Surgical Neurology International

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Original Article

Comparison of outcomes and utilization of extracranial–intracranial bypass versus intracranial stenting for intracranial stenosis

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Received: 17 February 14 Accepted: 08 September 14 Published: 11 December 14

This article may be cited as:
Wilson TA, Tanweer O, Huang PP, Riina HA. Comparison of outcomes and utilization of extracranial-intracranial bypass versus intracranial stenting for intracranial stenosis. Surg Neurol Int 2014;5:178.
Available FREE in open access from: http://www.surgicalneurologyint.com/text.asp?2014/5/1/178/146831

Abstract

Background: Extracranial–intracranial (EC-IC) bypass and intracranial stenting (ICS) are both revascularization procedures that have emerged as treatment options for intracranial atherosclerotic disease (ICAD). This study describes and compares recent trends in utilization and outcomes of intracranial revascularization procedures in the United States using a population-based cohort. It also investigates the association of ICS and EC-IC bypass with periprocedural morbidity and mortality, unfavorable discharge status, length of stay (LOS), and total hospital charges.

Methods: The National Inpatient Sample (NIS) was queried for patients with ICAD who underwent EC-IC bypass or ICS during the years 2004–2010. Patient characteristics, demographics, perioperative complications, outcomes, and discharge data were collected.

Results: There were 627 patients who underwent ICS and 249 patients who underwent EC-IC bypass. Patients who underwent ICS were significantly older ($P < 0.001$) with more comorbidities ($P = 0.027$) than those who underwent EC-IC bypass. Patients who underwent EC-IC bypass experienced higher rates of postprocedure stroke ($P = 0.014$), but those who underwent ICS experienced higher rates of death ($P = 0.006$). Among asymptomatic patients, the rates of postprocedure stroke ($P = 0.341$) and death ($P = 0.887$) were similar between patients who underwent ICS and those who underwent EC-IC bypass. Among symptomatic patients, however, there was a higher rate of postprocedure stroke in patients who underwent EC-IC bypass ($P < 0.001$) and a higher rate of death among patients who underwent ICS ($P = 0.015$).

Conclusion: The ideal management of patients with ICAD cannot yet be defined. Although much data from randomized and prospective trials on revascularization have been collected, many questions remain unanswered. There still remain cohorts of patients, specifically patients who have failed aggressive medical management, where not enough evidence is available to dictate decision-making. In order to further elucidate the safety and efficacy of these intracranial revascularization procedures, further clinical trials are needed.

Key Words: Extracranial–intracranial bypass, intracranial atherosclerotic disease, intracranial stenosis, intracranial stenting, National inpatient sample database

Access this article online

Website:
www.surgicalneurologyint.com

DOI:
10.4103/2152-7806.146831

Quick Response Code:

INTRODUCTION

Intracranial stenosis, caused by intracranial atherosclerotic disease (ICAD), is responsible for ischemic stroke in a significant number of patients annually.[7,13,18,25,28] There are approximately 900,000 cases of ischemic stroke or transient ischemic attack (TIA) per year in the United States, and of these cases, roughly 90,000–100,000 are due to ICAD.[15,27] Despite aggressive medical therapy, the risk of recurrent stoke in patients with symptomatic ICAD is as high as 15% per year.[6,7,15] In patients with severe stenosis (>70%) and in certain high-risk groups, the risk of recurrent stroke has been reported to be as high as 25% per year.[15,23,30]

Successful management of patients with ICAD requires an intervention that is safe, effective, and has minimal complications.[32] Medical treatment can reduce the risk of ischemic stroke due to thromboembolic events, but it does not reduce the risk of ICAD progression and the associated patholophysiologic components of hypoperfusion and poor collateral circulation.[8,9,12,15,24,31] Technological advances in recent years have given rise to several surgical approaches to treating ICAD, which include extracranial–intracranial (EC-IC) bypass and intracranial stenting (ICS).[2] These revascularization procedures were developed to reduce the risk of ischemic stroke in patients with impaired cerebral hemodynamics due to occlusive cerebrovascular disease by improving blood flow to the territory distal to the stenotic vessel.[26,29] These procedures may provide benefit to symptomatic patients with severe stenosis who are at the highest risk of ischemic stroke in the region of the stenotic artery,[6] but these patients also pose the most procedural risks. In this study, we compare utilization and outcome trends in ICS and EC-IC bypass with a retrospective, observational analysis using the National Inpatient Sample (NIS) database from 2004 to 2010.

The goal of this study is to describe the national trends in intracranial revascularization procedures for patients with intracranial stenosis. We investigate the association of ICS and EC-IC bypass with periprocedural morbidity and mortality, rate of unfavorable discharge, length of stay (LOS), and total hospital costs.

METHODS

The NIS is a database obtained from the Agency for Healthcare Research and Quality for the years 2004–2010. This database includes approximately 8 million hospitalizations annually. It represents a stratified sample of roughly 20% of all hospital admissions per year, and it serves as a representative sample of inpatient admissions in the United States (http://www.hcup-us.ahrq.gov/nisoverview.jsp).

For the purposes of this study, the NIS was queried using ICD-9 codes to identify individual cases of patients with the diagnosis of intracranial stenosis who underwent ICS or EC-IC bypass from 2004 to 2010. The ICD-9 codes for the diagnoses and procedures used to identify these patients are listed in Table 1.

