a,c,d} , NS ^b	S ^{a,b} , NS ^{c,d}	O ^{a-d}	X ^{a-d}	O ^{a-d}
Nuño et al., 2014	O	NS	S	O	S
Rambachan et al., 2014	O	O	O	O	O
Sarda et al., 2014	O	S	S	O	O
Shah et al., 2013	NS	O	O	O	O
Vaziri et al., 2014	O	O	O	O	X
Wilson et al., 1999	O	O	O	O	O
Wrubel et al., 2014	NS	NS	S	O	O

LOS = length of stay; NS = not statistically significant; O = the variable was not assessed or considered in the model; S = the variable was found to be statistically significant; X = the variable was considered in the model but statistical significance was not reported or was unclear.

* Reported 4 separate sets of data—for patients with neoplasm (a), seizure (b), vascular condition (c), and trauma (d).

agnoses, and it was not a significant predictor for patients with vascular conditions and trauma. On the other hand, Dickinson et al.,¹⁶ Nuño et al.,³⁶ and Wrubel et al.⁵² did not find admission type at index admission to be a significant predictor.

Reasons for readmission and complications presenting after surgery are listed in Tables 5 and 6, and were identified by all but one study.⁴² Sarda et al., who focused on pediatric cases, however, found that a stay at the ICU during index admission was a predictor of readmission. Surgical and wound complications, including surgical site and wound infections, were frequent causes for readmission.^{6,9,16,32,38,43,47,50,52} Rambachan et al.³⁸ reported surgical

site infection as the most significant predictor of readmission when compared with patients who were not readmitted after carotid endarterectomy. Both Marcus et al.³² and Rambachan et al. found sepsis and septicemia as significant predictors of readmission for patients with neoplasm and vascular conditions. Rates of urinary tract infection were associated with higher rates of readmission in patients with vascular conditions,³⁸ and with lower odds of readmission following surgery for tumors.³² Pulmonary embolism (PE) and deep venous thrombosis (DVT)^{6,16,32,34,36,38,43} were significant predictors of readmission following surgery for vascular conditions³⁸ and tumors.³² Cardiac arrest and myocardial infarction were found to be significant predic-

TABLE 5. Surgical and medical complications during hospital stay and readmission

Authors & Year	Infectious Complications	Surgical Complications					Medical Complications		
		Surgical Wound	SSI/ Wound Infection	Shunt Malfunction/ Revision	Wound Dehiscence/ Revision	Sepsis/ Septic Shock/ Septicemia	Cardiac	UTI	Pneumonia
Buchanan et al., 2014	O	X	X	O	O	O	O	X	X
Chern et al., 2014	O	O	O	X	X	O	O	O	O
Dickinson et al., 2015	X	O	X	O	O	O	X	X	O
Marcus et al., 2014	S	S	O	O	O	S	O	S	O
Moghavem et al., 2015*	X ^{a-d}	O	O	O	O	X ^{a,c,d}	O	X ^{c,d}	X ^{a,c,d}
Nuño et al., 2014	X	O	O	O	O	O	X	O	O
Rambachan et al., 2014	O	O	S	O	NS	S	S	S	S
Sarda et al., 2014	O	O	O	O	O	O	O	O	O
Shah et al., 2013	O	X	X	O	X	O	O	X	X
Vaziri et al., 2014	O	O	X	X	X	O	X	X	O
Wilson et al., 1999	O	X	O	O	O	O	O	O	O
Wrubel et al., 2014	O	X	O	O	O	O	O	O	O

NS = not statistically significant; O = the variable was not assessed or considered in the model; S = the variable was found to be statistically significant; SSI = surgical site infection; UTI = urinary tract infection; X = the variable was considered in the model but statistical significance was not reported or was unclear.

* Reported 4 separate sets of data—for patients with neoplasm (a), seizure (b), vascular condition (c), and trauma (d).

TABLE 6. Medical complications during hospital stay and readmission

Authors & Year	Medical Complications								
	Thromboembolic Complications			Neurological Complications					
	General	PE	DVT	General	CVA/Stroke	Hydrocephalus	Sz & Convulsive Disorder	Hemorrhage	CSF Leak
Buchanan et al., 2014	O	X	X	X	O	X	X	O	X
Chern et al., 2014	O	O	O	O	O	O	O	O	O
Dickinson et al., 2015	X	X	X	X	O	X	X	X	O
Marcus et al., 2014	O	S	S	O	O	S	S	O	O
Moghavem et al., 2015*	O	X ^{a-c}	X ^{a,b}	X ^a	O	X ^{a,b}	X ^{b,d}	X ^{c,d}	O
Nuño et al., 2014	X	O	O	X	O	O	O	O	O
Rambachan et al., 2014	O	S	S	O	S	O	O	O	O
Sarda et al., 2014	O	O	O	O	O	O	O	O	O
Shah et al., 2013	X	O	O	O	X	X	O	O	X
Vaziri et al., 2014	O	O	O	O	O	X	X	O	X
Wilson et al., 1999	O	O	O	O	O	O	X	O	O
Wrubel et al., 2014	O	O	O	O	O	O	O	O	O

CVA = cerebrovascular accident; O = the variable was not assessed or considered in the model; S = the variable was found to be statistically significant; Sz = seizure; X = the variable was considered in the model but statistical significance was not reported or was unclear.

