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ORIGINAL ARTICLE

Patient Age and the Outcomes after Decompressive Hemicraniectomy for Stroke: A Nationwide Inpatient Sample Analysis

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Abstract

Background Decompressive hemicraniectomy (DHC) for space-occupying cerebral infarction in older adults remains controversial, and there are limited nationwide data evaluating the outcomes after craniectomy for stroke by patient age.

Methods Patients who underwent DHC for ischemic stroke were extracted from the Nationwide Inpatient Sample (2002–2011). Multivariable logistic regression examined in-hospital mortality and a poor outcome (death, tracheostomy and gastrostomy, or discharge to institutional care). Covariates included year of admission, comorbidities, severity indices, and treatment variables (including the timing of decompression).

Results Craniectomy was performed in 1673 patients: 62.4 % were aged 18–60 years, 20.6 % aged 61–70 years, and 17.0 % aged greater than 70 years. DHC was associated with reduced adjusted odds of in-hospital death compared with medical treatment alone among patients with cerebral edema in all age categories, including those older than 70 years ($p \leq 0.008$). However, among surgical patients, the adjusted odds of mortality were significantly greater for patients aged 61–70 (30.7 %, $p = 0.02$) and greater than 70 years (34.5 %, $p = 0.02$), but not different for patients aged 51–60 (22.8 %), compared to those aged 18–50 years (19.7 %). The adjusted odds of a poor outcome also increased significantly with age, particularly for patients greater than 60 years.

Conclusion In this nationwide analysis, DHC was associated with reduced mortality regardless of patient age, including among those aged greater than 70 years. However, patients aged greater than 60 years treated surgically experienced higher odds of mortality (32.4 %), discharge to institutional care (47.1 %), and a poor outcome (77.0 %) compared with younger patients.

Keywords Age · Cerebral infarction · Decompressive hemicraniectomy · Hemicraniectomy · Ischemic stroke · Middle cerebral artery · Nationwide inpatient sample

Introduction

The performance of decompressive hemicraniectomy (DHC) for space-occupying cerebral infarction in older adults is contentious [1]. The initial three randomized control trials that established the efficacy of DHC after stroke were restricted to patients aged 18–60 years [2–4]. Discussion about the appropriate utilization of DHC in older adults was revived by DESTINY II, a randomized controlled trial published in 2014 that concluded DHC in patients aged 61–82 years was efficacious [5]. Although there was a significant reduction in mortality—33 % in the surgical arm compared to 70 % in the medical arm—most survivors had a modified Rankin Scale (mRS) score of 4, indicating moderate–severe disability (such as inability to walk independently or care for one's bodily needs) [5].

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Given this degree of disability, some have questioned the utility of DHC for space-occupying infarction in older adults [1, 6]. In 2012, Zhao et al. reported a randomized controlled trial that enrolled patients up to 80 years: although a subgroup analysis of patients aged greater than 60 years showed improved mortality, the sample size of this subgroup was small [7]. Additional (retrospective, institutional) studies have found that older age is a predictor of poor outcomes, making the role of DHC in this population debatable [8–12].

Population-based data can evaluate the applicability of findings of randomized controlled trials to the general population and assess the effectiveness of an intervention in practice, providing a broad clinical perspective. However, there are limited nationwide analyses of the association of patient age with the outcomes after craniectomy for space-occupying infarction. The goal of this study is to utilize the Nationwide Inpatient Sample (NIS) to evaluate the national estimates of mortality, discharge to institutional care, and poor outcome after DHC in older adults in the United States.

Methods

Data Source

Data were extracted from the NIS (2002–2011, 2012–2013), the largest all-payer inpatient database in the United States (Healthcare Cost and Utilization Project, Agency Healthcare Research and Quality). The NIS is a 20 % stratified sample of American discharges and has been used extensively to evaluate patients with acute ischemic stroke [13–29]. After 2011, there was a redesign of the NIS: the creation of new discharge weights prohibits appropriate variance calculations using samples combined before and after the redesign; therefore, patients admitted between 2012 and 2013 were evaluated separately. Our institutional review board has determined that studies using the NIS are exempt from review.

Inclusion Criteria

Patients were included if (1) they had a primary *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM) diagnosis code of acute ischemic stroke (433.11, 433.31, 433.81, 433.91, 434.01, 434.11, and 434.91); (2) they had an ICD-9-CM procedure code indicating a craniectomy (01.25) or craniotomy (01.24), with or without concomitant lobectomy (01.39, 01.53, 01.59); (3) they were aged at least 18 years; and (4) their hospital admission was nonelective hospital. Similar diagnosis and procedure codes have been used in other NIS studies evaluating DHC for stroke [30]. Patients with a diagnosis code indicating lobectomy were included because at some institutions, patients may undergo excision of infarcted regions (strokectomy) at the time of craniectomy [31].

To increase the specificity of the analysis, admissions with the following secondary diagnosis codes were excluded: head trauma (80x.xx, 85x.xx), subarachnoid hemorrhage (430), extra-axial hematoma (432.0, 432.1, 432.9), vertebral artery dissection (443.24), vertebrobasilar infarction (433.01, 433.21), arteriovenous malformation (747.81), unruptured cerebral aneurysm (437.3), cerebral arteritis (437.4), Moyamoya disease (437.5), venous sinus thrombosis (437.6), brain tumor (191.x, 192.0, 192.1, 194.3 198.3, 198.4, 199.0, 200.5, 225.x, 227.3, 237.0, 237.5, 237.6), or intracranial abscess (324.0). Additionally, admissions with the following procedure codes were excluded: microsurgical clipping of a cerebral aneurysm (39.51, 39.52), repair of an arteriovenous malformation (39.53), cranioplasty (02.03–02.07), stereotactic radiosurgery (92.3x), carotid artery stent placement (00.63), or carotid endarterectomy (38.12), to restrict the population to patients presenting with acute, space-occupying infarction.

