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ORIGINAL ARTICLE - BRAIN TUMORS

Adverse events in brain tumor surgery: incidence, type, and impact on current quality metrics

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Abstract

Background The aim of the study was to determine pre-operative factors associated with adverse events occurring within 30 days after neurosurgical tumor treatment in a German center, adjusting for their incidence in order to prospectively compare different centers.

Methods Adult patients that were hospitalized due to a benign or malignant brain were retrospectively assessed for quality indicators and adverse events. Analyses were performed in order to determine risk factors for adverse events and reasons for readmission and reoperation.

Results A total of 2511 cases were enrolled. The 30 days unplanned readmission rate to the same hospital was 5.7%. The main reason for readmission was tumor progression. Every 10th patient had an unplanned reoperation. The incidence of surgical revisions due to infections was 2.3%. Taking together all monitored adverse events, male patients had a higher risk for any of these complications (OR 1.236, 95%CI 1.025–1.490, $p = 0.027$). Age, sex, and histological diagnosis were predictors of experiencing any complication. Adjusted by incidence, the increased risk ratios greater than 10.0% were found for male sex, age, metastatic tumor, and hemiplegia for various quality indicators.

Conclusions We found that most predictors of outcome rates are based on preoperative underlying medical conditions and are not modifiable by the surgeon. Comparing our results to the literature, we conclude that differences in readmission and reoperation rates are strongly influenced by standards in decision making and that comparison of outcome rates between different health-care providers on an international basis is challenging. Each health-care system has to develop own metrics for risk adjustment that require regular reassessment.

Keywords Quality indicators · Brain tumor · Readmission · Reoperation · Surgical site infection

Background

Surgical treatment of brain tumor patients is a high-risk subspecialty in neurosurgery. Over the last decades, surgical outcome has improved as a result of numerous innovations in imaging technology, surgical instrumentation, and medical management [20, 24]. A high level of performance is expected and increasingly scrutinized due to the direct relationship between quality and price of healthcare. Not surprisingly, care administrators are shifting their focus toward analyzing the quality of delivered care [9].

Short-term postoperative complications and adverse events (AEs) are important surgical outcome measures and can be used as a guide for improving quality [5]. It is well-known that surgical AEs can lead to permanent disability, longer length of inpatient stay, or unplanned readmissions, all factors associated with raising health care costs [15, 21, 45]. AEs are in close relationship to quality indicators that are being discussed and used for the field of neurosurgery, ensuring that financial reimbursement is justified by the surgeon's performance. Among these quality indicators, 30 days readmission,

Portions of the content of the paper have not been presented previously.

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reoperation and mortality rates, length of stay (LOS), rates of nosocomial infections, and surgical site infections have been considered [9, 30, 31, 37, 38, 40].

The purpose of this study was to identify AEs in patients with primary and secondary brain tumors and to stratify the AEs according to associated quality indicators. We aimed to analyze the reasons for unplanned neurosurgical readmissions and reoperations and to determine independent predictors for short-term complications and adverse events. When related to the incidences of conditions in cohorts of patients in different services, our data serve to adjust for overall quality adjustment for differing characteristics of patients in different services. Understanding the predictors and outcome rates in a brain tumor center will provide a benchmark for future prevention strategies and will also help in adjusting risks related to patient characteristics, which will differ depending on the type of service being assessed.

Material and methods

All adult patients with the diagnosis of a primary or secondary brain tumor that were hospitalized between January 2013 and June 2017 at the Department of Neurosurgery, University Hospital Münster, Germany, were retrospectively included in this study. Patients with primary and recurrent tumor were included; however, patients that were previously neurosurgically treated in a different institution due to their tumor were excluded from analysis.

Administrative data with baseline characteristics like age, sex, data on admission and surgery, LOS, surgery, ICD-10-GM (International Statistical Classification of Diseases and Related Health Problems, 10th revision, German modification) diagnoses codes were obtained.

Histological diagnoses were subdivided into gliomas, meningiomas, cerebral metastases, sellar tumors, vestibular schwannomas, and others.

Secondary diagnoses were classified according to the 19 items from the Charlson Comorbidity Index (CCI) items (Table 1) [7]. The age-adjusted CCI was calculated as described before [7, 8]. Only diagnoses present on admission were considered part of the patient's preadmission comorbidity profile. All adverse events (infections, CSF-leakage, postoperative hemorrhage, residual tumor, hydrocephalus, neurological deterioration, medical complications) occurring during the inpatient stay were extracted from the data and merged into the different categories of quality metrics.

