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ORIGINAL ARTICLE

Work relative value units and perioperative outcomes in patients undergoing brain tumor surgery

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Abstract

The work relative value unit (wRVU) is a commonly cited surrogate for surgical complexity; however, it is highly susceptible to subjective interpretation and external forces. Our objective was to evaluate whether wRVU is associated with perioperative outcomes, including complications, after brain tumor surgery. The 2006–2014 American College of Surgeons National Surgical Quality Improvement Program database was queried to identify patients ≥ 18 years who underwent brain tumor resection. Patients were categorized into approximate quintiles based on total wRVU. The relationship between wRVU and several perioperative outcomes was assessed with univariate and multivariate analyses. Subgroup analyses were performed using a Current Procedural Terminology code common to all wRVU groups. The 16,884 patients were categorized into wRVU ranges 0–30.83 (4664 patients), 30.84–34.58 (2548 patients), 34.59–38.04 (3147 patients), 38.05–45.38 (3173 patients), and ≥ 45.39 (3352 patients). In multivariate logistic regression analysis, increasing wRVU did not predict more 30-day postoperative complications, except respiratory complications and need for blood transfusion. Linear regression analysis showed that wRVU was poorly correlated with operative duration and length of stay. On multivariate analysis of the craniectomy subgroup, wRVU was not associated with overall or respiratory complications. The highest wRVU group was still associated with greater risk of requiring blood transfusion (OR 3.01, $p < 0.001$). Increasing wRVU generally did not correlate with 30 days postoperative complications in patients undergoing any surgery for brain tumor resection; however, the highest wRVU groups may be associated with greater risk of respiratory complications and need for transfusion. These finding suggests that wRVU may be a poor surrogate for case complexity.

Keywords Brain tumor · Postoperative complications · Surgery · Work relative value unit

Introduction

The Resource-Based Relative Value Scale was developed by the Centers for Medicare and Medicaid Services to quantify physicians' total work on particular service or procedure, where total work was defined as time and intensity expended during pre-, intra-, and post-service [7, 9, 10]. The meaning of the scale changed in 1992 when the US Health Care Financing Administration began to use it as a medium of monetary conversion, from which physicians' compensations for Medicare services were determined [9]. It is now better known as work relative value unit (wRVU), with higher units generally receiving greater reimbursements under the fee-for-service model. Because of the lack of a common denominator that quantifies complexity of procedures across surgical subspecialties, wRVU has been cited frequently as a surrogate for surgical complexity [16, 17, 27]. However, wRVU determination is highly susceptible to subjective interpretation by the American Medical Association Relative Value Scale Update Committee and external forces set by Medicare budget restrictions and resource allocations [2]. In addition, without understanding the nuances of each procedure and amount/intensity of work required for management of each surgical pathology, wRVU may not

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necessarily represent the actual surgical complexity. Therefore, although it is generally accepted that increasing surgical complexity may be associated with more complications, longer operations, and increased length of stay (LOS), in fact, few studies have evaluated whether the wRVU measurement, as a surrogate for surgical complexity, is actually associated with these perioperative outcomes [21, 25]. We sought to explore this relationship in patients who underwent neurosurgical procedures for brain tumor resection by using the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database.

Materials and methods

ACS-NSQIP participant use data file

The ACS-NSQIP is a prospective, risk-adjusted national surgical outcomes data registry that contains demographic and clinical information for > 4.5 million patients [3, 14, 15]. The information is collected from > 600 sites across the country, making this database one of the most robust registries available to clinicians. Patient data are tracked for a 30-day window after the index procedure. To ensure data reliability, regular audits are performed with reported interrater disagreement rate of 1.56% [26]. The granularity of the database has been validated [24]. Because the data are deidentified in the database, institutional review board approval is not needed for its use. The procedures followed were in accordance with the ethical standards of the research on humans.

Patient selection and stratification

Using the primary Current Procedural Terminology (CPT) codes, we retrospectively queried the 2006–2014 ACS-NSQIP database and identified patients who underwent resection of all types of brain tumors (primary/secondary, benign/malignant, supratentorial/infratentorial, convexity/skull base). We excluded patients who were < 18 years of age, who had missing variables, or who underwent emergency procedures. Because some proportion of the patients underwent additional procedures besides the index procedure (e.g., osteotomies for skull base procedures, complex duraplasty, cranioplasty, fat/fascia grafts, complex closure), total wRVU for each patient was calculated by adding wRVU for the index procedure and all associated additional procedures and technologies (e.g., intraoperative magnetic resonance imaging/microscope/ultrasound). The patients were then subdivided into approximate quintiles based on wRVU. The five groups consisted of wRVU ranges of 0–30.83 (group 1), 30.84–34.58, 34.59–38.04, 38.05–45.38, and ≥ 45.39 (group 5). These ranges were chosen to most evenly distribute the patients into approximate quintiles and to improve risk stratification among the wRVU groups. For instance, CPT code 61,510, which was the most commonly performed procedure for the lower wRVU groups (group 1 and 2), had an wRVU assignment of 30.83. Therefore, the range of the wRVU for group 1 was designated as 0–30.83. Any additional procedures performed would increase the total wRVU, prompting those patients to fall under higher wRVU groups.