Patient characteristics, including age, gender, race, and preexisting comorbidities were identified. For each record, the comorbidity score was calculated based on the Elixhauser comorbidity scoring system.[21] For the purposes of this study, the Elixhauser comorbidity score was modified by removing the "paralysis" and "other neurological disorders" sub-scores. Additionally, the Elixhauser comorbidity sub-scores for "diabetes-uncomplicated" and "diabetes complicated" were combined into a single sub-score referred to as "diabetes". Similar modifications to the Elixhauser comorbidity sub-score have been made in other research using the NIS databases to study carotid artery revascularization procedures.[10,11] The primary endpoints of the study were inpatient postprocedure stroke and death. The NIS captures information from single inpatient hospitalization experiences, which prevented measurement of long-term ICH, stroke, and mortality risks.[10] Secondary endpoints of interest include discharge status, LOS and hospital charges. Hospital charges were compared overall or annually, but not between years, in order to prevent bias due to inflation. Discharge status was separated into home and transfer. Home includes patients who were discharged routinely home or were discharged with home health care, and transfer includes patients who were transferred to another hospital or other care facility, such as a skilled nursing facility or intermediate care. Patient primary payer information was also collected, and divided into public, private, and other. Public includes patients who were covered by Medicare or Medicaid.

All data was analyzed using SPSS version 20 (International Business Machines, Armonk, New York). Descriptive statistics were obtained, and a comparison was made between patients with intracranial stenosis who underwent ICS versus those who underwent EC-IC bypass. Additionally, patients were stratified by presentation type (symptomatic or asymptomatic), and a comparison was made between patients undergoing ICS versus EC-IC bypass within presentation type. Statistical analysis was

Table 1: ICD-9 codes used in NIS query

Intracranial stenosis (asymptomatic)	433.00, 433.20, 434.00, 434.10, 434.90, 437.00
Intracranial stenosis (symptomatic)	433.01, 433.21, 434,01, 434.11, 434.91
Intracranial stent	00.65
Extracranial-intracranial bypass	39.28
Postprocedure stroke	997.02

ICD: International classification of diseases, NIS: National inpatient sample performed using Chi-square, Mann–Whitney U, and Kruskal–Wallis tests where appropriate. A multivariate analysis was done to identify those variables associated with the various outcomes. Logistic regression was used for categorical variables, and linear regression was used for continuous variables. We used a stepwise regression model with backward elimination. Variables included in the multivariate model were age, gender, comorbidities, presentation type, hospital teaching status, payer, and procedure type.

RESULTS

Comparison of patients who underwent intracranial stenting versus extracranial–intracranial bypass

During the years 2004–2010, there were 627 patients with ICAD who underwent ICS and 249 who underwent EC-IC bypass. Descriptive and statistical data for these patients is listed in [Table 2]. Patients who underwent ICS were significantly older than those who underwent EC-IC bypass (62.2± 14.2 years versus 53.3± 14.2 years; $P < 0.001$). Slightly, more males underwent ICS (53.7% male, 46.3% female), whereas slightly more females underwent EC-IC bypass (48.4% male, 51.6% female), but these gender differences did not reach statistical significance ($P = 0.175$). The majority of patients who underwent either procedure were White, and there was a similar racial distribution between each group ($P = 0.390$). Patients who underwent ICS had a significantly higher mean number of comorbidities (2.4± 1.6 comorbidities versus 2.1± 1.5 comorbidities; $P = 0.027$). A significantly larger amount of patients who underwent ICS were symptomatic at presentation (61.2% versus 50.6%; $P = 0.004$) and were admitted nonelectively (67.5% versus 44.2%; $P < 0.001$). The percentage of EC-IC bypass procedures performed at teaching hospitals was significantly higher than ICS procedures (93.7% versus 85.5%; $P = 0.012$). Postprocedure stroke occurred at a significantly higher rate among patients who underwent EC-IC bypass (13.7% versus 8.0%; $P = 0.014$). Death, however, occurred at a significantly higher rate in patients who underwent ICS (8.3% versus 2.8%; $P = 0.006$). More patients who underwent ICS were discharged home either routinely or with home health versus transfer to another hospital or care facility compared with patients who underwent EC-IC bypass, but this difference did not reach statistical significance ($P = 0.123$). Patients who underwent EC-IC bypass had significantly longer median LOS (8 days versus 6 days; $P < 0.001$) and significantly higher total hospital charges ($P < 0.001$). A significantly larger proportion of patients who underwent ICS had Medicare or Medicaid, whereas a significantly higher percentage of patients who underwent EC-IC bypass had private insurance ($P = 0.010$).