* Reported 4 separate sets of data—for patients with neoplasm (a), seizure (b), vascular condition (c), and trauma (d).

tors of readmission in patients with vascular conditions in 1 of the 12 studies reviewed.³⁸

The most frequent reasons for readmission were related to neurological complications³⁰ including seizures and convulsive disorders,^{6,16,32,34,47,50} hydrocephalus,^{6,16,32,34,43,47} and hemorrhage.^{16,34} After surgery for vascular conditions, cerebrovascular accident and/or stroke predicted readmission, whereas coma and peripheral nerve complications did not.³⁸ Six studies also found that seizures were frequent causes for readmission following neurosurgery for neoplasm, seizure, and trauma.^{6,16,32,34,47,50} Finally, 30-day readmission was a significant predictor of death in patients surviving brain tumor surgeries¹⁶ and increased the risk of dying by 30% for patients with glioblastoma.³⁶

Discussion

We found considerable variability, ranging from 6.0% to 23.89%, in the 30-day readmission rates for neurosurgical cranial procedures. Factors found to be predictive of readmission were also notably different between studies. This variance is related to a number of different issues. First, study characteristics between these reports differed in selection criteria based on procedures and diagnoses. Second, coding systems for diagnoses and procedures also differed between studies; some studies used CPT,^{9,38,42,52} others used ICD-9,^{32,34,36,38,52} and yet others did not use a coding system.^{6,16,43,47,50} Between the 2 studies that assessed only patients with glioblastoma,^{16,36} an 8.3% discrepancy in readmission rates (7.5% vs 15.8%) was observed, which may have resulted from differences between the studies' selection of patients' procedures. Future investigations may address this discrepancy by using standardized patient coding processes to increase comparability between studies.

The differences in readmission rates can also be accounted for by discrepancies in the definition of readmis-

sion between studies. Readmission varied in definition by readmission type (whether planned or unplanned), the type of services to which patients were readmitted (whether neurosurgical or general), and whether all patients were recorded as readmitted or only as inpatients. For example, Dickinson et al.¹⁶ used same-hospital readmission rates, whereas Marcus et al.³² and Moghavem et al.³⁴ captured patients readmitted to nonindex and index admission sites. Moghavem et al. found that less than 43% of patients were readmitted to the site of the index procedure, regardless of diagnosis group, demonstrating the importance of capturing from both index and nonindex sites. Several studies urge caution with respect to same-hospital readmission metrics because their use can produce artificially lower readmission rates for hospitals whose patients are readmitted elsewhere, resulting in a bias in favor of said hospitals.^{15,20,35} Studies that have proposed the use of a general definition for readmission are scarce in the current literature.⁴⁰ Therefore, future studies should try to include all hospital readmission data sources available in their comparisons to avoid these limitations.

Most^{9,16,36,38,52} of the studies found that age was not a predictor of 30-day readmission after neurosurgery procedures. This finding is surprising because age has been found to be positively associated with mortality and complication rates in spine surgery^{44,49} as well as many other surgical procedures.^{22,26,43} Nevertheless, our results regarding cranial neurosurgery suggest that resource allocation for quality of care improvement should depend on comorbidities and complications to a greater extent than age.

Although some inconsistency was found between studies, a patient's race was generally found to be an important factor in 30-day readmission. Being African American, Hispanic, or nonwhite was found to be a risk factor by 3^{32,34,36} of the 5 studies^{9,16,32,34,36} that evaluated the role of race and readmission. This finding agrees with the conclu-

sion that there are racial disparities in patient outcomes after craniotomy for tumor. Previous literature has shown that African American patients are significantly more prone to fluid or electrolyte and renal or urinary diseases compared with white patients.¹² This may provide an explanation for the underlying cause of the association between race and readmission. Other social factors, such as socioeconomic status, can influence the extent of a patient's insurance coverage. In particular, we found that Medicare, Medicaid, and Medi-Cal increased risk of readmission in neurosurgical patients.^{9,32,34} However, we investigated an equal number of studies that did not find insurance coverage to be significant. This finding is corroborated by past studies in other surgical disciplines, which do not form a consensus on the impact of insurance type on readmission rate.^{3,39,45} Evidently, additional studies that examine the role of social factors in defining quality outcomes, such as 30-day readmission, are required.