Study demographics and outcomes

Baseline differences in patient demographics, comorbidities, and operative characteristics were compared and potential confounders were identified across the wRVU groups. The primary outcomes of interest in this study were 30-day complication rates, length of hospital stay (LOS), operative duration, and reoperation. Complications were classified as overall, surgical, or medical. To account for any procedural confounding, a separate subgroup analysis was performed using a principal CPT code that was common to all wRVU groups (i.e., 61,510, supratentorial craniectomy for excision of brain tumor, except meningioma). Any differences in total wRVU in this CPT were due to additional procedures or surgical tools. In general, additional procedures performed were high in wRVU (e.g., osteotomies), whereas additional technologies used were low in wRVU (e.g., intraoperative microscope).

Statistical analysis

IBM SPSS Statistics v24 (IBM Corp., Armonk, NY) was used to perform all descriptive and comparative statistics. Significance was defined at $p < 0.05$. Categorical variables were analyzed by using the Pearson χ^2 test. Continuous variables were analyzed by using the one-way analysis of variance test. To assess the increasing wRVU as an independent risk factor for 30-day postoperative complications, multivariate logistic regression models were constructed while adjusting for screened covariates ($p < 0.2, \geq 10$ occurrences). The C-index was calculated for each regression model to measure its discriminative capacity. Linear regression was performed to assess relationship of increasing wRVU with respect to LOS and operative duration.

Results

Patient population

A total of 16,884 patients met the inclusion criteria (Fig. 1). The number of patients in each group was 4664, 2548, 3147, 3173, and 3352, respectively. The demographic profile differed significantly among the cohorts

(Table 1). Group 5 was the youngest, with a mean age of 54 years, whereas group 3 was the oldest (mean age 57 years, $p < 0.001$). There was a higher proportion of males in groups 1–2 compared with groups 3–5 ($p < 0.001$). In general, the medical comorbidities and operative characteristics were also significantly different among the groups, with groups 1–2 carrying higher rates of comorbid conditions (Table 1). Groups 1–2 had a greater percentage of patients who were smokers ($p = 0.045$); had a history of chronic obstructive pulmonary disease ($p < 0.001$), disseminated cancer ($p < 0.001$), or chronic steroid use ($p < 0.001$); had > 10% weight loss in past 6 months ($p < 0.001$); and had received chemotherapy within 30 days of admission ($p < 0.001$). In addition, a higher proportion of group 1 patients demonstrated dependent status ($p < 0.001$); had previous coronary procedures ($p = 0.023$), impaired sensorium ($p < 0.001$), history of paralysis ($p \leq 0.001$), and history of radiotherapy within 30 days ($p < 0.001$); and were designated American Society of Anesthesiologists (ASA) grade 4 or 5 ($p < 0.001$). The mean LOS was longest for group 5 (7.3 ± 8.2 days) and shortest for group 3 (5.9 ± 7.3 days, $p < 0.001$). The total operative duration increased in a stepwise fashion as the wRVU increased (174 to 306 min, $p < 0.001$).

CPT code distribution

As the principal procedure, the vast majority of patients underwent craniectomy for supratentorial brain mass that was not meningioma (CPT 61,510) (Table 2), including over 94% of the patients in groups 1 and 2. Patients who underwent surgery for supratentorial brain mass, including meningioma, comprised a large part of group 3 (50.3%). Groups 4 and 5 consisted of greater proportion of patients who underwent surgery for infratentorial mass lesions and/or skull-base lesions.

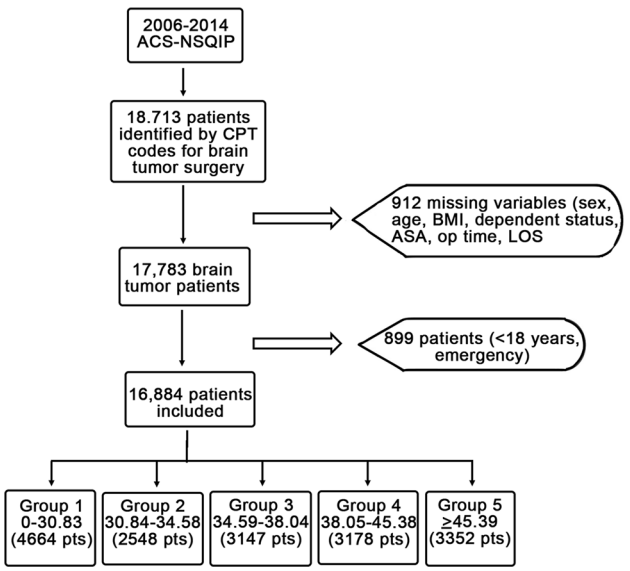

Fig. 1 Patient attrition diagram. The 16,884 patients who were included were subdivided into approximate quintiles based on total wRVU units. The quintile ranges were determined to ensure most even distribution of the patients and to best discriminate the procedure types across the wRVU groups