Table 2: Comparison of patients with intracranial stenosis who underwent intracranial stenting versus extracranial-intracranial bypass

	Stent	EC-IC bypass	*P* value
Total # patients	627	249	
Age (mean±SD)	62.2±14.2 years	53.3±14.2 years	<0.001
Gender			0.175
Male	53.7%	48.4%	
Female	46.3%	51.6%	
Race			0.390
White	67.3%	71.5%	
Black	17.3%	11.0%	
Hispanic	8.4%	8.7%	
Asian	4.1%	5.2%	
Other	2.9%	3.5%	
CMs (mean±SD)	2.4±1.6 CMs	2.1±1.5 CMs	0.027
No	8.6%	13.3%	0.054
1-3	68.9%	69.1%	
≥4	22.5%	17.7%	
Presentation			0.004
Asymptomatic	38.8%	49.4%	
Symptomatic	61.2%	50.6%	
Admission			<0.001
Nonelective	67.5%	44.2%	
Elective	32.5%	55.8%	
Hospital teaching status			0.012
Nonteaching	14.5%	6.3%	
Teaching	85.5%	93.7%	
Complications			
Stroke	8.0%	13.7%	0.014
Death	8.3%	2.8%	0.006
Discharge			0.123
Home	65.1%	59.1%	
Transfer	34.9%	40.9%	
Payer			0.010
Public	54.4%	44.0%	
Private	35.9%	46.8%	
Other	9.7%	9.3%	
LOS			<0.001
Median	6 days	8 days	
IQR	2-10 days	4-18 days	
Total charges			<0.001
Median	$87,137	$116,333	
IQR	$51,940-144,630	$58,930-214,212	

SD: Standard deviation, EC-IC: Extracranial-Intracranial, CMs: Comorbidities, LOS: Length of stay, IQR: Interquartile range

Comparison of patients who presented symptomatically versus asymptomatically

Of the 627 patients who underwent ICS and 249 patients who underwent EC-IC bypass, there were 384 and 126, respectively, who presented symptomatically. Descriptive and statistical data for these patients are listed in [Tables 3 and

4]. Regardless of procedure type, the mean age of patients with ICAD who presented symptomatically was significantly older than those who were asymptomatic (60.7± 15.4 years versus 58.3± 13.9 years; $P = 0.010$). When divided by presentation type, the mean age of both asymptomatic and symptomatic patients who underwent ICS was significantly older than those who underwent EC-IC bypass (asymptomatic: 60.7± 14.9 years versus 53.6 ± 14.1 years; $P < 0.001$; symptomatic: 63.2± 14.9 years versus 53.1± 14.4 years; $P < 0.001$).

Regardless of procedure type, patients who presented symptomatically had a significantly higher mean number of comorbidities (2.5± 1.6 comorbidities versus 2.0± 1.4 comorbidities; $P < 0.001$). There were significantly more asymptomatic patients with no comorbidities (14.5% versus 6.7%; $P < 0.001$) and significantly more symptomatic patients with four or greater comorbidities (26.1% versus 14.2%; $P < 0.001$). The mean number of comorbidities among asymptomatic patients was similar between those

Table 3: Comparison of asymptomatic patients with intracranial stenosis who underwent intracranial stenting versus extracranial-intracranial bypass

	Stent	EC-IC bypass	*P* value
Total # patients	243	123	
Age (mean±SD)	60.7±14.9 years	53.6±14.1 years	<0.001
Gender			0.600
Male	56.0%	52.5%	
Female	44.0%	47.5%	
Race			0.919
White	67.8%	69.6%	
Black	17.1%	13.0%	
Hispanic	7.0%	7.6%	
Asian	5.5%	6.5%	
Other	2.5%	3.3%	
CMs (mean±SD)	2.0±1.4 CMs	1.9±1.4 CMs	0.829
No CMs	12.8%	17.9%	0.429
1-3 CMs	72.8%	68.3%	
≥4 CMs	14.4%	13.8%	
Admission			0.037
Nonelective	36.6%	25.2%	
Elective	63.4%	74.8%	
Hospital teaching status			0.168
Nonteaching	13.4%	7.5%	
Teaching	86.6%	92.5%	
Complications			
Stroke	4.1%	1.6%	0.341
Death	2.5%	1.6%	0.887
Discharge			0.080
Home	91.1%	84.3%	
Transfer	8.9%	15.7%	
Payer			0.195
Public	47.3%	37.4%	
Private	44.0%	52.0%	
Other	8.6%	10.6%	
LOS			<0.001
Median	2 days	5 days	
IQR	1–5 days	3–8 days	
Total charges			0.003
Median	$52,908	$68,939	
IQR	$31,673-85,367	$42,918-120,909	

SD: Standard deviation, EC-IC: Extracranial-Intracranial, CMs: Comorbidities, LOS: Length of stay, IQR: Interquartile range

Table 4: Comparison of symptomatic patients with intracranial stenosis who underwent intracranial stenting versus extracranial-intracranial bypass

	Stent	EC-IC bypass	*P* value
Total # patients	384	126	
Age (mean±SD)	63.2±14.9 years	53.1±14.4 years	<0.001
Gender			0.151
Male	52.3%	44.4%	
Female	47.7%	55.6%	
Race			0.446
White	66.9%	73.8%	
Black	17.5%	8.8%	
Hispanic	9.2%	10.0%	
Asian	3.2%	3.8%	
Other	3.2%	3.8%	
CMs (mean±SD)	2.6±1.6 CMs	2.3±1.6 CMs	0.028
No CMs	6.0%	8.7%	0.270
1-3 CMs	66.4%	69.8%	
≥4 CMs	27.6%	21.4%	
Admission			<0.001
Nonelective	87.0%	62.7%	
Elective	13.0%	37.3%	
Hospital teaching status			0.042
Nonteaching	12.5%	5.2%	
Teaching	87.5%	94.8%	
Complications			
Stroke	10.4%	25.4%	<0.001
Death	12.0%	4.0%	0.015
Discharge			0.020
Home	46.7%	33.9%	
Transfer	53.3%	66.1%	
Payer			0.079
Public	58.9%	50.4%	
Private	30.7%	41.6%	
Other	10.4%	8.0%	
LOS			<0.001
Median	8 days	16 days	
IQR	5-13 days	8-28 days	
Total charges			<0.001
Median	$119,660	$196,907	
IQR	$74,478-176,905	$115,296-320,266	