The primary outcomes of interest in this study were 30 days unplanned reoperation rates, 30 days unplanned readmission rates, 30 days mortality rates, LOS, and nosocomial and surgical site infections. These indicators have previously been considered as quality indicators [9, 30, 31, 37, 38, 40].

Data on all neurosurgical *readmissions* and *reoperations* were obtained. Only unplanned readmissions and reoperations were included. Reasons for these events were extracted from the electronical medical records and classified into the following categories:

For readmissions:

- CSF-leakage (including subcutaneous CSF collections)
- Postoperative hemorrhage
- Tumor progression
- Hydrocephalus
- Surgical site infection
- Medical reasons, neurological deterioration, seizures

For reoperation:

- CSF-leakage
- Postoperative hemorrhage
- Residual tumor/second look surgery
- Tumor progression, hydrocephalus
- Surgical site infections
- Postoperative coma and others.

Indication for reoperation for postoperative hematomas was space-occupying mass, new neurological deficit, and impaired vigilance.

Thirty days all-cause mortality was obtained from medical records.

Postoperative surgical site infections were recorded and in superficial incisional, deep incisional, and organ space infections. Nosocomial infections were documented. Infection was defined as the presence of clinical or radiological features with obtained cultures being positive. All patients received 30 min prior to surgery an antibiotic prophylaxis that was repeated every 2 h during surgery. No prolonged antibiotic prophylaxis was used. Early same day mobilization was favored, and urinary catheters were used restrictively and were postoperatively removed at the earliest possible time point.

The LOS was stratified according to the median LOS into ≤ 8 days and extended LOS of > 8 days.

Patients were mainly discharged home. In some cases, patients were referred to other hospitals or rehabilitation centers.

Furthermore, a variable was calculated that represents the presence of any of these events. Analysis was based on cases and was not patient-specific. The study was approved by the local ethic committee.

Statistical analyses

Statistical analyses were performed using the software IBM SPSS Statistics 24.0 (IBM, Armonk, New York, USA). Data was described by standard statistics, using absolute and relative frequencies for categorical variables and median and

Table 1 Baseline characteristics of the 2511 included cases

		n	
Age	Mean, range	55.38	18–94 years
	18–56	1271	50.6%
	< 56	1240	49.4%
Sex	Male	1253	49.9%
	Female	1258	50.1%
Neurosurgical diagnosis	Glioma	1055	42.0%
	Meningioma	519	20.7%
	Metastasis	468	18.6%
	Sellar tumor	279	11.1%
	Vestibular schwannoma	127	5.1%
	Other benign brain tumors	63	2.5%
Treatment	Operative	2257	89.9%
	Conservative	254	10.1%
Secondary diagnoses	Myocardial infarction	6	0.2%
	Congestive heart failure	30	1.2%
	Peripheral arterial disease	15	0.6%
	Cerebrovascular disease	36	1.9%
	Dementia	4	0.2%
	COPD[a]	48	1.9%
	Connective tissue disease	18	0.7%
	Gastric ulcer	11	0.4%
	Liver disease	7	0.3%
	Diabetes	161	6.4%
	Hemiplegia	258	10.3%
	Renal disease	116	4.6%
	Diabetes with end organ damage	27	1.1%
	Tumor	1548	61.6%
	Leukemia	7	0.3%
	Lymphoma	51	2.0%
	Severe liver disease	4	0.2%
	Metastatic solid tumor	457	18.2%
	AIDS[b]	0	0%
Age-adjusted CCI[c]	Median, range	3	0–18 years
	0–3	1382	55.0%
	> 3	1129	45.0%

[a] Chronic obstructive pulmonary disease

[b] Acquired immune deficiency syndrome

[c] Charlson Comorbidity Index

range for continuous variables. Chi-square test and univariate logistic regression modeling were used for categorical and continuous variables, respectively. All factors significant in the bivariate analyses were entered into a multivariable logistic regression model. Odds ratios (ORs) were obtained with corresponding 95% confidence intervals (CIs). In addition, the relative risk (RR) was calculated as previously described [46]. In order to find the proportion of cases for an outcome of interest that can be attributed to a given risk factor among the study population, the attributable risk was calculated, first described in 1953 [27]. We used the risk difference between the exposed and unexposed group, divided by the incidence of the outcome in the exposed group. The log-rank test was used for time to event analyses. A probability value less than 0.05 was considered statistically significant throughout the whole analyses. All reported *p* values are two-sided. We have included not only patients that were operated but patients that were treated conservatively as well to provide the full spectrum of adverse events in daily routine in a brain tumor center.

