Simulating Episode-Based Bundled Payments for Cranial Neurosurgical Procedures

Zachary Medress, MD*
Beatrice Ugiliweneza, PhD, MSPH‡
Jonathon Parker, MD, PhD*
Dengzhi Wang, MS‡
Eric Burton, MD§
Maxwell Boakye, MD, MPH, MBA‡
Stephen Skirboll, MD*¶

*Department of Neurosurgery, Stanford University, Stanford, California; ‡Department of Neurosurgery, University of Louisville, Louisville, Kentucky; §Department of Neurology, University of Louisville, Louisville, Kentucky; ¶Department of Surgery, Palo Alto Veterans Affairs, Palo Alto, California

Correspondence:
Zachary Medress, MD,
Department of Neurosurgery,
School of Medicine,
Stanford University,
300 Pasteur Drive,
Stanford, CA 94305.
Email: zmedress@stanford.edu

Received, March 14, 2019.
Accepted, June 27, 2019.
Published Online, September 12, 2019.

BACKGROUND: Episode-based bundled payments were introduced by Medicare in 2013 as the Bundled Payments for Care Improvement (BPCI) in order to improve care coordination and cost efficiency. BPCI has not yet been applied to cranial neurosurgical procedures.
OBJECTIVE: To determine projected values of episode-based bundled payments when applied to common cranial neurosurgical procedures using retrospective data from a large database.
METHODS: We performed a large retrospective observational study using the MarketScan administrative database to project bundled payment payments for 4 groups of common cranial neurosurgical procedures.
RESULTS: We identified 15 276 procedures that met our inclusion criteria. We observed significant variability between groups, with 90-d bundle projected payments ranging from $ 58,200 for craniotomy for meningioma to $ 102,073 for craniotomy for malignant glioma. We also found significant variability in projected bundled payments within each class of operation. On average, payment for the index hospitalization accounted for 85% of projected payments for a 30-d bundle and 70.5% of projected payments for a 90-d bundle. Multivariable analysis showed that hospital readmission, discharge to postacute care facilities, venous-thrombo-embolism, medical comorbidities, adjuvant therapies, and payer status significantly contributed to projected cranial bundle payments.
CONCLUSION: For the first time, to our knowledge, we project the values of episode-based bundled payments for common vascular and tumor cranial operations. As previously identified in orthopedic procedures, there is significant variability in total bundle payments within each cranial procedure. Compared to spine and orthopedic procedures, postdischarge care significantly impacts total bundle payments in cranial neurosurgery.

KEY WORDS: Bundled payments, Health care delivery, Cost efficiency, Readmission, Craniotomy, Medicare

Neurosurgery 87:86–95, 2020 DOI:10.1093/neuros/nyz353 www.neurosurgery-online.com

Center for Medicare and Medicaid Services (CMS) introduced the Bundled Payments for Care Improvement (BPCI) in 2013 as a strategy to control health-care costs and improve quality.[1] Under BPCI, payments to hospitals, inpatient and outpatient providers, and other health-care services are combined in a single episode of care lump sum, which incentivizes providers to control costs, minimize complications, and reduce readmission rates in order to keep a portion of the cost savings.[2] BPCI initially included spine, general, cardiac, and orthopedic procedures in addition to medical conditions. In the newest iteration of this payment model announced in 2018, BPCI advanced will expand coverage to hepatic disorders.[3] Currently, cranial neurosurgical operations are not eligible for BPCI, yet given the intention of CMS to move away from traditional fee-for-service reimbursement models, cranial operations could be included in future editions of BPCI.

ABBREVIATIONS: BPCI, Bundled Payments for Care Improvement; **CI,** Confidence Interval; **CMS,** Center for Medicare and Medicaid Services; **CPT,** current procedure terminology; **DRG,** diagnosis related group; **IQR,** interquartile range; **IRB,** Institutional Review Board; **ICD,** International Classification of Diseases; **VTE,** venous thrombo-embolism

We generated projected bundle payments for hypothetical episodes of care at 30-, 60-, and 90-d intervals using retrospective billing data from the MarketScan database for 4 classes of cranial operations: craniotomy for unruptured aneurysm, craniotomy for meningioma, craniotomy for malignant glioma, and craniotomy for metastasis. We describe the relative contribution of physician, hospital, and outpatient payments to total bundle prices for cranial operations and identify readmission rates and discharge status at each time interval. We hypothesize that postdischarge care will account for a significant portion of the total bundle payment for cranial operations given the increased medical complexity of patients requiring cranial operations.

METHODS

Data Source

We use the MarketScan data from Truven Health Analytics-IBM Watson Health. Contained in these data are paid claims for individuals covered by employer sponsored insurance, government, and public organizations. The MarketScan captures all the health care utilization of individuals through its databases (inpatient, outpatient, medication, primary care electronic medical records, lab results, dental, etc) grouped into commercial claims and encounters, Medicare supplemental, and Medicaid.[4] A unique ID is provided for each patient and can be used to link to different databases. For this project, we used inpatient and outpatient claims.

Subjects and Case Extraction

Our study was approved by the Institutional Review Board (IRB) and carried out in compliance with Health Insurance Portability and Accountability Act. Consent was not deemed to be necessary by the IRB given that only de-identified data were used in the study. Inclusion criteria included patients older than 18 yr who were hospitalized between 2000 and 2016 undergoing cranial operations within the following categories: craniotomy for unruptured aneurysm, craniotomy for meningioma, craniotomy for malignant glioma, and craniotomy for metastasis. We used International Classification of Diseases (ICD)-9, ICD-10, and current procedure terminology (CPT) codes to organize cases into the appropriate category (Table 1). We identified patients who underwent an operation within the 4 groups (Figure) from the inpatient files and flagged the first hospitalization satisfying the above conditions as the index operation stay. Next, we used inpatient and outpatient files to identify associated pre- and postoperative hospital admissions and outpatient services. We excluded patients who had less than 2 yr enrollment prior to the index operation (look-back time), history of prior cranial operation, and less than 90 d of postoperative follow-up time. These exclusion criteria were applied to make sure that only an incidence cohort is analyzed. We define postoperative look-back time as the difference between the date of enrollment and the index hospitalization date. Follow-up time was calculated in a similar way as the difference between the index hospitalization discharge date and the end of enrollment date.

Simulation of Episode of Care-Based Bundled Payments

In this study, we performed simulations of 30-, 60-, and 90-d episode of care bundles. In each of these 3 analyses, we examined the payments of the index hospitalization, with subsequent postoperative inpatient and outpatient care. We chose time-points 30, 60, and 90 d based on historical precedents and insights from the literature. The CMS pilot study utilized 30-d bundles and defined the episode of care as starting 3 d prior to surgery and ending 30 d after the operation.[5] The 60-d bundles were included based on the insight that health care expenditures return to preoperative baseline 4 to 6 wk after an operation. We included 90-d bundles because the BPCI advanced payment model has shifted to 90-d episodes of care.[5] The payments for all the postdischarge hospital admissions and outpatient services occurring within the bundle period were included in the analysis as postdischarge. We then analyzed the percent contribution of postoperative inpatient and outpatient payments to total bundle payment. All payments were inflated to 2016 United States dollars using the medical component of the consumer price index which can be accessed through the bureau of the United States Bureau of Labor Statistics website (www.bls.gov).