SD: Standard deviation, EC-IC: Extracranial-Intracranial, CMs: Comorbidities, LOS: Length of stay, IQR: Interquartile range who underwent ICS and those who underwent EC-IC bypass (P = 0.829). Among symptomatic patients, however, those who underwent ICS had significantly more comorbidities (2.6± 1.6 comorbidities versus 2.3± 1.6 comorbidities; P = 0.028).

Symptomatic patients were admitted nonelectively at a significantly higher rate than asymptomatic patients (81.0% versus 32.8%; P < 0.001). When divided by presentation type, a larger proportion of both asymptomatic and symptomatic patients who underwent ICS had been admitted nonelectively (asymptomatic: 36.6% versus 25.2%; P = 0.037; symptomatic: 87.0% versus 62.7%; P < 0.001).

Regardless of procedure type, there were significantly higher rates of both postprocedure stroke (14.1% versus 3.3%; P < 0.001) and death (10.0% versus 2.2%; P < 0.001). Among asymptomatic patients, the rates of both postprocedure stroke (P = 0.341) and death (P = 0.887) were similar between those who underwent ICS and those who underwent EC-IC bypass. The rate of postprocedures stroke was significantly higher among symptomatic patients who underwent EC-IC bypass (25.4% versus 10.4%; P < 0.001), but the rate of death was significantly higher among symptomatic patients who underwent ICS (12.0% versus 4.0%; P = 0.015). Significantly more asymptomatic patients were discharged home, routinely or with home health, while significantly more symptomatic patients required transfer to another hospital or care facility (P < 0.001). Among asymptomatic patients, a higher percentage of those who underwent ICS were discharged home compared with those who underwent EC-IC bypass, but this difference did not reach statistical significance (P = 0.080). Among symptomatic patients, a significantly higher percentage of those who underwent EC-IC bypass required transfer to another hospital or care facility compared with those who underwent ICS (P = 0.020).

Symptomatic patients had significantly longer median LOS and higher median total hospital charges than asymptomatic patients. Regardless of presentation type, patients who underwent EC-IC bypass had significantly longer median LOS and higher median total hospital charges. Regardless of procedure type, a significantly larger percentage of symptomatic patients had Medicare or Medicaid, whereas significantly more asymptomatic patients had private insurance (P < 0.001). Among both asymptomatic and symptomatic patients, significantly more patients who underwent ICS has Medicare or Medicaid (P = 0.195), whereas significantly more of those who underwent EC-IC bypass had private insurance (P = 0.079), but these differences, however, did not reach statistical significance in either subgroup.

Trends in intracranial stenting and extracranial–intracranial bypass

Over the years, there was an increase in the utilization of both ICS and EC-IC bypass for patients with ICAD [Table 5]. Looking at ICS and EC-IC bypass procedures combined, the percentage that were ICS significantly increased over time, whereas the percentage that were EC-IC bypass significantly decreased over time (P < 0.001) [Figure 1]. The mean age of patients who underwent ICS remained similar over time (P = 0.279), but there was a significant decrease in the mean age of patients who underwent EC-IC bypass over time (P < 0.001). There was a significant increase in the percentage of patients who underwent either ICS or EC-IC bypass procedures for revascularization of intracranial stenosis with four or more comorbidities over time (P < 0.001). This increase was observed both in patients who underwent ICS (P < 0.001) and those who underwent EC-IC bypass (P = 0.006). There was also an increase in proportion of patients who presented symptomatically over time (P < 0.001). When divided by procedure type, there was a significant increase in the percentage of symptomatic patients who underwent ICS (P = 0.003). There was a slight increase in the percentage of symptomatic patients who underwent EC-IC bypass, but this increase did not reach statistical significance (P = 0.065).

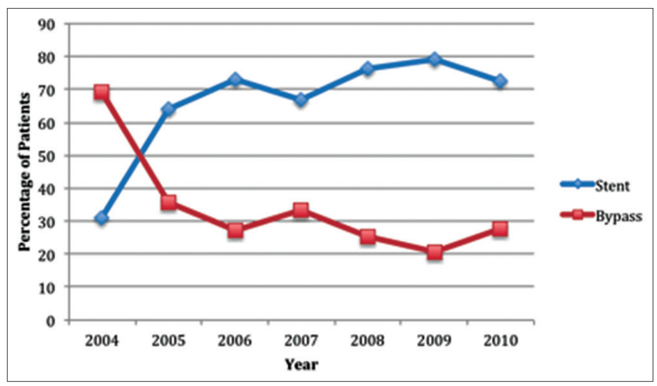

Figure 1: Trends in utilization of intracranial stenting and extracranial–intracranial bypass procedures for revascularization of patients with intracranial stenosis

Table 5: Trends in utilization of intracranial stenting and extracranial-intracranial bypass procedures for revascularization of patients with intracranial stenosis