For calculation of surgery-specific adverse events like reoperation, only cases with a previous surgery were included.

This study was approved by the local ethic committee. Informed consent was obtained via the hospital admission contract from all participants included in the study.

Results

Demographic data

This study included 2511 cases of patients with different malignant and benign primary and secondary brain tumors. The most common diagnosis was glioma (42.0%). Baseline characteristics and the presence of secondary diagnoses can be adapted from Table 1.

Adverse events

The main adverse event were nosocomial infections with 12.1% ($n = 305$) (of which 46.8% [$n = 143$] were surgical site infections or meningitis). CSF leakage occurred in 6.2% ($n = 156$). In total, 3.8% ($n = 95$) of patients experienced postoperative hemorrhage (Table 2).

Outcome variables

We registered 143 unplanned readmissions (5.7%) within 30 days of discharge from index hospitalization. The median time period between discharge and readmission was 8.5 days (range 1–30) and between index surgery and readmission 17 days (range 1–75). Every 10th patient (9.9%, $n = 223$) had an unplanned operation within 30 days after index surgery. The median time period between index surgery and reoperation was 3 days (range 0–30 days) (Fig. 1). Most reoperations occurred during index admission (76.7%, $n = 171$). There were no significant differences between the unplanned reoperation and readmission rates regarding the different tumor entities. The overall mortality rate after 30 days was 1.1%, ($n = 27$) being the highest in patients with cerebral metastases (2.4%, $n = 11$, $p = 0.022$).

Nosocomial infection rates were the highest in patients with cerebral metastasis (16.9%, $n = 79$). The overall surgical site infection rate was 4.1% ($n = 104$). The incidence of surgical revisions due to infections was 2.3%. The median LOS was 8 days (range 1–122 days).

Taken together all these recorded events, 23.7% ($n = 596$) of patients experienced at least one of these complications. Table 3 summarizes the outcome rates based on tumor pathology.

Table 2 Adverse events and complications within 30 days after admission to our brain tumor center

Adverse event	*n* (%)
Nosocomial infection	305 (12.1%)
CSF-leakage	156 (6.2%)
Surgical site infection	104 (4.1%)
Postoperative hemorrhage	95 (3.8%)
Tumor progression	66 (2.6%)
Hydrocephalus	30 (1.2%)
Minor neurological deterioration/seizure	26 (1.0%)
Residual tumor	24 (1.0%)
Medical complications	22 (0.9%)
Postoperative severe neurological deterioration	15 (0.6%)

Reasons for readmission

The most common reason for unplanned readmission within 30 days was tumor progression in 23.1% ($n = 33$) of cases, followed by surgical site infections in 22.4% ($n = 32$) (Fig. 2a). Tumor progression was the main reason for readmission in glioma patients (38.6%, $n = 28$). Among patients with the admission diagnosis of metastasis, meningioma, or vestibular schwannoma, the majority of readmission was for surgical site infections (46.7% ($n = 7$), 42.9% ($n = 12$), and 50.0% ($n = 3$), respectively). The reasons for readmissions among the tumor types were significantly different ($p < 0.001$).

Reasons for reoperation

Reasons for reoperation in the whole patient collective were postoperative hemorrhage (37.7%, $n = 84$), hydrocephalus (11.2%, $n = 25$), surgical site infection (11.7%, $n = 26$), CSF leakage (11.1%, $n = 25$), tumor progression (11.2%, $n = 25$), residual tumor/second look surgery (10.2%, $n = 23$), tumor progression (11.2%, $n = 25$), postoperative coma (6.7%, $n = 15$), and others (4.5%, $n = 10$) (Fig. 2b). In all tumor entities except for other benign brain tumors, postoperative hemorrhage was the main reason for reoperation within 30 days of index surgery. The reasons for reoperations among the tumor types were significantly different ($p = 0.002$).