Data Analysis

We calculated bundle payment by taking the sum of the index hospitalization payments and the postoperative hospital admission and outpatient payments. Cases with an index hospitalization less than $ 500 and with postdischarge inpatient or outpatient payments above the 99th percentile were excluded from our analysis. The average bundle payment and associated standard deviation were calculated for each of the 4 groups using 30-, 60-, and 90-d bundle models. We performed multivariable linear model analyses on logged outcomes to quantify the effect of patient demographics, payer status, medical comorbidities, adjuvant therapy, and opioid use on projected bundle payments. Estimates were presented in terms of percent change with associated 95% CI. For each of the bundle payment outcomes considered (30, 60, and 90 d), only a subset of comorbidities which were statistically significant in bivariate analyses were included in the multivariable model. The bivariate analyses were performed with the either the Wilcoxon rank-sum test for continuous variables or the Chi-square test for categorical variables. All tests were 2-sided with a significance level of 0.05. Data preprocessing and analyses were performed in SAS 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

We included 15 276 cranial cases in our analysis. We formed 4 groups using ICD-9, ICD-10, and CPT codes to organize similar cases: craniotomy for unruptured aneurysm (group 1, n = 2118), craniotomy for meningioma (group 2, n = 4356), craniotomy for malignant glioma (group 3, n = 5304), and craniotomy for metastasis (group 4, n = 3498) (Table 1).

The mean age of patients included in our analysis ranged from 55.1 yr in the unruptured aneurysm group to 58.4 yr in the metastasis group (Table 2). The gender breakdown showed the highest percentage of female patients in the unruptured aneurysm group at 77.4%. Breakdown of payer status showed that the metastasis group had the lowest percentage of commercial insurance payer status at 68.3%, compared with the malignant glioma group which had the highest percentage of commercial payers at 75.8%. The most frequently encountered medical comorbidities affecting patients in the study were hypertension, hyperlipidemia, and depression. Hypertension was most common in the craniotomy for unruptured aneurysm group at 56.0%.

The index hospitalization and total bundle payments were calculated for each craniotomy group. The mean index

TABLE 1. Definition of Craniotomy Subgroups

Group	Description	ICD9/10 code	CPT code	No. (%)
1	Craniotomy for unruptured aneurysm	437.2, 437.3/I67.1	61 697, 61 698, 61 700, 61 702	2118 (13.9%)
2	Craniotomy for meningioma	225.2/D32.0, D32.9	61 512, 61 519	4356 (28.5%)
3	Craniotomy for malignant glioma	191.*/C71.*	61 510, 61 518	5304 (34.7%)
4	Craniotomy for metastasis	198.3/C79.3*	61 510, 61 518	3498 (22.9%)
Total				15 276 (100%)

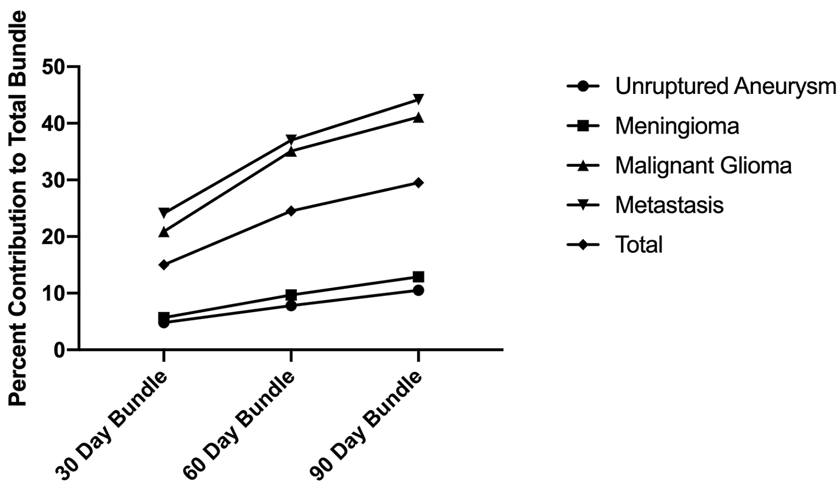

FIGURE. *For each class of cranial operation, the percent contribution of postacute services to total bundle payments was calculated at 30-, 60-, and 90-d time-points. Postacute service refers to any service rendered following the index hospitalization including postoperative nursing facility and rehabilitation facility stays, postoperative visits, adjuvant therapies, and hospital readmissions.*

hospitalization payments were $ 55,946, $ 50,002, $ 55,858, and $ 49,866 for groups 1, 2, 3, and 4, respectively (Table 3). The total mean index hospitalization payment across all operations was $ 52,828. We then projected mean 30-, 60-, and 90-d bundle payments for each group (Table 4). In Group 1, the mean 30-, 60-, and 90-d bundle payments were $ 58,937, $ 61,244, and $ 63,373, respectively. In Group 2, 30-, 60-, and 90-d bundle payments were $ 52,963, $ 55,609, and $ 58,200, respectively. In Group 3, 30-, 60-, and 90-d bundles were $ 71,244, $ 90,325, and $ 102,073, respectively. In Group 4, mean bundle payments were $ 67,024, $ 82,427, and $ 95,174 for 30-, 60-, and 90-d bundles, respectively.

We found that postdischarge payments contributed significantly to projected bundled payments, particularly in 90-d projected bundles. Postdischarge payments contributed to 15%, 24.5%, and 29.5% of total 30-, 60-, and 90-d bundles, respectively. Postdischarge payments most significantly contributed to the total bundle payments in craniotomy for metastasis, representing 24.1%, 37.0%, and 44.2% of total bundle payments for 30-, 60-, and 90-d bundles (Figure). We found that postdischarge payments contributed least to total bundle payments in craniotomy for unruptured aneurysm, representing 4.8%, 7.8%, and 10.5% of total bundle payments.

On average, 8.9% of all patients in our study were discharged to a postacute-care facility after the index hospitalization (Table 5). Patients undergoing craniotomy for clipping of unruptured aneurysm had the lowest rate of discharge to postacute-care facility (6.4%), whereas 10.6% of patients undergoing craniotomy for malignant glioma were discharged to a postacute-care facility. Readmission rate is an important metric in predicting total bundle payments. We found that patients undergoing craniotomy for malignant glioma and metastasis had readmission rates of 11.0% and 11.8%, respectively, in a 30-d model, which increased to 22.5% and 29.3%, respectively, in a 90-d projected bundle. Conversely, readmission rates were relatively flat when projected in 30-, 60-, and 90-d bundled models for craniotomy for unruptured aneurysm and craniotomy for meningioma. Craniotomy for meningioma cases had the lowest readmission rates in our models, with 7.0%, 9.4%, and 11.2% readmission rates at 30, 60, and 90 d.