	Stent (%)	EC-IC bypass (%)	P
2004	31.0	69.0	<0.001
2005	64.1	35.9	
2006	72.9	27.1	
2007	66.7	33.3	
2008	76.1	25.5	
2009	79.3	20.7	
2010	72.4	27.6	

EC-IC: Extracranial-Intracranial

Multivariate analysis to identify predictors of outcomes

Symptomatic presentation is the strongest predictor of postprocedure stroke and death for patients with intracranial stenosis undergoing either procedure. Patients who presented symptomatically were 5.1 times more likely to experience postprocedure stroke ($P < 0.001$) and 5.7 times more likely to die ($P < 0.001$) compared with patients who presented asymptomatically. Procedure type is also a significant predictor of outcomes. Patients who underwent EC-IC bypass were 2.1 times more likely to experience postprocedure stroke than those who underwent ICS ($P = 0.003$). Patients who underwent ICS were 3.3 times more likely to die than those who underwent EC-IC bypass ($P = 0.016$). Age was also associated with in-hospital death ($P = 0.044$).

When subdivided by procedure type, symptomatic presentation is again the strongest predictor of postprocedure stroke and death. Of patients who underwent ICS, those who presented symptomatically were 2.6 times more likely to experience postprocedure stroke ($P = 0.011$) and 6.1 times more likely to die ($P < 0.001$). Of patients who underwent EC-IC bypass, those who presented symptomatically were 18.1 times more likely to experience postprocedure stroke ($P < 0.001$). Multivariate analysis identified symptomatic presentation as the strongest predictor of death in patients undergoing EC-IC bypass, but this did not reach statistical significance ($P = 0.241$).

DISCUSSION

Revascularization procedures, which include ICS and EC-IC bypass, have been used to treat patients with ICAD. There have not been any studies done on comparing these revascularization procedures. Separately, however, they have been studied among different cohorts. As a result, the safety and efficacy of revascularization procedures for the treatment of ICAD is in an era of uncertainty, preventing them from being definitively accepted or completely rejected as treatment options for patients with ICAD.

The purpose of our study is to describe national trends in outcomes and utilization of intracranial revascularization procedures for treatment of patients with ICAD. Additionally, we investigate the association of ICS and EC-IC bypass with periprocedural morbidity and mortality, unfavorable discharge status, LOS, and total hospital charges. This study is one of the largest retrospective, observational analyses using a population-based cohort examining ICS and EC-IC bypass. It includes 876 patients, 627 who underwent ICS and 249 who underwent EC-IC bypass, from all over the United States with their differences in age, gender, race, and comorbidities. It includes patients treated nonelectively on emergency basis as well as those treated electively, and it is not limited based on patient insurance plan.[16]

Patients with symptomatic ICAD are generally sicker with more severe stenosis than patients with asymptomatic stenosis. They also tend to be older with more comorbidities than patients with asymptomatic ICAD. Consistent with previous studies, our study also found that, regardless of the procedure performed, patients with symptomatic ICAD were older and had more comorbidities than patients with asymptomatic ICAD.[16,32] Increasing age is associated with anatomical changes, such as narrowing of small vessels and loss of elasticity in vessel walls, and increased tendency for atheroma formation, which both play an important role in the development of ICAD.[18] Patients with multiple comorbid conditions, especially hypertension, hyperlipidemia, diabetes, and obesity, are at a higher risk of developing ICAD compared with healthier patients with fewer or no comorbidities.[16]

The strongest predictor of ischemic stroke and death in patients with ICAD is the severity stenosis.[15,22] Thus, as patients with symptomatic ICAD are usually sicker with more severe stenosis, they generally have worse outcomes compared with patients with asymptomatic ICAD. Consistent with this data, our study found that patients with symptomatic ICAD had higher rates of postprocedure stroke and death than patients with asymptomatic ICAD regardless of revascularization procedure. Multivariate analysis also revealed that symptomatic presentation was the strongest predictor of adverse events regardless of procedure type. Furthermore, a higher percentage of patients with symptomatic ICAD required transfer to another hospital or care facility, whereas the majority of patients with asymptomatic ICAD were discharged home. This suggests that patients with symptomatic ICAD were more likely to need additional care following their revascularization procedure, which further supports that patients with symptomatic ICAD have worse outcomes.

In 2004, prior to Food and Drug Administration (FDA) approval of the Wingspan stent for ICS, the majority of patients who underwent an intracranial revascularization procedure underwent EC-IC bypass. In 2005 and subsequent years, the majority of patients who underwent an intracranial revascularization procedure underwent ICS. Over time, the number of patients undergoing both revascularization procedures increased, but the rate of increase in utilization of ICS was higher than that of EC-IC bypass. Overall, significantly more patients underwent ICS than EC-IC bypass. Of the patients who underwent ICS, a higher percentage had symptomatic ICAD, but of the patients who underwent EC-IC bypass, a higher percentage was asymptomatic. Endovascular methods have been previously preferred in the more infirm population, especially in cases of aneurysm treatment.[3,4] Consistent with this, our study found that patients who underwent ICS were significantly older with more comorbidities than those who underwent EC-IC bypass. In order to eliminate this bias, subgroup analysis was also performed to compare the utilization and outcomes of asymptomatic patients and symptomatic patients who underwent each revascularization procedure separately.