The reasons for readmission were time dependent (Fig. 3). The shortest median time to reoperation was found in patients with postoperative coma (median 2 days, SE 0.966). The longest interval between index surgery and reoperation was documented in patients with SSI (median 19 days, SE 0.85).

Postoperative hemorrhage

The total occurrence of postoperative hematomas requiring surgery was 3.8% ($n = 95$). Patients with meningiomas had the highest rate of postoperative hemorrhage (4.4%, $n =$

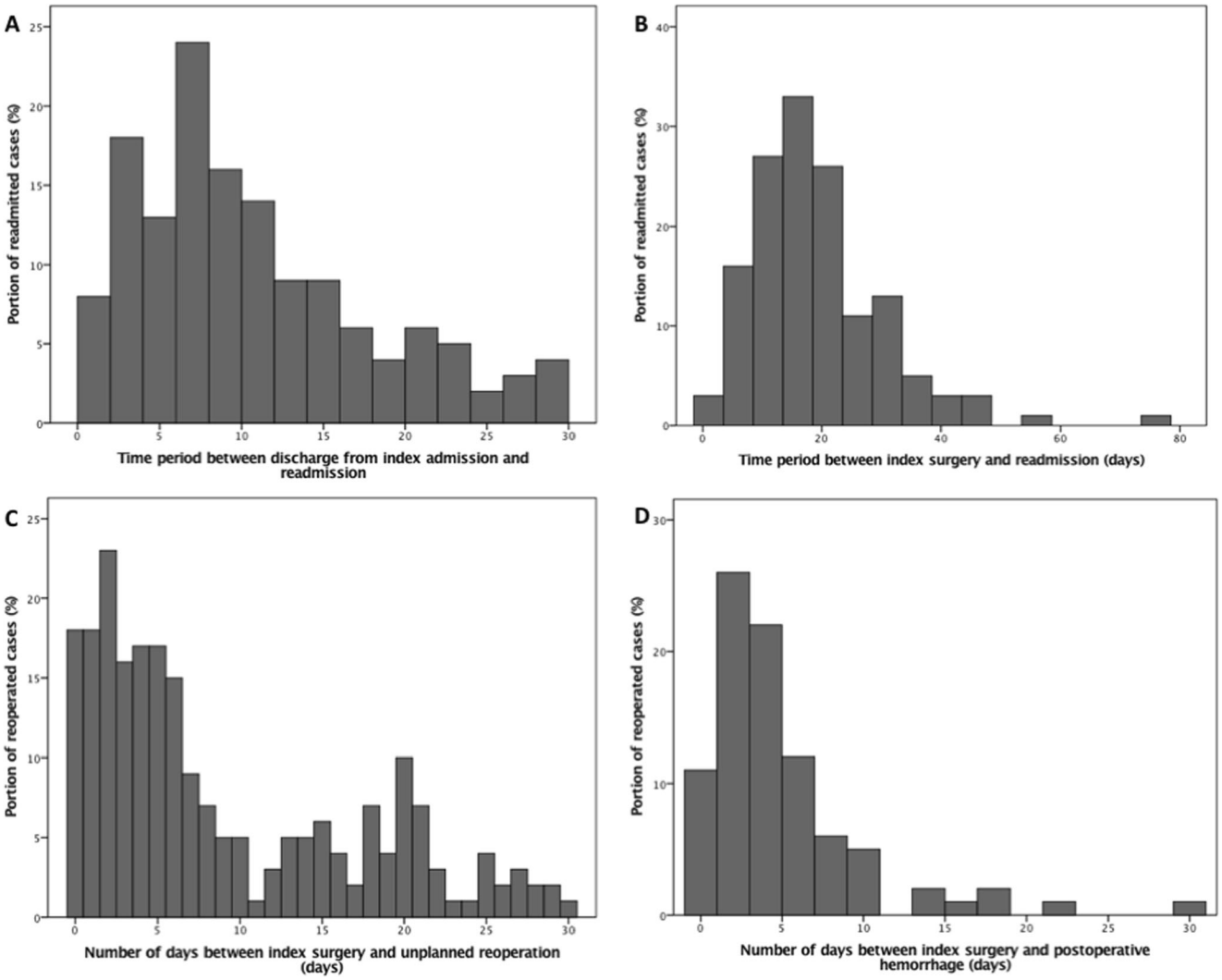


Fig. 1 Time periods between **a** discharge from index admission and readmission in days and **b** between index surgery and readmission presented in cumulative histograms. The median time period in panel **a** was 8.5 days (range 1–30) and in panel **b** 17.0 (range 1–75). **c** The time period between index surgery and reoperation is presented with a median of 6 days (range 0–30). Histogram **d** shows the time period between index surgery and postoperative hemorrhage independently from whether the patient was readmitted for reoperation or reoperation occurred during index admission. The median time was 3 days (range 0–30)