TABLE 2. Demographics

	Unruptured aneurysm n = 2118	Meningioma n = 4356	Malignant glioma n = 5304	Metastasis n = 3498
Age				
Mean (SD)	55.1 (9.7)	56.2 (12.5)	52.9 (14.4)	58.4 (10.7)
Median (IQR)	56 (49, 61)	57 (48, 64)	54 (44, 62)	59 (52, 64)
Range, (min-max)	18-84	18-96	18-95	18-90
Gender				
Male, n (%)	479 (22.62%)	1165 (26.74%)	3034 (57.2%)	1455 (41.6%)
Female, n (%)	1639 (77.38%)	3191 (73.26%)	2270 (42.8%)	2043 (58.4%)
Insurance				
Commercial, n (%)	1552 (73.28%)	3070 (70.48%)	4019 (75.77%)	2389 (68.3%)
Medicaid, n (%)	273 (12.89%)	348 (7.99%)	343 (6.47%)	278 (7.95%)
Medicare, n (%)	293 (13.83%)	938 (21.53%)	942 (17.76%)	831 (23.76%)
Comorbidities				
Morbid obesity, n (%)	32 (1.51%)	131 (3.01%)	83 (1.56%)	37 (1.06%)
Hepatitis B, n (%)	150 (7.08%)	454 (10.42%)	571 (10.77%)	350 (10.01%)
Cirrhosis, n (%)	16 (0.76%)	40 (0.92%)	67 (1.26%)	79 (2.26%)
Obesity, n (%)	116 (5.48%)	266 (6.11%)	242 (4.56%)	105 (3%)
Chronic obstructive pulmonary disease, n (%)	60 (2.83%)	41 (0.94%)	40 (0.75%)	137 (3.92%)
Depression, n (%)	282 (13.31%)	467 (10.72%)	478 (9.01%)	316 (9.03%)
Smoking, n (%)	425 (20.07%)	293 (6.73%)	391 (7.37%)	386 (11.03%)
Hepatitis C, n (%)	30 (1.42%)	20 (0.46%)	27 (0.51%)	16 (0.46%)
Atrial fibrillation, n (%)	54 (2.55%)	154 (3.54%)	144 (2.71%)	119 (3.4%)
Hyperlipidemia, n (%)	297 (14.02%)	555 (12.74%)	562 (10.6%)	337 (9.63%)
Chronic kidney disease, n (%)	3 (0.14%)	10 (0.23%)	12 (0.23%)	11 (0.31%)
Diabetes mellitus, n (%)	229 (10.81%)	691 (15.86%)	557 (10.5%)	476 (13.61%)
Hypertension, n (%)	1187 (56.04%)	1842 (42.29%)	1838 (34.65%)	1280 (36.59%)
Radiosurgery, n (%)	35 (1.65%)	1397 (32.07%)	2029 (38.25%)	1749 (50%)
Radiation therapy, n (%)	81 (3.82%)	364 (8.36%)	3621 (68.27%)	2711 (77.5%)
Chemotherapy, n (%)	31 (1.46%)	71 (1.63%)	3028 (57.09%)	1566 (44.77%)
Opioid use, post 30 d, n (%)	846 (39.94%)	1064 (24.43%)	1341 (25.28%)	1122 (32.08%)
Opioid use, post 60 d, n (%)	912 (43.06%)	1228 (28.19%)	1604 (30.24%)	1430 (40.88%)
Opioid use, post 90 d, n (%)	960 (45.33%)	1334 (30.62%)	1777 (33.5%)	1613 (46.11%)

IQR, interquartile range.

On multivariable analysis, Medicare/Medicaid payer status was uniformly associated with lower bundle payments in each of the 4 treatment groups for 30-, 60-, and 90-d bundles (Table 6). Adjuvant radiosurgery and radiation therapy were uniformly associated with higher bundle payments in each of the 4 treatment groups for 30-, 60-, and 90-d bundles. Medical comorbidities such as hepatitis B and atrial fibrillation were associated with higher projected bundle payments for craniotomy for unruptured aneurysm, the percent difference and 95-percent CI were 17.09% (6.06% and 29.26%) and 19.04% (2.68% and 38.0%), respectively for a 30-d bundle. In craniotomy for meningioma, hepatitis B, and atrial fibrillation were associated with higher bundle payments, the percent difference and 95% CI were 16.31% (9.56% and 23.46%) and 13.64% (2.46% and 26.03%), respectively, for a 30-d bundle. In the craniotomy for malignant glioma group, hepatitis B (percent difference 7.82%, 95% CI: 2.59%, 13.31%) was associated with higher 30-d bundle payments. In craniotomy for metastasis, hepatitis B was associated with higher 30-, 60-, and 90-d bundle payments. Interestingly, opioid use was associated with lower payments in 30-, 60-, and 90-d bundles in craniotomy for unruptured aneurysm, but was not associated with a change in bundle payment for craniotomy for malignant glioma or metastasis.

Postdischarge destination status and readmission were included in the multivariable analysis. Discharge to an acute care facility vs home and hospital readmission was universally associated with significantly higher bundle payments at 30, 60, and 90 d for each craniotomy group. In the craniotomy for unruptured aneurysm group, discharge to an acute care facility postoperatively was associated with a 78.86% increase in bundle payment (95% CI: 65.42%, 93.17%), and hospital readmission was associated with a 47.79% increase in bundle payment value (95% CI: 37.2%, 59.2%). Venous thrombo-embolism was included in the multivariable analysis and was universally associated with higher bundle prices within 30-d epochs for each craniotomy group, particularly in craniotomy for malignant glioma, where venous thrombo-embolism was associated with a 27.8% increase in bundle price (95% CI: 20.1% to 36.1%).