Patient Age

To maximize available data, patient age was first evaluated as a continuous variable. Thereafter, to increase clinical interpretability, age was evaluated categorically in four divisions (18–50, 51–60, 61–70, >70 years). Fifty years was the first age division as this was approximately the lower quartile of the interquartile range. Sixty years was selected as the second division as this was the age cutoff for enrollment in the prior randomized controlled trials [2–4]; seventy years was the third division as some have advocated that craniectomy should be more broadly offered to patients up to seventy years [32].

Covariates

Patient sex, year of admission, primary expected payer, and hospital characteristics were extracted. Comorbidities were evaluated using the Elixhauser scale, a comorbidity index comprising 26 conditions, which was designed for use with administrative data [33]. Given the potential misclassification with the primary diagnosis, neurological disorders or paralysis were not evaluated as comorbidities; likewise, comorbidities encoded in fewer than 20 patients were not evaluated individually. Additional stroke risk factors that are not in the Elixhauser score were extracted: atrial fibrillation (427.31), carotid dissection (443.21), carotid stenosis (433.10, 433.11), hypercoagulable status (289.81-2), hyperlipidemia (272.x), and tobacco use (305.1).

Hypothrombotic conditions evaluated were long-term aspirin (V58.66) and anticoagulant (V58.62) use, as well as a bleeding disorder (including hemophilias, von Willebrand's disease, vitamin K deficiency, and thrombocytopenia 269.0 = vitamin K, 286.4 = vWD, other 286.x = hemophilias, 287.3-5 = thrombocytopenia).

Severity adjustment was estimated using pertinent ICD-9-CM codes [34]. Mechanical ventilation (96.7x) and coma (780.01, 780.03) were utilized as proxies for poor mental status. Aphasia (438.1x, 784.3) and hemiplegia/paresis (438.2-5x, 342.xx) were included to account for documented neurological deficits. Diagnoses of herniation (348.4) and cerebral edema (348.5) were used for differences in severity of infarction. Moreover, treatment variables extracted were thrombolytic administration (99.10, V45.88), mechanical thrombectomy (39.74), and ventriculostomy (02.2, 02.21). The timing of surgery was determined from procedure day codes.

Outcomes

Outcomes evaluated were in-hospital mortality, complications, length of hospital stay, and discharge disposition. Total complications included neurologic (intracerebral hemorrhage 431, 998.11–12, seizures 345.xx, neurological complications after procedure 997.01, 997.09); cardiac (410.xx, 248.xx, 427.5, 785.xx); pulmonary (514.x, 518.xx, 512.x); renal (584.x); gastrointestinal (578.x, 5601, 008.45); venous thromboembolic (453.x, 415.x); hematologic (285.x and 998.1x); and infectious complications (595.0, 996.64, 481–486, 507.0, 997.31, 38.x, 995.9x, 320.x, 041.x, 324.1, 790.7, 999.31, and 998.59). Placement of a ventricular shunt (02.3x), tracheostomy (31.1, 31.2x), and gastrostomy or jejunostomy (43.1x, 44.3x, 46.32) was evaluated. An extended hospitalization was defined as a hospital stay longer than the upper quartile of the interquartile range for the population. Discharge to institutional care was defined as to a nursing facility, extended care facility, or hospice but did not include discharge to rehabilitation or another acute care facility [35]. Analyses of additional procedures, length of stay, and discharge disposition were only performed for patients discharged alive; data on discharge disposition were only available from 2002 to 2011.

Additionally, the composite Nationwide Inpatient Sample-Subarachnoid hemorrhage Outcome Measure (NIS-SOM) was utilized. This dichotomous outcome measure defines a poor outcome based on in-hospital mortality, discharge to institutional care, or tracheostomy or gastrostomy placement. The NIS-SOM has been shown (in the subarachnoid hemorrhage population) to have 91 % agreement with a mRS score greater than 3 and has been suggested to be a good outcome measure when evaluating neurologic patients using administrative data [34].

Sensitivity Analysis

Additionally, given that the association of age with perioperative outcomes may be impacted by the number of comorbidities, the timing of intervention, or transtentorial herniation, sensitivity analyses were performed evaluating for an interaction between patient age and these characteristics.

Missing Data

Data were missing on two variables of interest: timing of intervention and discharge disposition. Patients missing timing of surgery were placed in a separate category for that variable. Detailed data on discharge disposition (including to institutional care) were not recorded in the NIS from 2002 to 2011 for patients from California, Maryland, or Maine. Patients from these states constituted 20.5 % ($n = 262$) of patients who did not die during the hospitalization and were excluded from the analysis of this outcome.