23). However, there were no significant differences regarding the postoperative hematoma rate and tumor pathology ($p = 0.471$). Half of all postoperative hemorrhages manifested within 3 days after index surgery (Fig. 1d).

Nosocomial and surgical site infections

Nosocomial infections occurred in 305 cases (12.1%). Among nosocomial infections, surgical site infections account for the majority of infection (31.5%, $n = 96$), followed by urinary tract infections (23.9%, $n = 73$), pneumonia (19.1%, $n = 58$), meningitis/ventriculitis (12.8%, $n = 39$), shunt infection (2.3%, $n = 7$), sepsis (2.0%, $n = 6$), and others (11.1% $n = 34$).

Among the surgical site infections, 22.3% ($n = 21$) were superficial (SSI grade I), 42.6% ($n = 40$) were deep (SSI grade II), and 35.1% ($n = 33$) affected the brain.

Prognostic factors for outcome

30 days unplanned readmission rate Male patients had higher odds of being readmitted within 30 days after discharge (OR 1.502, 95%CI 1.064–2.121, $p = 0.021$). In addition, younger patients (18–56 years) were at higher risk for unplanned readmission (OR 1774, 95%CI 1.188–2.650, $p = 0.005$) (Table 4).

30 days unplanned reoperation rate Male sex (OR 1.321, 95%CI 1.001–1744, $p = 0.049$), presence of hemiplegia (OR

Table 3 Overview over the outcome rates stratified according to the tumor entity. The reoperation rates refer only to the group of patients operated during the inpatient stay ($n = 2251$), while the remaining rates base on the entire collective ($n = 2511$)

	30 days unplanned readmission rate	30 days unplanned reoperation rate	30 days mortality rate	Nosocomial infection rate	Surgical site infection rate	Length of stay in days (median)	Any event
Glioma	6.8% ($n = 72$)	10.6% ($n = 99$)	1.2% ($n = 13$)	10.3% ($n = 109$)	3.4% ($n = 36$)	8	23.1% ($n = 244$)
Meningiomas	5.4% ($n = 28$)	9.6% ($n = 46$)	0.4% ($n = 2$)	15% ($n = 78$)	9.1% ($n = 47$)	8	24.9% ($n = 129$)
Metastasis	3.2% ($n = 15$)	10.0% ($n = 40$)	2.4% ($n = 11$)	16.9% ($n = 79$)	3.4% ($n = 16$)	9.5	24.4% ($n = 114$)
Sellar tumor	6.1% ($n = 17$)	10.7% ($n = 28$)	0.4% ($n = 1$)	9% ($n = 25$)	0% ($n = 0$)	7	27.2% ($n = 76$)
Vestibular schwannoma	4.7% ($n = 6$)	6.5% ($n = 8$)	0% ($n = 0$)	7.1% ($n = 9$)	3.1% ($n = 4$)	8	17.3% ($n = 22$)
Other benign brain tumors	7.9% ($n = 5$)	3.6% ($n = 2$)	0% ($n = 0$)	7.9% ($n = 5$)	1.6% ($n = 1$)	8	17.5% ($n = 11$)
Total	5.7% ($n = 143$)	9.9% ($n = 223$)	1.1% ($n = 27$)	12.1% ($n = 305$)	4.1% ($n = 104$)	8	23.7 ($n = 596$)
p value	0.114	0.156	0.022	< 0.001	< 0.001	< 0.001	0.234

1.555, 95%CI 1.045–2.313, $p = 0.029$), and leukemia (OR 6.184, 95%CI 1.045–20.338, $p = 0.022$) were factors with patients having an increased risk of returning to the operating room within 30 days.

30 days mortality In univariate analysis, patients with metastasis had a significant higher mortality rate than patients with other brain tumor entities ($p = 0.002$). The risk ratio was 3.001.