30-day complications

The 30 days postoperative complication rates were compared among the groups (Table 3). The overall complication rates ranged from 12.3 to 19.7%. Groups 1 and 2 had the lowest rates of overall complications (12.6 and 12.3%, respectively), whereas groups 3–5 demonstrated increasing complication rates as the wRVU increased ($p < 0.001$). This trend was also seen in surgical ($p = 0.031$) and medical complications ($p < 0.001$). In terms of specific complications, groups 4 and 5 had higher rates of respiratory complications (reintubation, failure to wean ventilator > 48 h) ($p < 0.001$), stroke ($p = 0.001$), bleeding complications requiring transfusions ($p < 0.001$), and sepsis/septic shock ($p = 0.005$). Death and reoperation were statistically significantly different among the wRVU groups; however, there was no correlation between increasing wRVU and increasing rates of death or reoperation.

Subgroup analysis

To minimize procedural variations, a subgroup analysis was performed using one CPT code that was present across all wRVU groups (Table 4). Groups 1–5 included 4388, 2418, 1481, 388, and 549 patients, respectively. Any difference in total wRVU in this subgroup was due to additional procedures performed and CPT modifiers, such as use of operating microscope, intraoperative imaging, fat/fascia graft, cranioplasty, or implantation of intracavitary chemotherapy. Similar to Table 3, the overall complication rates were significantly different among the groups and demonstrated increasing trend across groups 3–5 that was significantly higher for group 5 ($p = 0.014$). The surgical complications did not demonstrate this trend ($p = 0.489$). The medical complication rates were highest in group 5, and only slightly higher in group 4 compared with groups 1–3 ($p = 0.028$). Only respiratory and bleeding complications requiring transfusion were notably high in group 5 ($p = 0.022, < 0.001$, respectively). Death, reoperation, and unplanned readmission showed no statistically significant differences among groups.