Statistical Analysis

Statistical analyses were completed with STATA 13.0 (College Station, Texas). Descriptive statistics were performed, and categorical demographics were compared with a global chi-square test, examining for differences across any strata of patient age. Multivariable logistic regression models were constructed accounting for the survey design of the NIS (STATA prefix SVY), with the hospital identification as the sampling unit, the NIS stratum as the strata, and the discharge weights as the weighting variable. All clinical preoperative and treatment characteristics evaluated were utilized as covariates in multivariable models, due to their potential to confound the association between patient age and outcomes. Concordance (C) statistics assessed the discriminatory capacity and the Hosmer–Lemeshow test the calibration of regression models. Concordance statistics vary between 0.5 and 1.0, with most values ranging between 0.65 and 0.85; the calibration of a model is accepted when the Hosmer–Lemeshow test is greater than 0.05. Probability values less than 0.05 were considered significant.

Results

Baseline Characteristics

One thousand six hundred and seventy-three patients who underwent DHC between 2002 and 2011 were included, and patients were stratified by age into four groups based on predetermined criteria: 35.5 % were aged 18–50 years ($n = 593$), 27.0 % aged 51–60 years ($n = 451$), 20.6 % aged 61–70 years ($n = 345$), and 17.0 % aged greater than 70 years ($n = 284$). The mean age was 55.9 (standard deviation: 13.7) years. The demographics of the study population are compared by patient age as shown in Table 1: many baseline characteristics—particularly comorbidities and stroke risk factors—varied significantly by patient age (Fig. 1).

Decompressive Hemicraniectomy Utilization

First, the utilization of DHC between 2002 and 2011 was evaluated. Although there is no specific ICD-9-CM code for space-occupying infarction, patients (treated medically and surgically) with a diagnosis of cerebral edema ($n = 67{,}011$) or herniation ($n = 3001$) were compared by the use of surgical treatment. Craniectomy was performed in 10.1 % of patients with cerebral edema and 19.0 % with a diagnosis of herniation. By patient age, craniectomy was utilized in 24.6 % of patients aged 18–50 years with cerebral edema, 17.0 % aged 51–60 years, 10.7 % aged 61–70 years, and 2.7 % aged at least 70 years. When evaluating patients with documented herniation, craniectomy was performed in 35.9 % of patients aged 18–50 years, 27.1 % aged 51–60 years, 20.2 % aged 61–70 years, and 6.2 % aged greater than 70 years. The in-hospital mortality of patients with cerebral edema and herniation are stratified by categories of patient age and compared within each category by craniectomy use using multivariable logistic regression (Table 2). Among all age groups evaluated, craniectomy was associated with reduced odds of in-hospital mortality, including those aged greater than 70 years ($p \leq 0.008$).

Outcomes

Multivariable logistic regression models evaluated the association of patient age when evaluated continuously (Table 3) and categorically (Table 4) with postoperative outcomes. Given the small number of patients treated between 2012 and 2013 ($n = 591$), this population was only analyzed with age continuously, as a categorical analysis is limited by a restricted number of patients in each division. The in-hospital mortality rate from 2002–2011 was 25.3 %, and mortality increased with age (aged 18–50 years: 19.7 %, 51–60 years: 22.8 %, 61–70 years: 30.7 %, greater than 70 years: 34.5 %, Fig. 1). The adjusted odds of in-hospital death were not significantly different for patients aged 51–60 years (odds ratio (OR) 1.17, 95 % confidence interval (CI), 0.83–1.64, $p = 0.37$) but were significantly greater for patients aged 61–70 years (OR 1.66, 95 % CI, 1.10–2.52, $p = 0.02$) or greater than 70 years (OR 1.84, 95 % CI, 1.12–3.02, $p = 0.02$), compared to those aged 18–50. The median hospital stay was 15 (interquartile range (IQR): 9–23) days and for patients discharged alive was 17 (IQR: 12–25) days; the discharge disposition of the population is stratified by patient age as shown in Table 3.

Sensitivity Analyses

Sensitivity analyses were performed evaluating the interaction between patient age and the number of comorbidities, the timing of intervention, or herniation on mortality or sustaining a poor outcome. No interaction between patient age and the number of comorbidities or the timing of surgery (data not shown) was discerned, suggesting that the association of these confounders with outcomes does not vary by strata of patient age. However, a protective interaction was detected among patients aged greater than 70 years and herniation for mortality (OR 0.44, 95 % CI, 0.20–0.96, $p = 0.40$) and poor outcome (OR 0.34, 95 % CI, 0.13–0.92, $p = 0.03$), suggesting that herniation was less detrimental for older patients compared with those aged 18–50 years.

Discussion

Patients with space-occupying hemispheric infarction often develop malignant cerebral edema, which may lead to death from transtentorial herniation; in appropriate patients, DHC may be mortality and, ideally, disability sparing [8–12, 31, 36–64]. Several initial retrospective (primarily institutional) studies found that greater age was a negative predictor of outcomes after hemicraniectomy [8–12, 49, 53, 63], which prompted the initial randomized controlled trials to restrict enrollment to patients aged 18–60 years [2–4, 65, 66]. However, some authors suggested these differences in outcomes by patient age may have been due to unadjusted confounding from baseline comorbidities, delayed surgery, or a greater proportion of patients who had already sustained transtentorial herniation [67]. As recent publications have reported a mortality benefit for older adults undergoing DHC [5], the appropriate age group for surgical intervention remains debated [67–75]. Some have suggested that patients aged 61–70 may benefit from DHC [32], while other studies (including DESTINY II) have included octogenarians [5] (Table 5).