Nosocomial infection rate The nosocomial infection rate was significantly influenced by several secondary diagnoses of the patient present at admission. Patients with gastric ulcer had a fourfold higher risk of nosocomial infections (OR 4.106, 95%CI 1.158–14.565, $p = 0.029$). Patients with COPD and renal disease had a more than twofold higher risk of nosocomial infection.

Surgical site infection Patients with meningioma were more likely to suffer a surgical site infection (OR 3.313, 95%CI 1.169–9.386, $p = 0.024$).

LOS Several secondary diagnoses, present at time of admission, were independently associated with longer LOS, with the highest odds of 8.9 for patients with congestive heart failure.

Postoperative hemorrhage Dementia (OR 19.580, 95%CI 2.540–150.913, $p = 0.004$) and diabetes (OR 2.67, 95%CI 1.070–6.675, $p = 0.035$) were associated with increased risk of developing postoperative hematoma.

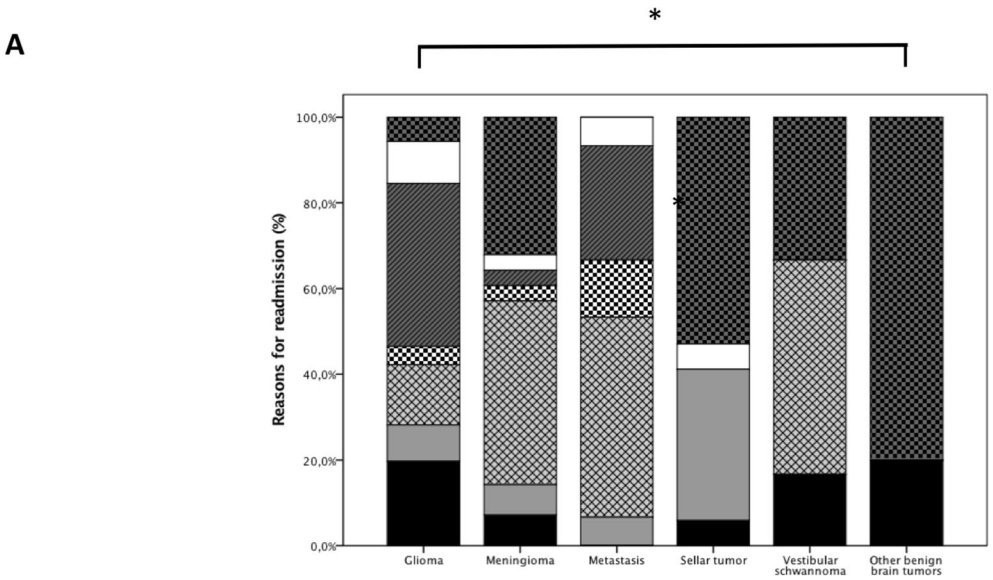
Any complication Taken together all of the monitored adverse events, male patients have a higher risk for any of these complications (OR 1.236, 95%CI 1.025–1.490, $p = 0.027$). Analysis demonstrated that renal disease, hemiplegia, leukemia, and liver disease were predictors of experiencing any complication.

Age-adjusted Charlson Comorbidity Index The age-adjusted CCI was significantly higher in patients that were readmitted within 30 days ($p = 0.045$) and correlated with a higher 30 days mortality rate ($p < 0.001$), a higher nosocomial infection rate ($p < 0.001$), a higher SSI rate ($p = 0.027$), and a longer LOS ($p < 0.001$) in univariate analysis (see Appendix A). However, in multivariate analysis, the CCI only influenced the LOS (Table 4).