Not surprisingly, our review shows that sick patients tend to get readmitted. Having diabetes mellitus or congestive heart failure was consistently found to be a risk factor.^{32,34,38} This supports past studies that showed a significant association between diabetes or hypertension and poor postoperative improvement after various procedures.^{1,5,10,21,32,46}

Most of the studies that examined LOS at index admission found that it was positively correlated with readmission.^{9,32,36,42} Wrubel et al.⁵² found a negative correlation between LOS and rate of readmission; however, after running a secondary analysis with the return to system based on day of discharge rather than day of surgery, they determined that no significant correlation was present. This further substantiates the consistent finding within the examined studies that LOS is positively correlated with readmission rates. Importantly, LOS correlates with but does not cause increases in readmission rates, because the relationship between LOS and readmission rates is confounded by preexisting underlying illness or in-hospital complications, which are typically the true causes of readmission.^{5,8,11}

Our study not only explored predictors of readmission, but also the reasons for readmission. Surgical and wound complications, including infectious complications, were two of the major reasons for hospital readmission.^{6,9,16,32,34,36,38,43,47,52} Effective preoperative, intraoperative, and postoperative measures of prophylaxis are available in other disciplines.^{19,41} Since these complications can be prevented by good technique and prophylactic antibiotics, systematic attempts at reducing these adverse events hold promise, particularly for patients who are prone to infection, such as those with diabetes mellitus.^{16,34}

Our review also showed that postoperative complications significantly predicted 30-day readmission.^{32,38} Patients who suffered seizures^{6,16,32,34,47,50,52} and hydrocephalus^{6,16,32,34,43,47} had higher rates of readmission. Similar to Kassin et al.,²⁵ who studied general surgical patients, we found that patients with pulmonary complications such as pneumonia, unplanned reintubation, mechanical ventilation for more than 48 hours, and acute respiratory failure had an increased risk of readmission.³⁸ A review of patients who underwent craniotomy for meningioma identi-

fies older patients and those undergoing longer procedures as being at higher risk of acquiring postoperative pneumonia.³⁷ Efforts should be put forward to establish all populations at risk and provide preventative measures, including patient education.^{7,51} The importance of postoperative complications has been repeatedly shown by a number of studies across a variety of surgical disciplines.^{6,13,25,23,36,50} Thus, continued concerted attempts at reducing postoperative complications are imperative in any quality improvement initiative.

Our review showed that DVT and PE were also 2 important preventable causes of 30-day readmission.^{6,16,32,34,38} In spite of this, the prevention of venous thromboembolism (VTE) is difficult in patients undergoing brain surgery.^{14,31} The risks of anticoagulation therapy (particularly intracranial hemorrhage) need to be weighed against its benefits.^{4,14,16} Although high-risk groups such as those with prior DVT, those with glioblastoma multiforme, and those with an immobile limb exist, as of yet no clearly safe time period for anticoagulation has been defined. For example, in our review, Moghavem et al.³⁴ showed that patients with diagnoses of vascular conditions and trauma have higher rates of hemorrhage, therefore making them higher-risk candidates for VTE prophylaxis. In contrast, other studies of patients with traumatic brain injury showed that current chemoprophylactic regimens provide a relatively high level of protection against VTE events, while not increasing risks of intracranial bleeding.^{17,28,33} Defining these criteria with statistical rigor within specific subgroups will require large multiinstitutional randomized controlled studies.

Limitations and Future Work

Although we identified 12 studies of postneurosurgery hospital readmission, given the proportion of conditions treated by neurosurgeons (e.g., trauma, stroke, and so on), more studies are required before we can generalize these results. Additionally, publication bias may have reduced the number of studies presenting nonsignificant results in the factors related to readmission.¹⁸ We found considerable variability in diagnoses, procedures, sample sizes, geographic location, and analytical methods. To improve comparability of causes and rates of readmission between studies, and of methods by which to reduce them, it is important that future studies follow a standardized methodology when assessing readmission rates. This review may serve as a guide for future variables inclusion. Because nearly all of the papers are from the US, future work should include studies from Canada and other developed and nondeveloped countries to gather a more holistic view of the causes for readmission, particularly in countries with different forms of health care financing. Prospectively collected surveillance data should form the basis of our work in the future, which may highlight the importance of organized neurosurgery through groups like the NeuroPoint Alliance.

Conclusions

Research that investigates readmission rates in patients who undergo cranial neurosurgery is scarce. Our review shows that there are patient factors, such as race, comorbidities, neurosurgical diagnoses, and procedures that are

important in predicting readmission. Moreover, we demonstrated that social factors including place of residence and insurance coverage are also predictive. Our review highlights the importance of having preventive systems in place to minimize postoperative complications. To achieve this, a framework that includes a consideration of the patient, the patient's social environment, community, and resources, and the whole hospital and surgical team and its resources is warranted. The review is limited by the small number of studies reported in neurosurgery readmission to date. Opportunities for preventive measures must be considered before, during, and after the surgical procedure. Working toward reducing 30-day readmission would be a reachable goal for many neurosurgical communities aiming for improved quality of care.

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Disclosures

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Author Contributions

Conception and design: all authors. Acquisition of data: Pshon-yak, Lee. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Cusimano. Administrative/technical/material support: all authors. Study supervision: Cusimano, Ilie.

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