All revascularization procedures have a risk of postprocedure stroke and death. ICS involves manipulation of guidewires and catheters through the intracranial vessels to allow proper implantation of the stent. This may cause vessel injury, including vessel perforation, dissection, or rupture, which can result in intracerebral hemorrhage and possibly death.[1,17,19,20] Hyperperfusion of chronically ischemic tissue can also result in intracranial hemorrhage following stent placement. Disruption of the atherosclerotic plaque can lead to embolic events, resulting in cerebral infarction.[2] Additionally, ICS requires antiplatelet therapy, which also increases the risk of bleeding complications. EC-IC bypass involves clamping of the vessel while the anastomoses is being created. This can lead to worsening of ischemia or infarction in the cerebral tissue distal to the stenosis. Following anastomosis of the extracranial and intracranial vessels, intracerebral hemorrhage, due to hyperperfusion of chronically ischemic tissue, can also occur with EC-IC bypass.

Our study found that postprocedure stroke occurred at a higher rate in patients who underwent EC-IC bypass, whereas death occurred more frequently in the ICS cohort. These findings are consistent with the fact that temporary flow occlusions with EC-IC bypass results in higher rates of stroke, while the hemorrhages associated with ICS leads to an increased risk of death. When divided into subgroups, there was a higher rate of postprocedure stroke among symptomatic patients who underwent EC-IC bypass, but the rate of postprocedure stroke in asymptomatic patients was similar regardless of procedure type. These findings suggest that it is the patients with symptomatic ICS who have an increased risk of postprocedure stroke with EC-IC bypass versus IS.

In contrast to postprocedure stroke, we found a higher rate of death in patients who underwent ICS. This higher rate of death with ICS was seen in both asymptomatic and symptomatic patients. In asymptomatic patients, however, the difference in death rate among patients who underwent ICS versus EC-IC bypass did not quite reach statistical significance. These findings suggest that, although asymptomatic patients have a slightly increased risk of death with ICS, it is the symptomatic patients who have the highest risk of death with ICS versus EC-IC bypass.

LOS and total charges have not been studied elsewhere. Our study found that symptomatic patients have significantly longer LOS than asymptomatic patients regardless of procedure type. This was expected, as symptomatic patients tend to be sicker with more severe stenosis and have more adverse events with worse overall outcomes compared with asymptomatic patients. Comparing procedures, we found that patients who underwent EC-IC bypass had significantly longer LOS regardless of presentation. This suggests that the EC-IC bypass procedure itself is associated with longer LOS than ICS, but the higher rate of postprocedure stroke observed with EC-IC bypass may also contribute to increased LOS. As total hospital charges are related to the LOS and the complication rate, it was expected that patients with symptomatic ICAD had higher total hospital charges regardless of procedure type. Similarly, it was expected that patients who underwent EC-IC bypass had higher total hospital charges regardless of presentation type.

The volume-outcome effect refers to the association between high volume surgeons and/or hospitals with improved outcomes. This hypothesis may be especially true for technically challenging procedures, such as EC-IC bypass. It would be interesting to examine whether the surgeon or hospital volume had a significant association with outcomes. This is possible with the NIS database; however, this is beyond the scope of what we examined in this study. Future studies, using the NIS database or other population of patients, should examine the relationship of high versus low volume surgeons and/or hospitals to better characterize the volume–outcome effect as it relates to intracranial revascularization procedures.

A major limitation of studies with the NIS is the difficulty with coding. This has the potential to cause miscoding and missing data, which may limit access to certain cases or result in misclassification of certain cases. For example, ICD-9 codes for stroke can be misrepresented up to 15% of the time.[14] An additional limitation is that the diagnosis for postprocedure stroke indicates that the patient experienced a postprocedure stroke, but does not specify the type of stroke nor its severity. Additionally, given that the treatment of asymptomatic intracranial stenosis falls outside standard treatment recommendations, the large proportion of asymptomatic patients identified through the chosen ICD-9 codes may be incorrect or incorrectly identifying such patients. For example, patients who received the ICD-9 code for asymptomatic IS may have presented symptomatically, but had a TIA or ischemic stroke with symptoms that improved or resolved by the time of the revascularization procedure and are now being treated electively. This explanation is highly reasonable as the majority of the asymptomatic patients are also listed as undergoing the procedure electively, whereas the majority of the symptomatic patients are listed as undergoing the procedure nonelectively. Another possibility is that the procedure was performed in the context of another indication, such as stent or bypass for aneurysms. In order to minimize this potential bias, all diagnosis codes for each patient were examined to look at each patient's other medical problems and rule out possible confounding disease. Lastly, providers may have inadvertently selected an ICD-9 code for IS without regard to whether it was for asymptomatic or symptomatic disease. This would be the most detrimental to our study, and future studies using the NIS database and other databases using ICD-9 codes to identify patients with IS should be aware of this possibility. Another limitation to this study is that we were unable to review relevant clinical data, such as medication and radiographic images. Other limitations of the NIS are similar to those of all retrospective studies using administrative data. This includes inability to acquire follow-up or long-term data.

Many of the limitations listed above are not unique to our paper, but are well known limitations to studies using the NIS database as well as to other studies using large administrative databases. Despite these limitations, much useful data can be generated using the NIS database. As Carter states in *Neurosurgery*, the NIS database is best used to understand and provide practical insight into procedure-related risks by looking at morbidity and mortality data based on type of procedure performed.[5] In our study, we used the NIS database to investigate the association of ICS and EC-IC bypass with periprocedural morbidity and mortality, unfavorable discharge status, LOS, and total hospital charges on a national level.