There remain limited nationwide data evaluating the impact of patient age on the outcomes after DHC for stroke. In a nationwide Japanese study evaluating 355 patients, older age was not found to be an independent risk factor for mortality [76]. The NIS is the largest all-payer database in the United States and has been used extensively

Table 1 The demographics of the study population, stratified by patient age

Variable	Total pop. (*n* = 167)	18–50 years (*n* = 593)	51–60 years (*n* = 451)	61–70 years (*n* = 345)	>70 years (*n* = 284)	*p* value
Sex						
Male	59.5	55.5	68.3	64.4	48.2	**<0.001**
Female	40.5	44.5	35.7	35.7	51.8	
Year of admission						
2002–2005	23.7	22.3	22.4	22.0	31.0	**0.006**
2006–2008	29.1	32.7	27.9	25.2	28.2	
2009–2011	47.2	45.0	49.7	52.8	40.9	
Insurance status						
Private	45.4	57.2	59.4	36.5	9.5	**<0.001**
Medicare	29.4	7.1	9.1	47.3	86.6	
Medicaid	16.6	24.5	21.1	8.4	3.1	
Self-pay/no-charge	8.6	11.3	10.6	7.8	0.7	
Comorbidities						
Alcohol abuse	7.1	8.9	10.2	4.0	2.1	**<0.001**
Anemia	16.0	18.6	15.3	13.6	14.4	0.17
Arthritis	1.3	1.2	1.6	0.9	1.4	0.85
Congestive heart failure	10.7	7.6	10.6	14.2	13.0	**0.007**
Chronic pulmonary disease	9.7	6.8	9.5	12.5	12.7	**0.008**
Coagulopathy	7.8	8.3	8.0	6.4	8.1	0.75
Diabetes	24.8	17.5	27.5	32.8	26.1	**<0.001**
Diabetes with complications	3.2	2.4	2.7	4.9	3.5	0.16
Hypertension	61.8	49.6	63.2	74.0	70.4	**<0.001**
Hypothyroidism	4.6	3.0	3.3	3.8	10.9	**<0.001**
Obesity	8.1	10.0	7.5	9.6	3.2	**0.004**
Peripheral vascular disease	8.0	11.3	6.9	6.4	4.9	**0.002**
Pulmonary hypertension	3.2	3.7	3.6	2.9	2.1	0.61
Renal failure	5.6	2.5	5.5	7.5	9.5	**<0.001**
Valvular disease	5.7	3.8	6.2	7.3	7.0	0.10
Weight loss	11.6	11.5	13.8	10.1	10.2	0.35
Stroke risk factors						
Atrial fibrillation	20.9	5.7	18.9	30.4	44.0	**<0.001**
Carotid dissection	4.0	8.6	2.9	0.6	0.4	**<0.001**
Carotid stenosis	17.0	20.1	18.7	14.8	10.6	**0.002**
Hypercoagulability	2.5	5.2	1.6	0.6	0.4	**<0.001**
Hyperlipidemia	25.4	17.2	27.3	35.1	27.8	**<0.001**
Tobacco use	18.4	24.5	25.3	11.9	2.8	**<0.001****
Hypothrombotic factors						
Long-term aspirin use	2.7	0.5	2.2	7.3	2.5	**<0.001**
Anticoagulant use	2.5	1.4	3.1	2.9	3.5	0.15
Bleeding disorder	7.0	7.6	6.9	5.8	7.4	0.76
Severity indices						
Mech. ventilation	67.0	64.1	68.3	72.5	64.1	**0.04**
Coma	9.7	9.4	8.4	9.3	12.7	0.28
Aphasia	15.7	17.5	17.3	11.0	14.8	**0.04**

Table 1 continued

Variable	Total pop. ($n = 167$)	18–50 years ($n = 593$)	51–60 years ($n = 451$)	61–70 years ($n = 345$)	>70 years ($n = 284$)	p value
Hemiparesis/hemiplegia	52.2	56.3	51.2	51.0	46.8	0.05
Herniation	28.0	28.3	29.9	29.9	22.2	0.10
Cerebral edema	37.8	40.8	40.6	35.7	29.9	**0.008**
Treatment variables						
Thrombolytic administration	19.5	18.1	20.6	22.9	16.6	0.15
Mech. thrombectomy	5.3	5.7	4.7	5.5	5.3	0.72
Ventriculostomy	22.7	21.3	20.2	24.4	27.5	0.09
Timing of surgery						
Admission day	17.3	15.7	20.8	16.8	15.5	0.17
Post admission day 1	27.2	29.7	24.6	27.0	26.4	
Post admission day 2	16.6	16.9	16.9	17.4	14.4	
Post admission day 3 or later	22.8	19.6	23.1	24.1	27.5	
Missing	16.2	18.2	14.6	14.8	16.2	
Hospital characteristics						
Hospital size						
Small/medium	17.3	16.1	18.2	17.7	17.6	0.85
Large	82.7	83.8	81.8	82.3	82.4	
Hospital location/teaching status						
Rural	2.8	2.2	1.1	4.4	4.9	**0.001**
Urban, nonteaching	20.9	19.4	19.1	21.5	26.4	
Urban, teaching	76.3	78.4	79.8	74.2	68.7	
Hospital control						
Government or private	83.2	85.5	84.9	80.3	79.2	**0.03**
Private, nonprofit	10.5	8.9	10.4	13.0	10.6	
Other	6.3	5.6	4.7	6.7	10.2	
Hospital geography						
Northeast	20.7	18.7	18.0	22.3	27.1	0.09
Midwest	22.9	25.1	22.6	20.3	21.8	
South	34.9	35.9	35.7	34.2	32.0	
West	21.6	20.2	23.7	23.2	19.0	