TABLE 3. Index Hospitalization Costs

Craniotomy for		Index hospitalization pay (physician), mean (SD), United States dollars	Index hospitalization pay (hospital), mean (SD), United States dollars	Index hospitalization other pay, mean (SD), United States dollars	Index hospitalization total pay, mean (SD), United States dollars
Unruptured aneurysm (n = 2118)	Mean (SD)	7274 (8375)	33 221 (26631)	15 451 (13836)	55 946 (38112)
	Median (IQR)	5831 (3721, 8739)	26 918 (16 944, 41 619)	11 773 (7505, 18 886)	47 531 (32 335, 68061)
	Range, (min-max)	0-143 482	0-199 315	0-143 647	732-252 921
Meningioma (n = 4356)	Mean (SD)	5393 (6450)	31 577 (25 832)	13 032 (12 619)	50 002 (35 245)
	Median (IQR)	4140 (2868, 6062)	25 614 (15 572, 39 701)	9866 (5807, 15 995)	41 768 (27 944, 61 691)
	Range, (min-max)	0-114 060	0-205 918	0-185 173	585-238 953
Malignant glioma (n = 5304)	Mean (SD)	5226 (5728)	34 953 (26 817)	15 679 (15 131)	55 858 (37 074)
	Median (IQR)	3952 (2631, 6045)	28 612 (17 442, 45 525)	11 635 (6 997, 18 775)	46 774 (31 626, 70 783)
	Range, (min-max)	0-86 500	0-219 640	0-175 941	574-259 041
Metastasis (n = 3498)	Mean (SD)	4821 (4976)	31 561 (24 055)	13 484 (11 567)	49 866 (31 976)
	Median (IQR)	3790 (2578, 5587)	25 885 (15 950, 41 892)	10 548 (6221, 16 678)	43 474 (28 383, 64 234)
	Range, (min-max)	0-74 796	0-173 971	0-115 883	516-206 420
Total (n = 15276)	Mean (SD)	5465 (6262)	32 973 (25 943)	14 390 (13 546)	52 828 (35 715)
	Median (IQR)	4164 (2741, 6373)	26 792 (16 536, 42 338)	10 901 (6497, 17 502)	44 747 (29 861, 66 491)
	Range, (min-max)	0-143 482	0-219 640	0-185 173	516-259 041

IQR, interquartile range.

DISCUSSION

Increasing the cost efficiency of health-care delivery and improving coordination of care have become important goals in the era of the Affordable Care Act. The BPCI was introduced by CMS in 2013 in order to provide coordinated and efficient care that controls costs and reduces preventable complications. The BPCI fits into a larger goal of CMS to trial innovative alternative payment models that improve quality and reduce cost for CMS beneficiaries and lies in contrast to traditional fee-for-service models in which Medicare reimburses providers for individual services rendered in both the inpatient and outpatient settings. When introduced in 2013, the BPCI included joint replacement, cardiac, and spine procedures but has not been applied to cranial neurosurgical procedures. For the first time in our knowledge, we simulate the payments of 30-, 60-, and 90-d bundled episodes of care in 4 classes of vascular and tumor cranial neurosurgical procedures. Bundle prices have been historically associated with diagnosis related group (DRG) codes, though we elected to use CPT, ICD-9, and ICD-10 codes because of the paucity of available cranial DRG codes, which did not offer sufficient specificity to accurately identify payments associated with disparate cranial neurosurgical procedures.

Unlike in our previous work projecting bundled payments for spinal procedures, postacute care payments significantly contributed to overall projected bundle payments for cranial neurosurgical procedures, particularly in craniotomy for malignant glioma and craniotomy for metastasis. Patients undergoing these procedures have high 90-d readmission rates, with up to 29.3% of craniotomy for metastasis requiring readmission during this time period, and high rates of discharge to postacute care facilities, with 10.6% of patients undergoing craniotomy for malignant glioma requiring discharge to an acute care facility after the index hospitalization. In addition, adjuvant radiation and chemotherapy treatments contributed to high postacute care expenditures for patients undergoing craniotomy for malignant glioma and metastasis. Huckfeldt et al[7] emphasized the importance of postacute care and discharge status in contributing to variability of 30-d costs and showed that the root cause of this variability depends on the procedure or disease treated. In their analysis, up to 92% of cost variations in 30-d costs for joint replacements were due to postdischarge spending, whereas up to 93% of 30-d cost variability in patients with myocardial infarction was due to readmission. Future work to better characterize the source of cost variability within 30, 60, and 90 d in each subcategory of cranial operations will provide operation-specific targets for achieving cost efficiency in a bundled care model for cranial operations.

In our analysis, unlike bundle payments for craniotomy for unruptured aneurysm or meningioma, bundles for craniotomy for malignant glioma and metastasis are impacted significantly from disease-specific adjuvant therapies rendered within the first 90 d after surgery. Drawing from these data for craniotomy for