CONCLUSION

The ideal management of patients with has yet to be defined. Although much data from randomized and prospective trials on revascularization have been collected, many questions remain unanswered. According to our results, there has been an increase in the utilization of both revascularization procedures over the time period studied. In subsequent years, however, there is likely to be decrease in utilization of these procedures given the recent findings of the SAMMPRIS and the COSS Trials. There still remain cohorts of patients, specifically patients who have failed aggressive medical management, where not enough evidence is available to dictate decision-making. In order to further elucidate the safety and efficacy of these intracranial revascularization procedures, further clinical trials are needed.

This figure shows the trends in utilization intracranial stenting (ICS) and extracranial–intracranial (EC-IC) bypass during the years 2004–2010. Data is shown as the percentage of revascularization procedures that were ICS versus EC-IC bypass for each year. ICS is represented by the diamonds, and EC-IC bypass is represented by the squares. In 2004, the majority of revascularization procedures performed were EC-IC bypass. In 2005 and the subsequent years, ICS surpassed EC-IC bypass as being the major revascularization procedure performed for patients with intracranial stenosis.

REFERENCES

1. Abou-Chebl A, Yadav JS, Reginelli JP, Bajzer C, Bhatt D, Krieger DW. Intracranial hemorrhage and hyperperfusion syndrome following carotid artery stenting: Risk factors, prevention, and treatment. J Am Coll Cardiol 2004;43:1596-601.
2. Al Hasan M, Murugan R. Stenting versus aggressive medical therapy for intracranial arterial stenosis: More harm than good. Crit Care 2012;16:310.
3. Barker FG 2nd, Amin-Hanjani S, Butler WE, Hoh BL, Rabinov JD, Pryor JC, *et al*. Age-dependent differences in short-term outcome after surgical or endovascular treatment of unruptured intracranial aneurysms in the United States, 1996-2000. Neurosurgery 2004;54:18-30.
4. Cai Y, Spelle L, Wang H, Piotin M, Mounayer C, Vanzin JR, *et al*. Endovascular treatment of intracranial aneurysms in the elderly: Single-center experience in 63 consecutive patients. Neurosurgery 2005;57:1096-102.
5. Carter BS. The Nationwide Inpatient Sample: The Gift that Keeps on Giving. Neurosurgery 2008;62:N9.
6. Chimowitz MI, Lynn MJ, Derdeyn CP, Turan TN, Fiorella D, Lane BF, *et al*. Stenting versus aggressive medical therapy for intracranial arterial stenosis. N Engl J Med 2011;365:993-1003.
7. Chimowitz MI, Lynn MJ, Howlett-Smith H, Stern BJ, Hertzberg VS, Frankel MR, *et al*.; Warfarin-Aspirin Symptomatic Intracranial Disease Trial Investigators. Comparison of warfarin and aspirin for symptomatic intracranial arterial stenosis. N Engl J Med 2005;352:1305-16.
8. Choi JW, Kim JK, Choi BS, Lim HK, Kim SJ, Kim JS, *et al*. Angiographic pattern of symptomatic severe M1 stenosis: Comparison with presenting symptoms, infarct patterns, perfusion status, and outcome after recanalization. Cerebrovasc Dis 2010;29:297-303.
9. Derdeyn CP. Mechanisms of ischemic stroke secondary to large artery atherosclerotic disease. Neuroimaging Clin N Am 2007;17:303-11, vii-viii.
10. Dumont TM, Rughani AI. National trends in carotid artery revascularization surgery. J Neurosurg 2012;116:1251-7.
11. Eslami MH, McPhee JT, Simons JP, Schanzer A, Messina LM. National trends in utilization and postprocedure outcomes for carotid artery revascularization 2005 to 2007. J Vasc Surg 2011;53:307-15.
12. Famakin BM, Chimowitz MI, Lynn MJ, Stern BJ, George MG; WASID Trial Investigators. Causes and severity of ischemic stroke in patients with symptomatic intracranial arterial stenosis. Stroke 2009;40:1999-2003.
13. Gandini R, Chiaravalloti A, Pampana E, Massari F, Morosetti D, Spano S, *et al*. Intracranial atheromatous disease treatment with the Wingspan stent system: Evaluation of clinical, procedural outcome and restenosis rate in a single-center series of 21 consecutive patients with acute and mid-term results. Clin Neurol Neurosurg 2013;115:741-7.
14. Goldstein LB. Accuracy of ICD-9-CM coding for the identification of patients with acute ischemic stroke: Effect of modifier codes. Stroke 1998;29:1602-4.
15. Gonzalez NR, Liebeskind DS, Dusick JR, Mayor F, Saver J. Intracranial arterial stenoses: Current viewpoints, novel approaches, and surgical perspectives. Neurosurg Rev 2013;36:175-84.
16. Gupta A, Desai MM, Kim N, Bulsara KR, Wang Y, Krumholz HM. Trends in intracranial stenting among medicare beneficiaries in the United States, 2006-2010. J Am Heart Assoc 2013;2:e000084.
17. Gupta R, Schumacher HC, Mangla S, Meyers PM, Duong H, Khandji AG, *et al*. Urgent endovascular revascularization for symptomatic intracranial atherosclerotic stenosis. Neurology 2003;61:1729-35.
18. Higashida RT, Meyers PM, Connors JJ 3rd, Sacks D, Strother CM, Barr JD, *et al*. Intracranial angioplasty and stenting for cerebral atherosclerosis: A position statement of the American Society of Interventional and Therapeutic Neuroradiology, Society of Interventional Radiology, and the American Society of Neuroradiology. J Vasc Interv Radiol 2009;20 (7 Suppl):S312-6.
19. Jiang WJ, Du B, Leung TW, Xu XT, Jin M, Dong KH. Symptomatic intracranial stenosis: Cerebrovascular complications from elective stent placement. Radiology 2007;243:188-97.