All data are presented as percentages

Statistically significant differences by the global chi-square test are shown in bold

Mech Mechanical; *Pop.* population

to evaluate the in-hospital outcomes of patients after stroke [13]; however, few studies have utilized this data source to evaluate outcomes after DHC [30]. In a study evaluating the trends in the utilization of DHC for stroke in American hospitals, Walcott et al. evaluated 2783 patients and reported a higher rate of mortality in patients aged greater than 60 years (44 vs. 24 %) but did not find this difference statistically significant [77]. However, their study was restricted to a dichotomous categorization of age, and the analyses had limited severity adjustment. Amidst uncertainty of the role of age in patient selection, DHC is being increasingly utilized [14, 77]; and additional data are needed on mortality and disability after DHC for stroke.

In this NIS analysis, 1673 patients who underwent DHC over a ten-year period from across the United States were evaluated. Many of the baseline characteristics and stroke risk factors of the patient population varied significantly by age, including a higher prevalence with greater age of several important comorbidities (such as hypertension and atrial fibrillation). However, several preoperative markers

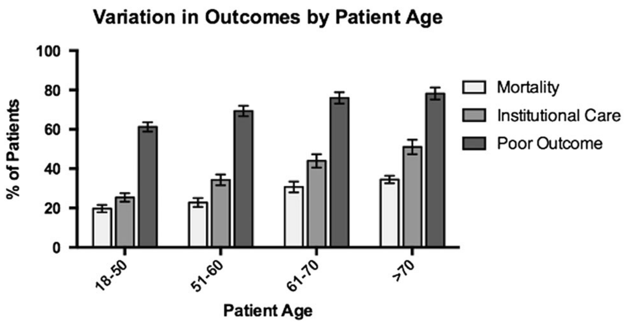

Fig. 1 *Bar graph* demonstrating differences by patient age in the unadjusted rates (and standard error) of in-hospital mortality, tracheostomy or gastrostomy placement, discharge to institutional care, and of a poor outcome

of stroke severity including coma, mechanical ventilation, and herniation did not differ by age; likewise, many treatment variables including intravenous thrombolysis, ventriculostomy, and the timing of surgical intervention did not vary with age.

The present study highlights the complex association between patient age and outcomes after craniectomy for stroke. DHC was associated with a survival benefit compared with medical treatment alone among patients with cerebral edema or herniation regardless of patient age, including in those aged greater than 70 years. Perhaps not surprisingly, older patients who were not treated surgically had very high in-hospital mortality rates, underscoring the life-saving role of DHC in all patients regardless of age, including in the elderly. However, craniectomy was sparingly utilized in this patient population.

On the other hand, while older patients treated surgically had reduced odds of death compared to those treated medically, they also sustained inferior outcomes compared with younger patients. More striking than simply the association of worse outcomes was that those older than 60 years had relatively high rates of postoperative death (32.4 %), discharge to institutional care (47.1 %), and poor outcome (77.0 %). While the decision to pursue DHC for stroke is highly individualized, based on the projected trajectory of neurologic recovery, the baseline health of the patient, and the values of the patient and his or her family, patients and clinicians may want to consider these nationally representative data regarding both the benefit and the postoperative outcomes of craniectomy when considering pursuing decompression.

The in-hospital mortality rate in this study was 32.4 % in patients aged greater than 60 years. This is similar to the 33.0 % six-month mortality reported in DESTINY II, although direct comparison is difficult as in-hospital mortality was not reported in the trial [5]. In multivariable logistic regression analyses utilizing important covariates—including patient demographics, comorbidities, stroke risk factors, severity indices, treatment variables, and hospital characteristics—both patients aged 61–70 and those aged greater than 70 had higher odds of in-hospital mortality. Likewise, when age was evaluated continuously, increasing age was also significantly associated with in-hospital mortality, among patients treated between 2002–2011 and 2012–2013. The reasons for the differential mortality are difficult to discern from the NIS as cause of death is not recorded. To that end, variations in rates of complications by system were analyzed. Although many medical complications did not differ by patient age, the odds of hemorrhagic conversion of the infarction increased with greater age; and in categorical analysis, this was

Table 2 The association of decompressive hemicraniectomy with mortality among patients with cerebral edema and herniation

Variable	Mortality rate		Multivariable logistic regression			
	Surgical treatment (%)	Medical treatment (%)	OR	95 % CI	*p* value	C
Cerebral edema						
Age 18–50 (*n* = 1005)	17.9	25.0	0.22	0.13–0.37	<0.001	0.84
Age 51–60 (*n* = 1677)	28.3	25.3	0.50	0.30–0.83	0.008	0.85
Age 61–70 (*n* = 1186)	30.6	29.1	0.29	0.16–0.54	<0.001	0.84
Age > 70 (*n* = 2833)	29.9	30.7	0.26	0.14–0.47	<0.001	0.76
Herniation						
Age 18–50 (*n* = 477)	27.2	55.9	0.16	0.09–0.30	<0.001	0.88
Age 51–60 (*n* = 620)	26.2	54.9	0.12	0.06–0.25	<0.001	0.87
Age 61–70 (*n* = 682)	39.9	60.7	0.24	0.12–0.48	<0.001	0.82
Age > 70 (*n* = 1226)	38.2	66.4	0.13	0.06–0.25	<0.001	0.77