Table 1 Patient clinical characteristics

Variables	wRVU					P-value
	Group 1 (0–30.83)	Group 2 (30.84–34.58)	Group 3 (34.59–38.04)	Group 4 (38.05–45.38)	Group 5 ≥ 45.39	
N (%)	4664 (27.6)	2548 (15.1)	3147 (18.6)	3173 (18.8)	3352 (19.9)	
Demographics						
Age (years, mean ± SD)	56 ± 15	56 ± 15	57 ± 15	56 ± 15	54 ± 15	**< 0.001**
BMI (kg/m^2, mean ± SD)	27.8 ± 6.5	28.5 ± 6.5	29.2 ± 7.2	29.1 ± 6.7	29.1 ± 6.7	**< 0.001**
Sex, N (%)						**< 0.001**
Male	2403 (51.5)	1387 (54.4)	1350 (42.9)	1318 (41.5)	1424 (42.5)	
Female	2261 (48.5)	1161 (45.6)	1797 (57.1)	1855 (58.5)	1928 (57.5)	
Race, N (%)						**< 0.001**
White	3498 (75.0)	2013 (79.0)	2417 (76.8)	2417 (76.2)	2487 (74.2)	
Black	265 (5.7)	144 (5.7)	210 (6.7)	255 (8.0)	240 (7.2)	
Asian	129 (2.8)	57 (2.2)	84 (2.7)	81 (2.6)	121 (3.6)	
Other/unspecified	772 (16.6)	334 (13.1)	436 (13.9)	420 (13.2)	504 (15.0)	
Medical comorbidities, N (%)						
Diabetes	533 (11.4)	292 (11.5)	395 (12.6)	396 (12.5)	371 (11.1)	0.219
Current smoker	960 (20.6)	526 (20.6)	571 (18.1)	626 (19.7)	635 (18.9)	**0.045**
Dyspnea	245 (5.3)	130 (5.1)	151 (4.8)	164 (5.2)	132 (3.9)	0.069
Dependent status	352 (7.5)	113 (4.4)	186 (5.9)	169 (5.3)	178 (5.3)	**< 0.001**
Current pneumonia	4 (0.1)	2 (0.1)	1 (0.0)	2 (0.1)	2 (0.1)	0.920
History of COPD	241 (5.2)	145 (5.7)	117 (3.7)	157 (4.9)	106 (3.2)	**< 0.001**
CHF/MI/Angina	21 (0.5)	7 (0.3)	8 (0.3)	13 (0.4)	6 (0.2)	0.211
Previous PCI/CS	76 (1.6)	22 (0.9)	45 (1.4)	42 (1.3)	32 (1.0)	**0.023**
Hypertension	1742 (37.3)	986 (38.7)	1297 (41.2)	1323 (41.7)	1272 (37.9)	**< 0.001**
Renal failure/HD	16 (0.3)	6 (0.2)	8 (0.3)	11 (0.3)	11 (0.3)	0.891
Impaired sensorium	102 (2.2)	18 (0.7)	42 (1.3)	38 (1.2)	32 (1.0)	**< 0.001**
TIA	23 (0.5)	4 (0.2)	17 (0.5)	13 (0.4)	14 (0.4)	0.207
CVA w/wo neurologic deficit	64 (1.4)	23 (0.9)	39 (1.2)	43 (1.4)	42 (1.3)	0.502
Paralysis	174 (3.7)	42 (1.6)	87 (2.8)	69 (2.2)	53 (1.6)	**< 0.001**
Disseminated cancer	1213 (26.0)	627 (24.6)	406 (12.9)	550 (17.3)	489 (14.6)	**< 0.001**
Open wound/wound infection	50 (1.1)	28 (1.1)	31 (1.0)	25 (0.8)	41 (1.2)	0.511
Chronic steroid use	912 (19.6)	491 (19.3)	510 (16.2)	436 (13.7)	416 (12.4)	**< 0.001**
> 10% weight loss in 6 mo	151 (3.2)	68 (2.7)	46 (1.5)	59 (1.9)	68 (2.0)	**< 0.001**
Bleeding disorders	111 (2.4)	48 (1.9)	75 (2.4)	74 (2.3)	51 (1.5)	**0.046**
Chemotherapy within 30 days	81 (1.7)	45 (1.8)	20 (0.6)	28 (0.9)	30 (0.9)	**< 0.001**
Radiotherapy within 30 days	52 (1.1)	14 (0.5)	12 (0.4)	17 (0.5)	16 (0.5)	**< 0.001**
Systemic sepsis	181 (3.9)	86 (3.4)	107 (3.4)	117 (3.7)	97 (2.9)	0.184
Prior operation in 30d	30 (0.6)	10 (0.4)	15 (0.5)	9 (0.3)	13 (0.4)	0.179
Operative details (mean ± SD or N (%))						
Length of hospital stay (days)	6.8 ± 8.0	6.0 ± 6.5	5.9 ± 7.3	6.7 ± 7.4	7.3 ± 8.2	**< 0.001**
Total operative time (minutes)	174 ± 98	187 ± 104	221 ± 126	232 ± 140	306 ± 175	**< 0.001**

Table 1 (continued)

Variables	wRVU					P-value
	Group 1 (0–30.83)	Group 2 (30.84–34.58)	Group 3 (34.59–38.04)	Group 4 (38.05–45.38)	Group 5 ≥ 45.39	
ASA class						**< 0.001**
Class 1	71 (1.5)	23 (0.9)	40 (1.3)	37 (1.2)	89 (2.7)	
Class 2	1173 (25.2)	667 (26.2)	917 (29.1)	908 (28.6)	1109 (33.1)	
Class 3	2800 (60.0)	1627 (63.9)	1915 (60.9)	1900 (59.9)	1889 (56.4)	
Class 4	615 (13.2)	231 (9.1)	274 (8.7)	328 (10.3)	265 (7.9)	
Class 5	5 (0.1)	0 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	

BMI, body mass index; *COPD*, chronic obstructive pulmonary disease; *CHF*, congestive heart failure; *MI*, myocardial infarction; *PCI*, percutaneous coronary intervention; *CS*, cardiac surgery; *HD*, hemodialysis; *TIA*, transient ischemic attack; *CVA*, cerebrovascular accident; *ASA*, American Society of Anesthesiologists