20. Jiang WJ, Wang YJ, Du B, Wang SX, Wang GH, Jin M, *et al*. Stenting of symptomatic M1 stenosis of middle cerebral artery: An initial experience of 40 patients. Stroke 2004;35:1375-80.
21. Johantgen M, Elixhauser A, Bali JK, Goldfarb M, Harris DR. Quality indicators using hospital discharge data: State and national applications. Jt Comm J Qual Improv 1998;24:88-105.
22. Kasner SE, Chimowitz MI, Lynn MJ, Howlett-Smith H, Stern BJ, Hertzberg VS, *et al*. Predictors of ischemic stroke in the territory of a symptomatic intracranial arterial stenosis. Circulation 2006;113:555-63.
23. Klopfenstein JD, Ponce FA, Kim LJ, Albuquerque FC, Nakaji P, Spetzler RF. Middle cerebral artery stenosis: Endovascular and surgical options. Skull Base 2005;15:175-89.
24. Liebeskind DS, Cotsonis GA, Saver JL, Lynn MJ, Turan TN, Cloft HJ, *et al*. Collaterals dramatically alter stroke risk in intracranial atherosclerosis. Ann Neurol 2011;69:963-74.
25. Moreira T, Michel P, Binaghi S, Hirt L. Risk factor impact on blood flow velocities and clinical outcomes of stented cervical and intracranial stenoses: Preliminary observations. Clin Neurol Neurosurg 2012;114:922-9.
26. Powers WJ, Clarke WR, Grubb RL Jr, Videen TO, Adams HP Jr, Derdeyn CP, *et al*. COSS Investigators. Extracranial-intracranial bypass surgery for stroke prevention in hemodynamic cerebral ischemia: The Carotid Occlusion Surgery Study randomized trial. JAMA 2011;306:1983-92.
27. Sacco RL, Kargman DE, Gu Q, Zamanillo MC. Race-ethnicity and determinants of intracranial atherosclerotic cerebral infarction. The Northern Manhattan Stroke Study. Stroke 1995;26:14-20.
28. Suri MF, Johnston SC. Epidemiology of intracranial stenosis. J Neuroimaging 2009;19 Suppl 1:11-6S.
29. Vilela MD, Newell DW. Superficial temporal artery to middle cerebral artery bypass: Past, present, and future. Neurosurg Focus 2008;24:E2.
30. Wityk RJ, Lehman D, Klag M, Coresh J, Ahn H, Litt B. Race and sex differences in the distribution of cerebral atherosclerosis. Stroke 1996;27:1974-80.
31. Yamauchi H, Fukuyama H, Fujimoto N, Nabatame H, Kimura J. Significance of low perfusion with increased oxygen extraction fraction in a case of internal carotid artery stenosis. Stroke 1992;23:431-2.
32. Zhou Y, Yang QW, Xiong HY. Angioplasty with stenting for intracranial atherosclerosis: A systematic review. J Int Med Res 2012;40:18-27.

Commentary

I have had personal experience with bypass for intracranial arterial stenosis, and the data presented is consistent with my experience. The stenting data is also believable, as small stents will probably not remain patency in intracranial vessels. There are obvious criticisms in such a retrospective study from the literature; however, I do not think that is the point of the paper. The key message is that we do not have a treatment for this disease with surgery or with stenting.

There is a good reason why the complications in the asymptomatic patients are smaller. That is because the stenosis is probably less in those patients. I do not believe the temporary clipping is the cause of the infarction, although it could contribute by allowing softening of the tissue from ischemia. From my experience, the bypass provides opposing flows to the antegrade flow from the carotid through the stenosis. This is seen more with proximal bypasses to the branches off the M2 just after the bifurcation to vessels on the temporal lobe supplied by the M2. The M2 branches at this point are larger than they are more distally. Thus, they will carry more flow. Stasis occurs and an infarction, usually a lenticulostriate infarction, from this stasis occurs at the site of the stenosis.

Endarterectomy is also an option. I tried five about 20 years ago, and three out of the five occluded. I found that the plaques in the middle cerebral artery (MCA) are not as distinct as in the Carotid Bifurcation. They do not seem to end and are part of the endothelium. So I did use some 10-0 sutures to tack the plaques down to proven turbulence and thrombosis. However, that was before more powerful antiplatelet agents than ASA were used. I did think of using a patch graft at the site of the stenosis. We did do this in the laboratory using a vein path as a graft to widen the site of the stenosis. We did not get to try this on patients but it might be a good solution. Recent work on encephaloduroarteriosynangiosis (EDAS) for patients with MCA stenosis, by Nestor Gonzalez, shows promise for treatment of this disease.

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