All multivariable logistic regression constructs include patient demographics, comorbidities, stroke risk factors, hypothrombotic conditions, severity indices, treatment variables, and hospital characteristics (listed in Table 1) as covariates

OR odds ratio; *C* concordance statistics; *CI* confidence interval

Table 3 Multivariable logistic regression analysis evaluating the association of patient age when evaluated continuously with postoperative complications and outcomes after decompressive hemicraniectomy for stroke in the 2002–2011 and 2012–2013 populations

Variable	NIS 2002–2011 (*n* = 1673)				NIS 2012–2013 (*n* = 591)			
	OR	95 % CI	*p* value	C	OR	95 % CI	*p* value	C
In-hospital mortality	**1.018**	**1.005–1.031**	**0.005**	0.75	**1.041**	**1.013–1.068**	**0.003**	0.81
Total complication rate	1.011	0.997–1.027	0.13	0.81	1.030	1.000–1.060	0.05	0.87
Total neurological complications	1.009	0.998–1.020	0.12	0.66	**1.029**	**1.010–1.048**	**0.003**	0.71
Intracerebral hemorrhage	**1.017**	**1.004–1.030**	**0.008**	0.71	**1.045**	**1.021–1.067**	**<0.001**	0.72
Cardiac complications	0.991	0.971–1.011	0.38	0.71	1.015	0.983–1.048	0.37	0.82
Pulmonary complications	0.996	0.984–1.009	0.57	0.79	0.987	0.967–1.006	0.18	0.79
Renal complications	1.010	0.993–1.028	0.25	0.75	1.008	0.983–1.033	0.55	0.78
Gastrointestinal complications	0.999	0.980–1.018	0.90	0.73	1.000	0.962–1.039	0.98	0.82
Infectious complications	1.011	0.999–1.022	0.07	0.69	0.992	0.972–1.013	0.46	0.74
Hematological complications	1.010	0.994–1.026	0.22	0.87	0.986	0.961–1.011	0.26	0.89
VTE	1.003	0.987–1.019	0.75	0.76	0.980	0.942–1.019	0.30	0.89
Tracheostomy or gastrostomy placement*	**1.017**	**1.003–1.030**	**0.02**	0.77	**1.034**	**1.008–1.060**	**0.01**	0.80
Ventricular shunt placement*	0.996	0.970–1.024	0.80	0.78	1.025	0.976–1.077	0.32	0.82
Extended hospitalization*	0.996	0.982–1.010	0.59	0.74	1.005	0.976–1.034	0.75	0.83
Discharge to institutional care**	**1.031**	**1.016–1.047**	**<0.001**	0.74	–	–	–	–
Poor outcome***	**1.030**	**1.017–1.043**	**<0.001**	0.78	–	–	–	–

Data on discharge disposition are not available from the 2012–2013 releases of the NIS

An extended hospitalization is longer than the upper quartile of the interquartile range in the entire study population

All multivariable logistic regression constructs include patient demographics, comorbidities, stroke risk factors, hypothrombotic conditions, severity indices, treatment variables, and hospital characteristics (Table 1) as covariates

OR odds ratio; *C* concordance statistics; *CI* confidence interval; *NIS* Nationwide Inpatient Sample; *VTE* venous thromboembolism

* Analysis of patients discharged alive

** Analysis only of patients discharged alive with a known destination

*** Analysis of patients with a known discharge disposition

Statistically significant differences are shown in bold. Odds ratios represent the odds of sustaining each complication or outcome with each additional year of patient age

primarily due to a higher rate of hemorrhagic conversion among patients greater than 70 years.

Although mortality is arguably the ultimate outcome, assessment of postoperative functional capacity is also important [78]; and the performance of DHC in patients with resultant severe disability remains controversial [6]. A nuanced evaluation of disability with the NIS is limited as standard neurologic outcome measures are not directly encoded. However, prior validation has shown that a composite outcome measure examining mortality, tracheostomy and gastrostomy placement, and discharge disposition in patients with neurologic disease may serve as a proxy for mRS score [34]. In this study, the adjusted odds of discharge to institutional care and of a poor outcome increased significantly with greater age for all groups evaluated; the largest effect sizes (and highest crude rates of adverse outcomes) were seen in patients aged 61–70 and greater than 70 years. Some authors have hypothesized that inferior outcomes for older adults is attributable to greater number of comorbidities, delayed surgery, or performing craniectomy after herniation has occurred [67]. However, these factors were included as covariates in all multivariable regression analyses, highlighting the independent effect of patient age. Additionally, sensitivity analyses did not find an interaction between the number of comorbidities or timing of surgery and patient age; and in fact, a protective interaction between herniation and age greater than 70 years was observed.