TABLE 4. Bundled Payment Values

Craniotomy for	Bundle length		Postdischarge inpatient pay, mean (SD), United States dollars	Postdischarge outpatient pay, mean (SD), United States dollars	Postdischarge total pay, mean (SD), United States dollars	Bundle pay, mean (SD), United States dollars	Postdischarge as percent of total bundle pay, mean (SD), %
Unruptured aneurysm	30-d	Mean (SD)	1779 (8183)	1213 (2313)	2991 (8806)	58 937 (40 140)	4.8 (10.5)
		Median (IQR)	0 (0, 0)	287 (21, 1325)	317 (30, 1715)	49 656 (33 716, 71 471)	0.7 (0.1, 3.6)
		Range, (min-max)	0-82 376	0-19 208	0-86 567	1067-335 297	0-83.2
	60-d	Mean (SD)	2992 (12 185)	2306 (3775)	5299 (13 339)	61 244 (42 199)	7.8 (13.6)
		Median (IQR)	0 (0, 0)	825 (196, 2731)	910 (206, 3814)	51 535 (34 525, 74 363)	2 (0.4, 8)
		Range, (min-max)	0-121 260	0-29 918	0-133 685	1156-376 290	0-87.1
	90-d	Mean (SD)	4185 (14 483)	3242 (4850)	7427 (16 055)	63 373 (43 726)	10.5 (15.8)
		Median (IQR)	0 (0, 0)	1335 (358, 4180)	1594 (383, 6032)	53 490 (35 932, 77 095)	3.4 (0.8, 12.7)
		Range, (min-max)	0-123029	0-35889	0-139539	1156-392459	0-88.8
Meningioma	30-d	Mean (SD)	1317 (5985)	1644 (2957)	2961 (7010)	52 963 (36 679)	5.7 (10.7)
		Median (IQR)	0 (0, 0)	439 (72, 1886)	481 (75, 2298)	44 647 (29 459, 66 144)	1.2 (0.2, 5.5)
		Range, (min-max)	0-61739	0-21 943	0-69 267	671-265 334	0-83.5
	60-d	Mean (SD)	2016 (8048)	3591 (6135)	5607 (10 838)	55 609 (38 271)	9.7 (14.4)
		Median (IQR)	0 (0, 0)	1396 (320, 3933)	1508 (332, 5016)	46 402 (30 521, 70 088)	3.6 (0.8, 11.3)
		Range, (min-max)	0-93 740	0-53 637	0-98 653	743-284 287	0-95.4
	90-d	Mean (SD)	2572 (9480)	5626 (9753)	8198 (14 525)	58 200 (40 137)	12.9 (16.7)
		Median (IQR)	0 (0, 0)	2314 (679, 5798)	2502 (709, 7584)	47 910 (31 913, 73 190)	6 (1.8, 16.6)
		Range, (min-max)	0-110 793	0-80 214	0-130 472	830-287 952	0-97.7
Malignant glioma	30-d	Mean (SD)	2764 (10 216)	12 622 (14 121)	15 386 (17 396)	71 244 (43 616)	20.9 (18.1)
		Median (IQR)	0 (0, 0)	7835 (1696, 18 462)	9857 (2010, 22 424)	61 681 (41 037, 92 564)	17.6 (4.2, 33.1)
		Range, (min-max)	0-83 984	0-80 542	0-121 857	653-318 547	0-92
	60-d	Mean (SD)	4790 (14 411)	29 677 (28 335)	34 467 (31 969)	90 325 (53 684)	35.1 (22.6)
		Median (IQR)	0 (0, 0)	22 832 (5893, 44 429)	27 048 (7483, 51 539)	80 001 (51 155, 119 398)	36.6 (14.7, 52.5)
		Range, (min-max)	0-130 519	0-154 978	0-194 417	732-397 769	0-97.7
	90-d	Mean (SD)	7065 (18 767)	39 150 (35 228)	46 215 (41 046)	102 073 (61 084)	41.1 (23.5)
		Median (IQR)	0 (0, 0)	31 564 (9411, 58 326)	37 335 (12 003, 68 100)	90 906 (56 630, 136 158)	43.9 (21.5, 59.6)
		Range, (min-max)	0-170 164	0-192 940	0-286 316	732-428 182	0-99.4
Metastasis	30-d	Mean (SD)	2963 (10 349)	14 194 (16 541)	17 157 (19 366)	67 024 (40 543)	24.1 (18.7)
		Median (IQR)	0 (0, 0)	8543 (3117, 18 673)	10 297 (3716, 23 573)	58 890 (38 232, 88 251)	20.8 (8.5, 36.4)
		Range, (min-max)	0-89 868	0-100 928	0-144 377	540-260 982	0-92.9
	60-d	Mean (SD)	6129 (15 989)	26 431 (24 707)	32 560 (29 804)	82 427 (49 089)	37 (20.6)
		Median (IQR)	0 (0, 0)	18 961 (8808, 36 475)	23 379 (10 480, 45 905)	72 936 (47 153, 109 240)	36.1 (20.9, 52.4)
		Range, (min-max)	0-118 881	0-153 235	0-203 569	540-362 295	0-99.1
	90-d	Mean (SD)	9586 (21 295)	35 722 (31 654)	45 308 (39 148)	95 174 (56 840)	44.2 (21.3)
		Median (IQR)	0 (0, 8303)	26 488 (12 537, 49 148)	34 567 (15 324, 64 080)	85 342 (53 127, 125 807)	45 (28.7, 60.5)
		Range, (min-max)	0-143 913	0-181 871	0-264 637	558-386 596	0-99.1
Total	30-d	Mean (SD)	2260 (8985)	8270 (13 006)	10 530 (16 067)	63 358 (41 253)	15 (17.7)
		Median (IQR)	0 (0, 0)	2506 (306, 10 922)	3153 (330, 14 385)	53 518 (35 567, 81 297)	7.1 (0.8, 25.1)
		Range, (min-max)	0-89 868	0-100 928	0-144 377	540-335 297	0-92.9
	60-d	Mean (SD)	4056 (13 122)	17 700 (24 251)	21 757 (28 479)	74 585 (49 438)	24.5 (23.1)
		Median (IQR)	0 (0, 0)	6403 (1120, 25 840)	8959 (1224, 33 002)	62 300 (39 566, 98 261)	18.1 (2.8, 42.8)
		Range, (min-max)	0-130 519	0-154 978	0-203 569	540-397 769	0-99.1
	90-d	Mean (SD)	5962 (16 969)	23 827 (30 948)	29 789 (37 186)	82 617 (56 109)	29.5 (25.2)
		Median (IQR)	0 (0, 0)	9610 (1955, 36 223)	13 666 (2189, 45 980)	68 087 (42 300, 110 638)	25.5 (5, 50.8)
		Range, (min-max)	0-170 164	0-192 940	0-286 316	558-428 182	0-99.4

IQR, interquartile range.

TABLE 5. Discharge Disposition and Readmission Rates by Group

Craniotomy group (n)	Discharge Disposition				Readmission Rates		
	Inpatient rehabilitation facility No. (%)	Skilled nursing facility No. (%)	Long-term care hospital No. (%)	Discharged to a postacute-care facility No. (%)	30-d No. (%)	60-d No. (%)	90-d No. (%)
Unruptured aneurysm (2118)	99 (4.7%)	35 (1.7%)	1 (0.1%)	135 (6.4%)	163 (7.7%)	221 (10.4%)	296 (14%)
Meningioma (4356)	260 (6%)	98 (2.3%)	3 (0.1%)	361 (8.3%)	306 (7%)	409 (9.4%)	489 (11.2%)
Malignant glioma (5304)	425 (8%)	132 (2.5%)	6 (0.1%)	563 (10.6%)	582 (11%)	897 (16.9%)	1195 (22.5%)
Metastasis (3498)	195 (5.6%)	97 (2.8%)	4 (0.1%)	296 (8.5%)	414 (11.8%)	724 (20.7%)	1025 (29.3%)
Total (N = 15276)	979 (6.4%)	362 (2.4%)	14 (0.1%)	1355 (8.9%)	1465 (9.6%)	2251 (14.7%)	3005 (19.7%)

malignant glioma and metastasis, if bundled payment models are extended to cranial operations, it would be reasonable to center episodes of care around disease entities with the goal of capturing the index operation, postoperative adjuvant therapies, and visits to specialists such as oncologists and radiation oncologists under a single bundle.

In our multivariable analysis, medical comorbidities including hypertension, atrial fibrillation, hepatitis B, diabetes mellitus, and chronic kidney disease significantly affected projected bundle payments for craniotomy patients. The arthroplasty literature has also demonstrated that medical comorbidities are associated with significantly higher inpatient costs,[8] which impact total bundle costs,[9] and that internal medicine and psychiatry consults significantly increased bundle costs.[10] We also found that payer status significantly affected projected bundle payments for all 4 groups in 30-, 60-, and 90-d bundles. The arthroplasty literature has also shown that payer status affects bundle reimbursements; however, Medicaid patients had higher mean inpatient costs after knee and hip arthroplasty,[11] whereas our analysis showed that Medicaid patients have lower projected bundle payments in all 4 craniotomy groups. These findings emphasize the importance of patient selection and resource utilization in the context of bundled payments and suggest that selecting healthy patients may reduce bundle costs but potentially at the risk of restricting access of neurosurgical care from sicker patients.