The bold entries indicate *p*-values that reached significance

Table 2 CPT distribution

CPT code (description	wRVU groups, N (%)				
	Group 1	Group 2	Group 3	Group 4	Group 5
	4664 (27.6)	2548 (15.1)	3147 (18.6)	3173 (18.8)	3352 (19.9)
61,500 (Craniectomy; with excision of tumor)	272 (5.8)	22 (0.9)	26 (0.8)	11 (0.3)	25 (0.7)
61,510 (Craniectomy; for excision of brain tumor, supratentorial, except meningioma)	4388 (94.1)	2418 (94.9)	1481 (47.1)	388 (12.2)	549 (16.4)
61,512 (Craniectomy; for excision of brain tumor, meningioma, supratentorial)	0 (0.0)	0 (0.0)	1582 (50.3)	1283 (40.4)	402 (12.0)
61,518 (Craniectomy; for excision of brain tumor, infratentorial, except meningioma)	0 (0.0)	0 (0.0)	2 (0.1)	1067 (33.6)	354 (10.6)
61,519 (Craniectomy; for excision of brain tumor, infratentorial, meningioma)	0 (0.0)	0 (0.0)	0 (0.0)	311 (9.8)	271 (8.1)
61,520 (Craniectomy; for excision of brain tumor, infratentorial, cerebellopontine angle)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	654 (19.5)
61,521 (Craniectomy; for excision of brain tumor, infratentorial, midline skull base)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	172 (5.1)
61,526 (Craniectomy; for excision of brain tumor, transtemporal, cerebellopontine angle)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	154 (4.6)
61,545 (Craniotomy for excision of craniopharyngioma)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	98 (2.9)
61,546 (Craniotomy for excision of pituitary tumor, intracranial approach)	0 (0.0)	80 (3.1)	12 (0.4)	19 (0.6)	14 (0.4)
61,575 (Transoral approach to skull base)	0 (0.0)	0 (0.0)	7 (0.2)	0 (0.0)	3 (0.1)
61,582 (Craniofacial approach to anterior cranial fossa, extradural)	0 (0.0)	0 (0.0)	12 (0.4)	0 (0.0)	14 (0.4)
61,583 (Craniofacial approach to anterior cranial fossa, intradural)	0 (0.0)	0 (0.0)	0 (0.0)	32 (1.0)	65 (1.9)
61,591 (Infratemporal post-auricular approach to midline cranial fossa)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	19 (0.6)
61,608 (Resection or excision of neoplastic lesion in parasellar area)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	105 (3.1)
61,616 (Resection or excision of neoplastic lesion in base of posterior fossa)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	159 (4.7)

Multivariate analysis

To assess whether wRVU independently predicts 30-day complications, multivariate logistic regression models were constructed for each outcome of interest (Table 5). After controlling for identified pre/intraoperative variables, increasing wRVU was not associated with increasing overall, surgical, or medical complications nor with some of the specific complications studied, including stroke, death, and reoperation. However, increasing wRVU, specifically group

Table 3 Association of increasing RVU with 30-day outcomes

30 days postoperative variables	wRVU group					*p*-value
	Group 1	Group 2	Group 3	Group 4	Group 5	
N (%)	4664 (27.6)	2548 (15.1)	3147 (18.6)	3173 (18.8)	3352 (19.9)	
Overall complications	589 (12.6)	314 (12.3)	476 (15.1)	530 (16.7)	659 (19.7)	**< 0.001**
Surgical complications	93 (2.0)	41 (1.6)	68 (2.2)	75 (2.4)	93 (2.8)	**0.031**
Superficial SSI	26 (0.6)	16 (0.6)	25 (0.8)	20 (0.6)	24 (0.7)	0.761
Deep SSI	25 (0.5)	7 (0.3)	8 (0.3)	15 (0.5)	24 (0.7)	**0.040**
Organ/space SSI	40 (0.9)	19 (0.7)	30 (1.0)	36 (1.1)	41 (1.2)	0.288
Wound dehiscence	8 (0.2)	4 (0.2)	5 (0.2)	10 (0.3)	10 (0.3)	0.440
Medical complications	530 (11.4)	294 (11.5)	426 (13.5)	488 (15.4)	609 (18.2)	**< 0.001**
Respiratory complications	140 (3.0)	100 (3.9)	104 (3.3)	**168 (5.3)**	**238 (7.1)**	**< 0.001**
PE/DVT	141 (3.0)	86 (3.4)	115 (3.7)	99 (3.1)	110 (3.3)	0.612
Renal complications	9 (0.2)	5 (0.2)	10 (0.3)	3 (0.1)	10 (0.3)	0.306
MI/cardiac arrest	27 (0.6)	10 (0.4)	13 (0.4)	21 (0.7)	20 (0.6)	0.526
Stroke	53 (1.1)	35 (1.4)	43 (1.4)	**55 (1.7)**	**77 (2.3)**	**0.001**
Coma > 24 h	1 (< 0.01)	1 (< 0.01)	5 (0.2)	3 (0.1)	9 (0.3)	**0.013**
UTI	123 (2.6)	50 (2.0)	62 (2.0)	73 (2.3)	78 (2.3)	0.267
Bleeding/transfusion	120 (2.6)	67 (2.6)	155 (4.9)	**191 (6.0)**	**291 (8.7)**	**< 0.001**
Peripheral nerve injury	1 (< 0.01)	0 (0.0)	2 (0.1)	2 (0.1)	0 (0.0)	0.370
Sepsis/septic shock	97 (2.1)	42 (1.6)	59 (1.9)	76 (2.4)	99 (3.0)	**0.005**
Death	162 (3.5)	87 (3.4)	**60 (1.9)**	87 (2.7)	90 (2.7)	**0.001**
Reoperation	83 (1.8)	28 (1.1)	37 (1.2)	49 (1.5)	61 (1.8)	**0.048**
Unplanned readmission	408 (8.7)	266 (10.4)	278 (8.8)	288 (9.1)	325 (9.7)	0.124