The limitations of this study merit closer evaluation. Coding inaccuracies are a concern for any study based on ICD-9-CM identifiers; however, there is little reason to suspect that coding inaccuracies would vary by patient age. Differences in the medical treatment of elevated intracranial pressure, including osmotic therapy, could not be evaluated. Additionally, clinical data without a corresponding ICD-9-CM code were not available; thus, preoperative functional status, National Institutes of Health Stroke Scale, hemispheric lateralization, and proportion of the hemisphere infarcted could not be evaluated. Moreover, the duration of postoperative mechanical intubation and the

Table 4 Univariable and multivariable logistic regression analyses evaluating the association of patient age when evaluated categorically with postoperative complications and outcomes after decompressive hemicraniectomy for stroke

Variable	Age (years)	Crude %	Univariable Analysis			Multivariable Analysis			HL	C
			OR	95 % CI	*p* value	OR	95 % CI	*p* value		
In-hospital mortality	18–50	19.7	Ref.			Ref.			0.93	0.75
	51–60	22.8	1.21	0.88–1.64	0.24	1.17	0.83–1.64	0.37		
	61–70	30.7	**1.79**	**1.31–2.41**	**<0.001**	**1.66**	**1.10–2.52**	**0.02**		
	>70	34.5	**2.09**	**1.56–2.81**	**<0.001**	**1.84**	**1.12–3.02**	**0.02**		
Total complication rate	18–50	83.8	Ref.			Ref.			0.05	0.81
	51–60	86.0	1.22	0.85–1.77	0.28	1.20	0.80–1.80	0.39		
	61–70	87.3	1.36	0.92–2.01	0.12	1.27	0.78–2.06	0.34		
	>70	86.6	1.25	0.83–1.89	0.29	1.47	0.77–2.73	0.25		
Total neurological complications	18–50	21.1	Ref.			Ref.			0.31	0.67
	51–60	25.9	1.31	0.97–1.76	0.08	1.314	0.95–1.81	0.10		
	61–70	27.3	1.39	0.99–1.94	0.06	1.23	0.83–1.83	0.31		
	>70	32.4	**1.82**	**1.32–2.51**	**<0.001**	1.54	0.99–2.40	0.06		
Intracerebral hemorrhage	18–50	12.5	Ref.			Ref.			0.63	0.71
	51–60	16.0	1.31	0.95–1.80	0.10	1.26	0.88–1.81	0.20		
	61–70	18.8	**1.61**	**1.12–2.30**	**0.01**	1.44	0.93–2.25	0.11		
	>70	25.0	**2.38**	**1.68–3.37**	**<0.001**	**2.23**	**1.38–3.56**	**0.001**		
Cardiac complications	18–50	9.4	Ref.			Ref.			0.13	0.71
	51–60	10.4	1.14	0.78–1.68	0.49	1.02	0.65–1.60	0.93		
	61–70	10.1	1.10	0.71–1.73	0.67	0.86	0.48–1.55	0.62		
	>70	10.6	1.14	0.71–1.83	0.58	0.94	0.43–2.07	0.89		
Pulmonary complications	18–50	59.0	Ref.			Ref.			0.03	0.79
	51–60	63.2	1.23	0.93–1.62	0.14	1.12	0.82–1.54	0.47		
	61–70	66.4	**1.39**	**1.03–1.86**	**0.03**	1.07	0.73–1.58	0.73		
	>70	58.1	0.96	0.71–1.29	0.77	0.75	0.46–1.22	0.25		
Renal complications	18–50	10.3	Ref.			Ref.			0.16	0.75
	51–60	14.0	1.43	1.00–2.03	0.05	1.21	0.81–1.81	0.34		
	61–70	16.2	**1.77**	**1.18–2.64**	**0.005**	1.23	0.73–2.01	0.45		
	>70	15.5	**1.65**	**1.05–2.61**	**0.03**	1.23	0.64–2.37	0.53		
Gastrointestinal complications	18–50	6.9	Ref.			Ref.			0.26	0.73
	51–60	7.3	1.09	0.69–1.71	0.71	1.12	0.67–1.87	0.67		
	61–70	6.4	0.90	0.55–1.50	0.70	1.00	0.53–1.87	0.99		
	>70	6.7	1.00	0.56–1.80	0.99	1.28	0.61–2.67	0.51		
Infectious complications	18–50	45.7	Ref.			Ref.			0.84	0.69
	51–60	55.2	**1.47**	**1.15–1.88**	**0.002**	**1.54**	**1.17–2.04**	**0.002**		
	61–70	53.2	**1.38**	**1.04–1.83**	**0.03**	1.40	0.99–1.99	0.06		
	>70	49.3	1.16	0.87–1.54	0.32	1.19	0.77–1.83	0.68		
Hematological complications	18–50	18.9	Ref.			Ref.			0.95	0.87
	51–60	18.2	0.98	0.72–1.34	0.92	1.14	0.72–1.78	0.58		
	61–70	18.0	0.96	0.67–1.37	0.80	1.29	0.74–2.20	0.52		
	>70	19.4	1.05	0.74–1.50	0.79	1.85	1.01–3.38	0.05		