Our group has previously published a study simulating payments of episode-based bundled care for instrumented and noninstrumented spine procedures.[12] As we showed previously in simulating bundle payments for spine procedures, simulated bundle payments for cranial neurosurgical procedure demonstrate significant variability within each operation subtype and between subtypes. Retrospective studies on the first several years of BPCI for spinal fusion procedures show that length of stay was reduced using BPCI in some studies; however, overall episode-based cost and readmission rates were not reduced, possibly because of an increase in case complexity in the BPCI era.[13,14]

So far, BPCI has been shown to decrease costs for joint replacement because of decreased utilization of postoperative services.[15,16] Importantly, there have been unintended consequences of BPCI including shifting rehabilitation and recovery after surgery way from acute rehabilitation or skilled nursing facilities.[6]

If bundled payments are expanded to cranial neurosurgical procedures, we anticipate that targeting hospital readmission, discharge destination, and reducing venous thrombo-embolism will be important in reducing total costs for bundled episodes of care. In fact, other authors have previously identified hospital readmission and ICU length of stay as significant drivers of cost following craniotomy procedures, with each readmission after brain tumor surgery estimated to add $ 20,296 in hospital charges.[17,18] Novel pilot programs designed to identify craniotomy patients who can be sent to a step-down in lieu of the intensive care unit have yielded cost savings.[19] Unlike spine operations, which demonstrate relatively flat bundle prices across 30-, 60-, and 90-d time-points, patients undergoing craniotomy for malignant glioma and metastasis experience high readmission rates and overall payments between 30 and 90 d, likely because of the need for adjuvant treatment and higher complication rates inherent to these patients. If bundled payments are expanded to cranial neurosurgery, opting for 30-d bundles may reduce the need to account for the high volume of care required by these patients more than 30 d after surgery.

Limitations

There are multiple limitations to the current study. Our analysis provides projected values of payments for elective cranial operations, which would not be an accurate estimate for emergent craniotomy, particularly in the setting of ruptured aneurysms. Projections of payments for ruptured aneurysms would require a separate analysis utilizing ruptured aneurysm diagnosis codes. Moreover, though we provide the first projected analysis of episode of care bundled payments for 4 major classes

TABLE 6. Multivariable Regression of Bundle Cost with Patient Characteristic, Comorbidites, and Opioid Use

	Craniotomy for unruptured aneurysm		
	30-d Percent difference (95% CI)	60-d Percent difference (95% CI)	90-d Percent difference (95% CI)
Age, 10 yr increase	−0.06% (−3.66%, 3.66%)	0.1% (−3.54%, 3.88%)	0.19% (−3.44%, 3.96%)
Gender, female vs male	−0.91% (−7.26%, 5.87%)	−0.38% (−6.85%, 6.53%)	−1.51% (−7.89%, 5.31%)
Insurance			
Medicaid vs commercial	−32.49% (−39.6%, −24.54%)	−33.81% (−40.9%, −25.87%)	−34.38% (−41.43%, −26.47%)
Medicare vs commercial	−31.49% (−39.12%, −22.89%)	−31.3% (−39.06%, −22.55%)	−29.15% (−36.97%, −20.35%)
Discharge disposition			
Postacute-care facility vs home	75.72% (62.27%, 90.28%)	76.96% (63.22%, 91.86%)	72.49% (59.03%, 87.1%)
Other vs home	26.67% (15.85%, 38.51%)	25.2% (14.35%, 37.07%)	25.32% (14.45%, 37.22%)
Readmission, yes vs no	47.07% (36.49%, 58.46%)	53.55% (43.48%, 64.32%)	56.75% (47.22%, 66.89%)
Comorbidities			
Hepatitis B, yes vs no	18.03% (6.93%, 30.28%)	16.28% (5.1%, 28.64%)	16.77% (5.78%, 28.9%)
Atrial fibrillation, yes vs no	15.42% (−0.97%, 34.5%)	11.53% (−5%, 30.95%)	10.27% (−6.21%, 29.66%)
VTE, yes vs no	20.89% (2.87%, 42.07%)	13.61% (−3.98%, 34.42%)	17.4% (−0.62%, 38.69%)
Radiosurgery, yes vs no	21.48% (3.46%, 42.64%)	31.46% (12.89%, 53.1%)	31.99% (13.63%, 53.32%)
Radiation therapy, yes vs no	16.29% (2.99%, 31.31%)	15.12% (1.73%, 30.28%)	17.03% (3.58%, 32.24%)
Opioid use, yes vs no	−9.3% (−14.58%, −3.68%)	−5.97% (−11.33%, −0.28%)	−6.04% (−11.34%, −0.42%)
	Craniotomy for meningioma		
	30-d Percent difference (95% CI)	**60-d Percent difference (95% CI)**	**90-d Percent difference (95% CI)**
Age, 10 yr increase	−1.37% (−3.68%, 0.99%)	−1.49% (−3.77%, 0.85%)	−1.75% (−4.02%, 0.57%)
Gender, female vs male	−3.01% (−7.34%, 1.52%)	−3.37% (−7.61%, 1.06%)	−3.93% (−8.11%, 0.44%)
Insurance			
Medicaid vs commercial	−32.21% (−38.59%, −25.17%)	−32.82% (−39.15%, −25.83%)	−34.01% (−40.24%, −27.13%)
Medicare vs commercial	−27.27% (−32.62%, −21.51%)	−25.62% (−31%, −19.82%)	−25.49% (−30.85%, −19.71%)
Discharge disposition			
Postacute-care facility vs home	38.47% (29.84%, 47.67%)	37.94% (29.53%, 46.9%)	37.02% (28.7%, 45.87%)
Other vs home	17.31% (9.81%, 25.32%)	18.03% (10.6%, 25.95%)	17.79% (10.4%, 25.68%)
Readmission, yes vs no	37.67% (29.83%, 45.98%)	45.18% (37.97%, 52.78%)	48.79% (41.82%, 56.11%)
Comorbidities			
Morbid obesity, yes vs no	3.03% (−7.35%, 14.59%)	2.1% (−8.21%, 13.57%)	0.04% (−10.03%, 11.22%)
Hepatitis B, yes vs no	16.21% (9.48%, 23.35%)	14.84% (8.25%, 21.84%)	13.46% (6.97%, 20.34%)
Cirrhosis, yes vs no	8.54% (−9.03%, 29.51%)	9.91% (−7.29%, 30.3%)	8.04% (−8.87%, 28.08%)
Smoking, yes vs no	−4.55% (−12.36%, 3.96%)	−4.2% (−11.91%, 4.18%)	−3.45% (−11.08%, 4.84%)
Atrial fibrillation, yes vs no	13.52% (2.34%, 25.92%)	13.46% (2.52%, 25.57%)	12.7% (1.84%, 24.72%)
Hyperlipidemia, yes vs no	1.99% (−3.93%, 8.28%)	1.97% (−3.84%, 8.13%)	2.1% (−3.69%, 8.23%)
Diabetes mellitus, yes vs no	5.58% (−0.23%, 11.72%)	5.43% (−0.26%, 11.44%)	4.61% (−1.02%, 10.55%)
VTE, yes vs no	23.29% (8.83%, 39.67%)	24.61% (10.47%, 40.55%)	27.36% (13.46%, 42.97%)
Hypertension, yes vs no	2.26% (−2.1%, 6.8%)	2.51% (−1.8%, 7%)	2.44% (−1.85%, 6.92%)
Radiosurgery, yes vs no	6.07% (1.41%, 10.95%)	6.55% (1.94%, 11.38%)	6.88% (2.27%, 11.69%)
Radiation therapy, yes vs no	13.84% (6.59%, 21.58%)	24.27% (16.91%, 32.09%)	39.92% (32.28%, 48%)
Chemotherapy, yes vs no	−4.98% (−19.14%, 11.67%)	0.13% (−13.66%, 16.11%)	4.84% (−8.32%, 19.88%)