Boldface type denotes a statistically significant value, $p < 0.05$

SSI, surgical site infection; *PE*, pulmonary embolism; *DVT*, deep vein thrombosis; *MI*, myocardial infarction; *UTI*, urinary tract infection

5, had greatest odds of developing respiratory complications (OR 1.682, $p < 0.001$). Groups 3, 4, and 5 also demonstrated that increasing wRVU may be an independent predictor of bleeding complications that require transfusions. Multivariate analysis of the subgroup (CPT 61,510) revealed that increasing wRVU was not associated with increasing complications in overall complications or respiratory complications. However, increasing wRVU was associated with bleeding complications in group 5 only (Table 6). C-indices ranged from 0.629 to 0.793, which demonstrated adequate to good discrimination.

Operative duration and LOS

Linear regression model demonstrated that increase in wRVU was correlated with an increase in operative duration ($\beta = 2.691$, $p \leq 0.001$) (Table 7); however, the wRVU only accounted for 12.8% of the variability in operative duration ($R^2 = 0.128$). In addition, the wRVU was inversely correlated with the LOS ($\beta = 0.1$, $p = 0.002$), however, with poor correlation ($R^2 = 0.001$).

Discussion

The definition of the wRVU has evolved and now includes several components in its total calculation: (1) the physician's work (estimate of time to perform the service pre-, intra-, postoperative; technical skills; physical/mental effort; clinical judgment; and stress) [18]; (2) the practice expense (operating and systems expenses); (3) the malpractice estimate (risk associated with procedures); and (4) the geographic practice cost [23]. Some of these factors are attributable to surgical complexity; however, other factors such as preoperative assessment, practice expense, or geographic variations do not necessarily contribute to surgical complexity. Regardless, the wRVU has now become the standard by which health care reimbursements and physician compensations are made. It is generally accepted that higher wRVU is correlated with greater surgical complexity, and it is commonly cited as a surrogate when evaluating surgical complexity across surgical disciplines. However, there is a paucity of literature that evaluates whether increasing wRVU necessarily correlates with longer surgical time, LOS, or increased postoperative complications [21, 25]. Thus, we sought to explore this relationship using a large, multi-institutional database.

Table 4 Association of increasing RVU with 30-day outcomes for CPT 61,510

30 days postoperative variables	wRVU					*p*-value
	Group 1	Group 2	Group 3	Group 4	Group 5	
N (%)	4388 (47.6)	2418 (26.2)	1481 (16.1)	388 (4.2)	549 (6.0)	
Overall complications	550 (12.5)	299 (12.4)	190 (12.8)	53 (13.7)	**97 (17.7)**	**0.014**
Surgical complications	83 (1.9)	39 (1.6)	33 (2.2)	10 (2.6)	13 (2.4)	0.489
Superficial SSI	23 (0.5)	15 (0.6)	8 (0.5)	3 (0.8)	2 (0.4)	0.915
Deep SSI	22 (0.5)	6 (0.2)	6 (0.4)	2 (0.5)	4 (0.7)	0.465
Organ/space SSI	38 (0.9)	19 (0.8)	17 (1.1)	4 (1.0)	7 (1.3)	0.686
Wound dehiscence	6 (0.1)	3 (0.1)	2 (0.1)	3 (0.8)	1 (0.2)	0.052
Medical complications	**499 (11.4)**	**280 (11.6)**	**166 (11.2)**	**47 (12.1)**	**88 (16.0)**	**0.028**
Respiratory complications	129 (2.9)	93 (3.8)	40 (2.7)	14 (3.6)	**28 (5.1)**	**0.022**
PE/DVT	136 (3.1)	84 (3.5)	57 (3.8)	15 (3.9)	11 (2.0)	0.242
Renal complications	8 (0.2)	5 (0.2)	6 (0.4)	0 (0.0)	4 (0.7)	0.076
MI/cardiac arrest	24 (0.5)	9 (0.4)	7 (0.5)	3 (0.8)	3 (0.5)	0.805
Stroke	52 (1.2)	34 (1.4)	13 (0.9)	4 (1.0)	10 (1.8)	0.416
Coma > 24 h	0 (0.0)	1 (0.0)	2 (0.1)	1 (0.3)	1 (0.2)	0.065
UTI	110 (2.5)	47 (1.9)	22 (1.5)	7 (1.8)	10 (1.8)	0.147
Bleeding/transfusion	112 (2.6)	64 (2.6)	45 (3.0)	13 (3.4)	**53 (9.7)**	**< 0.001**
Peripheral nerve injury	0 (0.0)	0 (0.0)	1 (0.1)	1 (0.3)	0 (0.0)	**0.011**
Sepsis/septic shock	87 (2.0)	39 (1.6)	29 (2.0)	8 (2.1)	13 (2.4)	0.746
Death	152 (3.5)	86 (3.6)	**37 (2.5)**	10 (2.6)	19 (3.5)	0.338
Reoperation	66 (1.5)	26 (1.1)	12 (0.8)	5 (1.3)	9 (1.6)	0.223
Unplanned readmission	392 (8.9)	254 (10.5)	156 (10.5)	33 (8.5)	53 (9.7)	0.163