Table 4 continued

Variable	Age (years)	Crude %	Univariable Analysis			Multivariable Analysis			HL	C
			OR	95 % CI	p value	OR	95 % CI	p value		
VTE	18–50	10.1	Ref.			Ref.			0.15	0.77
	51–60	12.2	1.22	0.81–1.83	0.34	1.43	0.90–2.28	0.13		
	61–70	11.3	1.12	0.74–1.70	0.58	1.46	0.87–2.43	0.15		
	>70	4.9	**0.47**	**0.26–0.84**	**0.01**	0.53	0.25–1.15	0.11		
Tracheostomy or gastrostomy placement* ($n = 1249$)	18–50	42.7	Ref.			Ref.			0.06	0.77
	51–60	49.4	1.32	0.99–1.76	0.06	1.31	0.93–1.85	0.12		
	61–70	51.5	**1.41**	**1.02–1.96**	**0.04**	**1.56**	**1.02–2.39**	**0.04**		
	>70	47.3	1.18	0.82–1.67	0.37	1.36	0.80–2.33	0.25		
Ventricular shunt placement* ($n = 1673$)	18–50	4.2	Ref.			Ref.			0.01	0.78
	51–60	3.6	0.71	0.34–1.47	0.35	0.64	0.28–1.46	0.29		
	61–70	6.1	1.36	0.68–2.72	0.38	1.33	0.56–3.12	0.52		
	>70	4.9	0.79	0.32–1.96	0.60	0.68	0.21–2.16	0.51		
Extended hospitalization* ($n = 1249$)	18–50	25.0	Ref.			Ref.			0.83	0.75
	51–60	31.3	1.40	1.04–1.88	0.03	1.31	0.93–1.84	0.12		
	61–70	21.3	0.83	0.55–1.24	0.36	0.78	0.47–1.30	0.34		
	>70	17.7	0.66	0.42–1.04	0.07	0.60	0.32–1.12	0.11		
Discharge to institutional care** ($n = 996$)	18–50	25.4	Ref.			Ref.			0.94	0.74
	51–60	34.3	**1.56**	**1.11–2.19**	**0.01**	**1.73**	**1.18–2.53**	**0.005**		
	61–70	44.0	**2.34**	**1.63–3.35**	**<0.001**	**2.37**	**1.50–3.74**	**<0.001**		
	>70	51.0	**3.00**	**1.95–4.61**	**<0.001**	**2.30**	**1.20–4.39**	**0.01**		
Poor outcome*** ($n = 1416$)	18–50	61.2	Ref.			Ref.			0.96	0.78
	51–60	69.3	**1.45**	**1.08–1.95**	**0.01**	**1.56**	**1.13–2.15**	**0.007**		
	61–70	76.0	**2.03**	**1.45–2.85**	**<0.001**	**1.97**	**1.29–3.02**	**0.002**		
	>70	78.2	**2.19**	**1.49–3.22**	**<0.001**	**1.97**	**1.13–3.45**	**0.02**		

An extended hospitalization is longer than the upper quartile of the interquartile range in the entire study population

All multivariable logistic regression constructs include patient demographics, comorbidities, stroke risk factors, hypothrombotic conditions, severity indices, treatment variables, and hospital characteristics (Table 1) as covariates

OR odds ratio; *C* concordance statistics; *CI* confidence interval; *HL* Hosmer–Lemeshow test; *Ref.* reference; *VTE* venous thromboembolism

* Analysis of patients discharged alive

** Analysis only of patients discharged alive with a known destination

*** Analysis of patients with a known discharge disposition

Statistically significant differences are shown in bold

timing of postoperative physiotherapy could not be evaluated; likewise, no data on the social support of patients were available, which may be an important determinant of discharge disposition. As the NIS only includes in-hospital data, long-term outcomes could not be assessed.

Nonetheless, there are many important advantages to the usage of a national data source to evaluate outcomes after craniectomy for stroke. The broad inclusion of patients from different hospitals from almost every American state allows the NIS to provide nationally accrued estimates of the mortality after DHC in the United States. Moreover, the large sample size of the NIS included many patients older than aged 60, who comprised 37.6 % of the population in this analysis. Additionally, data were extracted on several important potential confounding variables—including individual comorbidities, stroke risk factors, treatment variables, and the timing of intervention—that were utilized as covariates in all multivariable regression models.

Table 5 The discharge disposition of the study population, stratified by patient age

Discharge disposition	Total population ($n = 1249$)	18–50 years ($n = 476$)	51–60 years ($n = 348$)	61–70 years ($n = 239$)	>70 years ($n = 186$)
Home (±home health care)	8.7	11.0	9.8	5.5	6.0
Acute rehabilitation or short-term hospital	27.1	34.2	27.5	22.6	16.9
Long-term acute care hospital	13.1	10.3	14.6	12.2	17.6
Skilled nursing facility	7.7	6.6	6.4	11.0	8.1
Hospice	1.97	0.8	1.8	2.9	3.5
Died	25.3	19.7	22.8	30.7	34.5
Other discharge	3.0	4.4	3.1	1.5	1.8
Discharged alive, destination missing	13.1	13.0	14.0	13.6	11.1

Conclusions

In this NIS analysis, 1673 patients who underwent craniectomy for space-occupying infarction between 2002 and 2011 were included. The survival benefit to DHC extended to all age groups evaluated, including those greater than 70 years; and patients with cerebral edema or herniation treated without surgery had very high mortality rates. However, older patients also had higher odds of postoperative mortality and discharge to institutional care compared with younger patients. The adjusted odds of in-hospital mortality were increased for patients aged 61–70 and greater than 70 years; likewise, the odds of discharge to institutional care and of a poor outcome increased with greater age, and were highest for patients aged greater than 60 years. This provides recent data from across the United States for clinicians, patients, and their families when considering pursuing craniectomy for space-occupying infarction in older adults.

Conflict of interest M. A. Aziz-Sultan: Covidien and Codman, W. B. Gormley: Codman

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