of cranial neurosurgical operations, our study was retrospectively gathered and not randomly collected. Importantly, the database used in this study aggregates data from multiple data source, including commercial claims and encounters, Medicaid, and the Medicare supplement. Given that BPCI is a Medicare program, the data used in this study to project bundled payment payments for cranial operations may under-represent projected bundled values for the Medicare population, which has been shown to have higher hospital payments following brain tumor removal.[20] Nonetheless, given that private insurance payments have been shown to closely follow standards set by Medicare,[21] we believe the projected payments in this study reflect payment trends initiated by Medicare. Furthermore, in our analysis of the effect of comorbidity status on bundle payments

TABLE 6. *continued*

	Craniotomy for malignant glioma		
	30-d Percent difference (95% CI)	60-d Percent difference (95% CI)	90-d Percent difference (95% CI)
Age, 10-yr increase	−0.39% (−2%, 1.25%)	−0.52% (−2.09%, 1.08%)	−0.94% (−2.51%, 0.65%)
Gender, female vs male	−1.63% (−4.78%, 1.63%)	−1.15% (−4.2%, 1.99%)	−1.38% (−4.42%, 1.76%)
Insurance			
Medicaid vs commercial	−37.13% (−43.06%, −30.58%)	−42.86% (−48.73%, −36.33%)	−45.2% (−51.08%, −38.61%)
Medicare vs commercial	−30.59% (−34.94%, −25.94%)	−30.69% (−34.91%, −26.2%)	−30.16% (−34.39%, −25.67%)
Discharge disposition			
Postacute-care facility vs home	41.57% (35.45%, 47.97%)	33.1% (27.42%, 39.04%)	31.1% (25.49%, 36.95%)
Other vs home	19.46% (13.55%, 25.67%)	15.43% (9.85%, 21.29%)	14.1% (8.54%, 19.95%)
Readmission, yes vs no	32.33% (27.03%, 37.84%)	28.25% (23.83%, 32.84%)	32.53% (28.28%, 36.93%)
Comorbidities			
Hepatitis B, yes vs no	7.64% (2.43%, 13.12%)	7.01% (2.08%, 12.17%)	6.8% (1.92%, 11.91%)
Hyperlipidemia, yes vs no	−0.32% (−5.36%, 4.99%)	−1.18% (−5.95%, 3.84%)	−1.52% (−6.28%, 3.48%)
Diabetes mellitus, yes vs no	3.89% (−1.3%, 9.36%)	0.74% (−4.17%, 5.91%)	−0.03% (−4.94%, 5.12%)
VTE, yes vs no	28.61% (17.49%, 40.79%)	24.36% (13.54%, 36.22%)	20.7% (9.85%, 32.61%)
Hypertension, yes vs no	0.62% (−2.93%, 4.29%)	1.5% (−1.91%, 5.02%)	0.71% (−2.67%, 4.21%)
Radiosurgery, yes vs no	10.39% (6.63%, 14.28%)	13.68% (9.97%, 17.52%)	17.12% (13.31%, 21.05%)
Radiation therapy, yes vs no	20.37% (15.5%, 25.45%)	44.32% (38.11%, 50.8%)	50.04% (43.37%, 57.03%)
Chemotherapy, yes vs no	3.3% (−0.39%, 7.13%)	6.29% (2.58%, 10.15%)	6.93% (3.15%, 10.85%)
Opioid use, yes vs no	−1.39% (−4.96%, 2.31%)	0.47% (−2.83%, 3.88%)	1.45% (−1.79%, 4.8%)
	Craniotomy for metastasis		
	30-d Percent difference (95% CI)	**60-d Percent difference (95% CI)**	**90-d Percent difference (95% CI)**
Age, 10 yr increase	−3.79% (−6.21%, −1.3%)	−3.69% (−6.04%, −1.29%)	−3.66% (−6%, −1.26%)
Gender, female vs male	1.3% (−2.74%, 5.51%)	0.64% (−3.27%, 4.72%)	−0.33% (−4.19%, 3.69%)
Insurance			
Medicaid vs commercial	−42.06% (−48.3%, −35.07%)	−43.82% (−49.92%, −36.98%)	−47.01% (−53.1%, −40.14%)
Medicare vs commercial	−18.89% (−24.45%, −12.92%)	−18.89% (−24.4%, −12.99%)	−20.7% (−26.09%, −14.91%)
Discharge disposition			
Postacute-care Facility vs home	27.82% (20.05%, 36.09%)	22.61% (15.09%, 30.61%)	20.4% (12.89%, 28.42%)
Other vs home	17.39% (10%, 25.28%)	15.7% (8.51%, 23.37%)	15.73% (8.53%, 23.4%)
Readmission, yes vs no	39.39% (32.87%, 46.22%)	40.51% (34.85%, 46.4%)	37.38% (32.09%, 42.88%)
Comorbidities			
Hepatitis B, yes vs no	15.76% (9.04%, 22.89%)	15.41% (8.87%, 22.34%)	14.18% (7.71%, 21.04%)
Obesity, yes vs no	−0.97% (−11.07%, 10.29%)	2.01% (−7.86%, 12.95%)	3.47% (−6.45%, 14.45%)
Smoking, yes vs no	−0.76% (−7.03%, 5.94%)	1.02% (−5.06%, 7.5%)	−0.03% (−6.09%, 6.43%)
Chronic kidney disease, yes vs no	1.23% (−21.55%, 30.62%)	4.85% (−16.67%, 31.93%)	2.71% (−18.81%, 29.93%)
VTE, yes vs no	27.72% (14.87%, 42.02%)	24.87% (12.16%, 39.02%)	22.06% (9.31%, 36.3%)
Radiosurgery, yes vs no	14.93% (10.27%, 19.79%)	19.5% (14.74%, 24.45%)	20.32% (15.53%, 25.3%)
Radiation therapy, yes vs no	15.04% (9.36%, 21.02%)	20.98% (14.89%, 27.4%)	19.45% (13.43%, 25.8%)
Chemotherapy, yes vs no	6.9% (2.72%, 11.25%)	12.66% (8.36%, 17.13%)	19.61% (15.04%, 24.37%)
Opioid use, yes vs no	−2.33% (−6.39%, 1.9%)	−1.66% (−5.46%, 2.3%)	−0.15% (−3.98%, 3.82%)

VTE, venous thrombo-embolism.

we could not differentiate between payments for comorbidity-associated complications and payments for routine care for a given comorbidity, which is an inherent limitation of the database approach.