Boldface type denotes a statistically significant value, $p < 0.05$

SSI, surgical site infection; *PE*, pulmonary embolism; *DVT*, deep vein thrombosis; *MI*, myocardial infarction; *UTI*, urinary tract infection

Our analysis of over 16,000 brain tumor patients across the country revealed that increasing wRVU was not associated with overall/surgical/medical complications, mortality, or reoperations. However, in evaluation of specific medical complications, we found that patients in the higher wRVU groups were more likely to develop respiratory complications and bleeding requiring transfusion. We found a mild correlation between increasing wRVU and length of operative time, but there was an inverse relationship between wRVU and LOS.

Our subgroup analysis, which was performed to minimize procedural variability, only evaluated principal CPT code 61,510 (craniectomy; for excision of brain tumor, supratentorial, except meningioma) with or without CPT modifiers. In this subset of patients, increasing wRVU did not increase the odds of the patient having overall complications, respiratory complications, or transfusion.

Other studies have correlated the wRVU with surgical complexity, but few have attempted to demonstrate such correlation with wRVU and specific patient outcomes [5, 12, 19, 20, 25]. Nguyen et al. [21] analyzed nearly 15,000 patients who underwent plastic surgery procedures to assess the impact of increasing wRVU on surgical outcomes. This study demonstrated that a unit increase in wRVU was associated with a 1.7% increase in the odds of overall complications and 1.0% increase in surgical site complications. Increasing wRVU was also associated with prolonged operative duration, but only 15.6% of the variability was accounted for by the wRVU.

In contrast, Shah et al. [25] demonstrated that the current wRVU assignments poorly correlated with postoperative complications after high-volume general surgical procedures. In their study of over 14,000 patients, wRVU correlated poorly with LOS, operative time, and mortality and correlated moderately with serious adverse events and overall morbidity. Low- to mid-level wRVU correlated poorly with serious adverse events and overall morbidity. In addition, Ramirez et al. [22] found that patient complexity did not correlate with wRVU, particularly in general and vascular surgery.

As inferred from these studies, wRVU may not be an accurate indicator of surgical complexity, and subsequently, perioperative outcomes or postoperative complications, particularly in a clinically relevant manner. Surgical complexity is typically thought to be correlated with longer operations, harder-to-reach anatomical areas, and anatomical areas with higher risk to critical structures. However, these criteria do not always correlate with patient outcomes

Table 5 Multivariate logistic regression analysis

wRVU group	Odds ratio	95% CI	*p*-value
Overall complications			
Group 1			
Group 2	0.975	0.839–1.135	0.746
Group 3	1.039	0.907–1.192	0.579
Group 4	1.138	0.994–1.302	0.060
Group 5	1.130	0.986–1.295	0.078
Respiratory complications			
Group 1			
Group 2	1.336	1.022–1.747	**0.034**
Group 3	0.657	0.941–0.721	0.657
Group 4	1.502	1.182–1.910	**0.001**
Group 5	1.682	1.327–2.132	**< 0.001**
Stroke			
Group 1			
Group 2	1.208	0.783–1.861	0.393
Group 3	0.967	0.641–1.459	0.873
Group 4	1.250	0.848–1.843	0.260
Group 5	1.435	0.980–2.100	0.063
Death			
Group 1			
Group 2	1.107	0.841–1.458	0.467
Group 3	0.631	0.462–0.863	**0.004**
Group 4	0.932	0.706–1.231	0.622
Group 5	1.044	0.784–1.389	0.769
Medical complications			
Group 1			
Group 2	1.034	0.883–1.210	0.679
Group 3	1.007	0.872–1.163	0.920
Group 4	1.130	0.981–1.302	0.089
Group 5	1.116	0.968–1.287	0.131
Surgical complications			
Group 1			
Group 2	0.775	0.534–1.124	0.180
Group 3	1.062	0.770–1.464	0.715
Group 4	1.155	0.844–1.582	0.367
Group 5	1.195	0.874–1.634	0.264
Transfusion			
Group 1			
Group 2	1.028	0.753–1.403	0.861
Group 3	1.542	1.197–1.988	**0.001**
Group 4	1.740	1.362–2.224	**< 0.001**
Group 5	1.843	1.448–2.345	**< 0.001**
Re-operation			
Group 1			
Group 2	0.649	0.419–1.003	0.052
Group 3	0.612	0.411–0.911	**0.016**
Group 4	0.766	0.531–1.107	0.156
Group 5	0.740	0.511–1.070	0.110