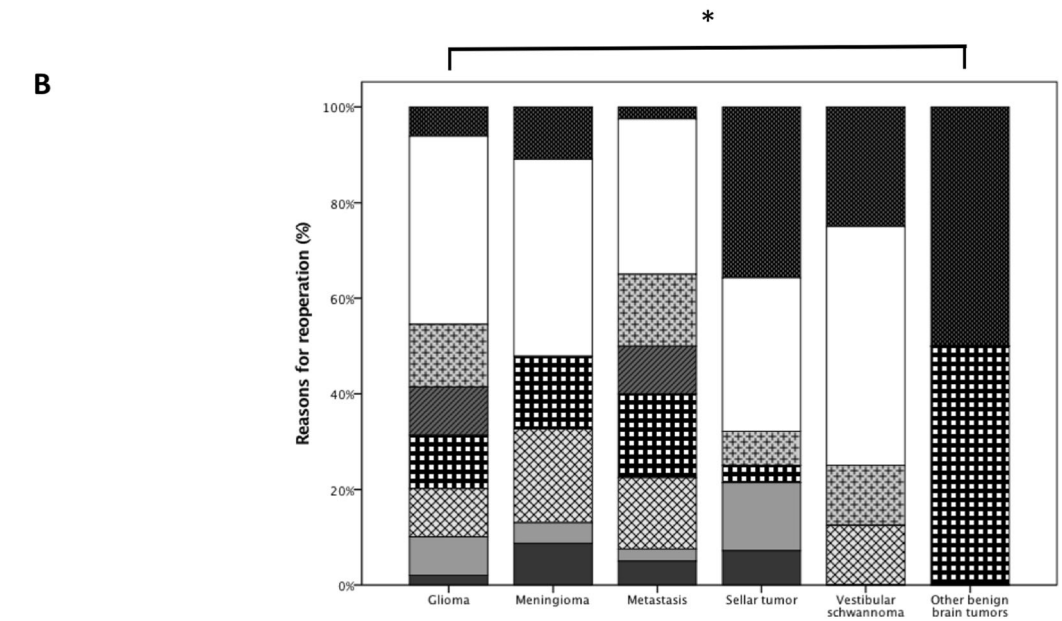
Characteristics with meaningful influence on outcome Based on the prevalence of individual characteristics in our patient cohort, we calculated the relative risks per outcome variable (Table 4). As expected, certain traits with a low prevalence only posed a low (relative) risk to our cohort, e.g., patients with pre-existing leukemia, although having a high odds ratio of 6.184 for unplanned reoperations, the prevalence was low (0.3%). Thus, the relative risk for our specific cohort was low (RR = 1.011).

Characteristics with increased risk ratios greater than 10.0% were male sex (RR 1.257) and age ≤ 56 years (RR 1.382) for unplanned readmission, male sex (RR 1.156) for unplanned reoperation, metastatic solid tumor (RR 1.107) for nosocomial infection, age ≥ 56 years (RR 1.124), age-adj. CCI > 3 (RR 1.215), hemiplegia (RR 1.1) for LOS > 8 days, hemiplegia (RR 1.144) for postoperative hemorrhage, and male sex (RR 1.115) for any complication.

Variables for risk adjustment We found several variables that can be used to perform risk adjustment as shown in Table 5. Cerebral metastasis (RR = 3), secondary diagnoses like congestive heart failure (RR = 6.6), peripheral arterial disease (RR = 6.4), etc., and a CCI of > 3 (RR = 5.8) can be used for risk adjustment for 30 days postoperative mortality. In addition, the attributable risk gives information about the attributable burden to a certain outcome, e.g., congestive heart failure has an attributable risk for 30 days mortality of 85.1%.



	Glioma	Meningioma	Metastasis	Sellar tumor	Vestibular schwannoma	Other benign brain tumors
CSF-leakage	4 (5.6%)	9 (32.1%)	0	9 (52.9%)	2 (33.3%)	4 (80.0%)
Postoperative haemorrhage	7 (9.7%)	1 (3.6%)	1 (6.7%)	1 (5.9%)	0	0
Tumor progression	28 (38.6%)	1 (3.6%)	4 (26.7%)	0	0	0
Hydrocephalus	3 (4.2%)	1 (3.6%)	2 (13.3%)	0	0	0
Surgical site infection	10 (13.9%)	12 (42.9%)	7 (46.7%)	0	3 (50.0%)	0
Medical	6 (8.3%)	2 (7.1%)	1 (6.7%)	6 (35.3%)	0	0
New neurological deficit/ seizure	14 (19.4%)	2 (7.1%)	0	1 (5.9%)	1 (16.7%)	1 (20.0%)