CONCLUSION

Bundled episode of care payments have been introduced in spine, orthopedic, general, and cardiac surgery but have not yet been applied to cranial neurosurgical operations. For the first time, we retrospectively analyzed 15 276 episodes of care from a large administrative database to generate projected 30-, 60-, and 90-d bundled payments for 4 major classes of cranial operations in tumor and vascular neurosurgery. Unlike our prior analysis of projected bundle payments for spine operations, we demonstrate that postdischarge care contributes significantly to total cranial bundle payments, with 29.5% of total bundle payments for all operations attributed to postdischarge care in 90-d bundles. Medical comorbidities, payer status, and adjuvant therapies significantly impacted total bundle payments for cranial neurosurgical procedures. Moving forward, bundled care payment systems need to be studied rigorously before they are applied to cranial neurosurgery, which is inherently heterogenous and involves complex patients.

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Greenwald AS, Bassano A, Wiggins S, Froimson MI. Alternative reimbursement models: bundled payment and beyond: AOA critical issues. *J Bone Joint Surg Am*. 2016;98(11):e45.
2. Joynt Maddox KE, Orav EJ, Zheng J, Epstein AM. Evaluation of medicare's bundled payments initiative for medical conditions. *N Engl J Med*. 2018;379(3):260-269.
3. Dalzell MD. CMS opens window for BPCI advanced but target prices are still behind the curtains. *Manag Care (Langhorne, Pa)*. 2018;27(3):17-19.
4. Hansen LG, Chang S. Health research data for the real world: the Thomson Reuters marketscan databases. *The MarketScan Databases (White Papers)*. 2012.
5. McLawhorn AS, Buller LT. Bundled payments in total joint replacement: keeping our care affordable and high in quality. *Curr Rev Musculoskelet Med*. 2017;10(3):370-377.
6. Jubelt LE, Goldfeld KS, Blecker SB, et al. Early lessons on bundled payment at an academic medical center. *J Am Acad Orthop Surg*. 2017;25(9): 654-663.
7. Huckfeldt PJ, Mehrotra A, Hussey PS. The relative importance of post-acute care and readmissions for post-discharge spending. *Health Serv Res*. 2016;51(5):1919-1938.
8. Hustedt JW, Goltzer O, Bohl DD, Fraser JF, Lara NJ, Spangehl MJ. Calculating the cost and risk of comorbidities in total joint arthroplasty in the United States. *J Arthroplasty*. 2017;32(2):355-361.e351.
9. Rosas S, Sabeh KG, Buller LT, Law TY, Roche MW, Hernandez VH. Medical comorbidities impact the episode-of-care reimbursements of total hip arthroplasty. *J Arthroplasty*. 2017;32(7):2082-2087.
10. Baumgartner BT, Karas V, Kildow BJ, et al. Inpatient consults and complications during primary total joint arthroplasty in a bundled care model. *J Arthroplasty*. 2018;33(4):973-975.
11. Courtney PM, Edmiston T, Batko B, Levine BR. Can bundled payments be successful in the medicaid population for primary joint arthroplasty? *J Arthroplasty*. 2017;32(11):3263-3267.
12. Ugiliweneza B, Kong M, Nosova K, et al. Spinal surgery: variations in health care costs and implications for episode-based bundled payments. *Spine*. 2014;39(15):1235-1242.
13. Bronson WH, Kingery MT, Hutzler L, et al. Lack of cost savings for lumbar spine fusions after bundled payments for care improvement initiative: a consequence of increased case complexity. *Spine*. 2018;44(4):298-304.
14. Martin BI, Lurie JD, Farrokhi FR, McGuire KJ, Mirza SK. Early effects of medicare's bundled payment for care improvement program for lumbar fusion. *Spine*. 2018;43(10):705-711.
15. Dummit LA, Kahvecioglu D, Marrufo G, et al. Association between hospital participation in a medicare bundled payment initiative and payments and quality outcomes for lower extremity joint replacement episodes. *JAMA*. 2016;316(12):1267-1278.
16. Navathe AS, Troxel AB, Liao JM, et al. Cost of joint replacement using bundled payment models. *JAMA Intern Med*. 2017;177(2):214-222.
17. Donoho DA, Wen T, Babadjouni RM, et al. Predictors of 30- and 90-day readmission following craniotomy for malignant brain tumors: analysis of nationwide data. *J Neurooncol*. 2018;136(1):87-94.
18. Marcus LP, McCutcheon BA, Noorbakhsh A, et al. Incidence and predictors of 30-day readmission for patients discharged home after craniotomy for malignant supratentorial tumors in California (1995-2010). *J Neurosurg*. 2014;120(5):1201-1211.
19. Osorio JA, Safaee MM, Viner J, et al. Cost-effectiveness development for the postoperative care of craniotomy patients: a safe transitions pathway in neurological surgery. *Neurosurg Focus*. 2018;44(5):E19.
20. Zygourakis CC, Liu CY, Yoon S, et al. Analysis of cost variation in craniotomy for tumor using 2 national databases. *Neurosurgery*. 2017;81(6):972-979.
21. Clemens J, Gottlieb JD. In the shadow of a giant: medicare's influence on private physician payments. *J Polit Econ*. 2017;125(1):1-39.

Acknowledgments

The authors acknowledge Dr Loren Baker for his useful comments on the manuscript.

COMMENT

As the Center for Medicare & Medicaid Services (CMS) continues to roll out the Bundled Payments for Care Improvement Advanced (BPCI Advanced) Model of its program for implementing voluntary episode payment models, 33 in-patient episodes, including fusion and non-fusion spine surgeries, have been included. Episodes of care associated with the remainder of neurosurgical procedures are likely to follow.

It is imperative that neurosurgeons take a proactive rather than reactive approach to the determination and administration of fair bundled payments structure for cranial procedures. This study represents the first analysis of projected bundled payments for common elective cranial operations based on data culled from a large national longitudinal commercial claims database. Analysis like these are a crucial exercise that may foreshadow and influence the eventual expansion of bundled payments models put forth by the CMS.

The study estimates typical 30-, 60-, and 90-day costs of open cranial procedures; cost analysis revealed large variance in cost depending on the pathology treated. Similar to experience in spine bundled payments, discharge disposition and readmissions have huge impacts on costs. The authors find that costs for malignant glioma and metastatic cancer include extensive additional costs beyond the surgical episode of care including rehabilitation, radiation, and chemotherapy performed within the 90-day postoperative period.

This granular detail is necessary to ensure that the foundations of neurosurgical bundled payments are sound. This data-driven analysis of costs will aid neurosurgeons and the institutions where they practice and will be instrumental in guiding future bundled payments for elective cranial surgery.

Allen L. Ho
Arjun V. Pendharkar
John K. Ratliff
Stanford, California