The bold entries indicate *p*-values that reached significance

Table 6 Multivariate logistic regression analysis

wRVU group	Odds ratio	95% CI	*p*-value
Overall complications			
Group 1			
Group 2	0.981	0.840–1.145	0.808
Group 3	0.925	0.770–1.112	0.407
Group 4	0.928	0.679–1.269	0.640
Group 5	1.251	0.976–1.605	0.077
Respiratory complications			
Group 1			
Group 2	1.307	0.991–1.724	0.058
Group 3	0.811	0.562–1.172	0.265
Group 4	1.074	0.605–1.905	0.808
Group 5	1.429	0.921–2.216	0.111
Transfusion			
Group 1			
Group 2	1.011	0.733–1.395	0.947
Group 3	0.970	0.672–1.399	0.869
Group 4	0.957	0.521–1.755	0.886
Group 5	3.055	2.115–4.414	**< 0.001**

The bold entries indicate *p*-values that reached significance

Table 7 Linear regression analysis

	β	p-value	R^2
Total wRVU vs. operative duration	2.691	< 0.001	0.128
Total wRVU vs. length of stay	0.1	0.002	0.001

[11]. Neurosurgery is a specialty in which most surgery is performed in difficult-to-reach anatomic areas and in direct apposition to critical organs and structures. Although the wRVU drives neurosurgical reimbursement and is supposed to do so based on the complexity of the case and the work done to treat the patient and the patient's disease, this is not always the case. Our data challenges how risk is implied by the wRVU as it stands now.

In neurosurgical practice, wRVU tend to drive practice patterns such that, all else being equal, neurosurgeons are more likely to choose procedures that have high wRVU but require less time and are less complex to perform when planning a case, thus maximizing their cost-to-benefit ratio [6, 11]. However, it appears that some of the higher wRVU cases do have a higher risk of complications, even though they may be associated with more benign conditions. For example, the highest wRVU group studied including those procedures with wRVU ≥ 45.39 consisted of more

procedures for infratentorial lesions or skull base lesions, whereas groups 1 and 2, with wRVU of 0–34.58 comprised patients undergoing procedures for supratentorial lesions that were not meningiomas, e.g., high-grade glial tumors. We observed that patients in wRVU groups 4 and 5 had greater risk of developing respiratory complications and bleeding complications, possibly because of proximity to critical structures such as the brainstem, the posterior circulation vasculature, the dural venous sinuses, and the lower cranial nerves. This finding is consistent with a study by Flexman et al. [8], who found that infratentorial neurosurgery was an independent predictor of respiratory failure.

One intraoperative factor that has been consistently cited as a predictor of postoperative complications is operative time [1, 4, 13]. In our study, as the wRVU increased, the operative duration also increased in stepwise fashion. However, the wRVU showed poor correlation with operative duration in the linear regression model, and it only accounted for 12.8% of the variability in operative duration. A similar finding was observed by Nguyen et al. [21], who found that wRVU accounted for only 15.6% of variability in operative duration.

Overall, the complexity of cases in neurosurgical practice should be correlated with both the skill required to perform the procedure and the care necessary to resuscitate and rehabilitate that patient postoperatively. This should be reflected in higher wRVU for cases that are at risk for more complications intraoperatively and postoperatively.

Limitations

This is a retrospective cohort study and has all of the limitations inherent to that study type. Although we attempted to minimize confounding by using strict stratification criteria and multivariate analysis, not all confounding can be eliminated. In addition, the use of the ACS-NSQIP database, which is not neurosurgery specific, carries the intrinsic limitation that only the captured variables can be assessed. For example, the database does not capture specific pathology information so types of tumor cannot be assessed. The database also does not capture specific outcomes that are relevant to neurosurgery, such as cerebrospinal fluid leak, tumor size, or electrolyte derangements.

Conclusions

Our study showed that increasing wRVU generally did not correlate with 30-day postoperative complications or LOS in patients undergoing any surgery for brain tumor resection. There was a correlation with increasing wRVU and operative duration, but it was not a strong association. However, the highest wRVU groups may be associated with increasing risk of respiratory complications and need for transfusion. These findings demonstrate that, although wRVU is frequently used as a surrogate for surgical complexity and is thought to be associated with several perioperative outcomes across multiple surgical disciplines, the current wRVU calculation may not adequately represent the risk of postoperative complications in patients with brain tumors.

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Author contributions Study conception: RK; manuscript preparation: RK, JS, RJ, SM; data analysis: RK, MK, SL.

Data availability All relevant data are reported in the paper. Further details are available on request.

Declarations

Ethics approval Institutional review board approval is not needed for the use of this deidentified ACS-NSQIP.

Consent to participate Not applicable.

Consent for publications Not applicable.

Conflict of interest The authors declare no competing interests.

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