	Glioma	Meningioma	Metastasis	Sellar tumor	Vestibular schwannoma	Other benign brain tumors
CSF leakage	6 (6.1%)	5 (10.9%)	1 (2.5%)	10 (35.7%)	2 (25.0%)	1 (50.0%)
Postoperative hemorrhage	39 (39.4%)	19 (41.3%)	13 (32.5%)	9 (32.1%)	4 (50.0%)	0
Remaining tumor/second look surgery	13 (13.1%)	0	6 (15.0%)	2 (7.1%)	1 (12.5%)	0
Tumour progression	10 (10.1%)	0	4 (10.0%)	0	0	0
Hydrocephalus	11 (11.1%)	7 (15.2%)	7 (17.5%)	1 (3.6%)	0	1 (50.0%)
Surgical site infection	10 (10.1%)	9 (19.6%)	6 (15.0%)	0	1 (12.5%)	0
Postoperative coma	8 (8.1%)	2 (4.3%)	1 (2.5%)	4 (14.3%)	0	0
Others	2 (2.0%)	4 (8.7%)	2 (5.0%)	2 (7.1%)	0	0

Fig. 2 **a** Reasons for readmission and **b** for reoperation stratified according the different tumor entities. The reasons for readmission and reoperation were significant different between the various tumors ($p < 0.001$ and $p = 0.002$, respectively). Asterisk indicates significance

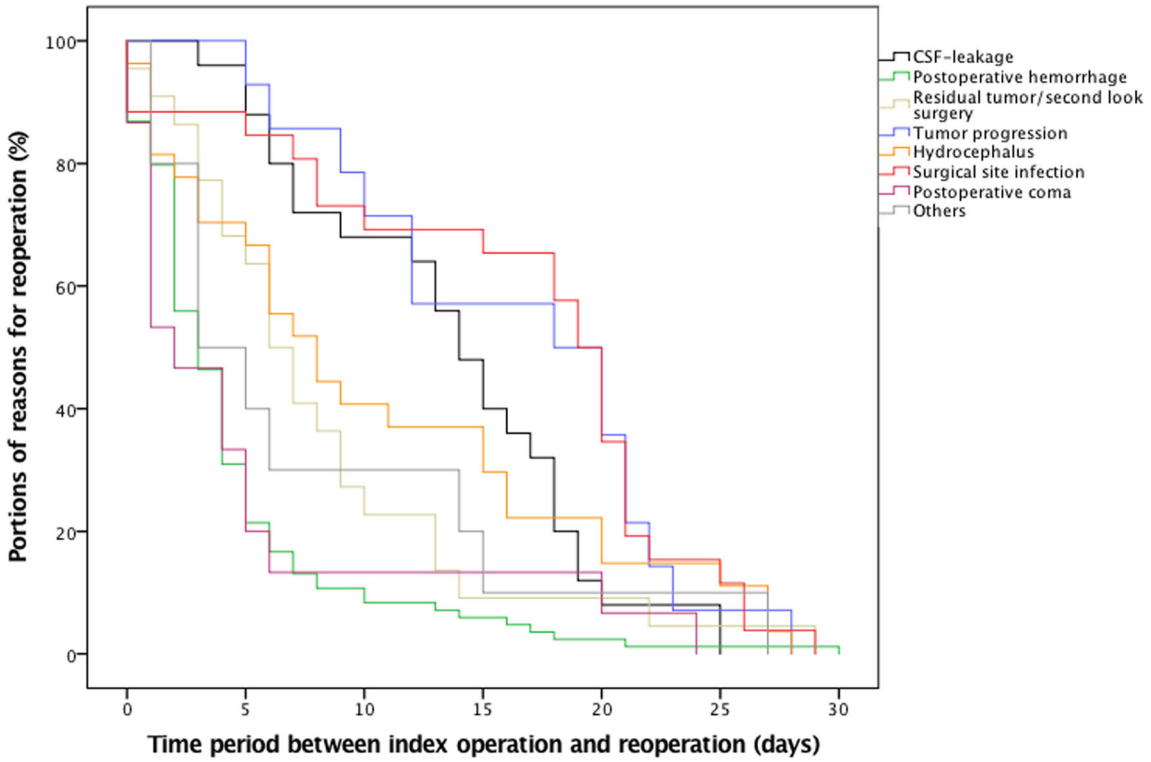


Fig. 3 Time to reoperation stratified according to the reasons for reoperation. Timing of reoperation was significantly associated with reason for reoperation ($p < 0.001$)

Discussion

The incidence of short-term postoperative complications remains high in patients treated for brain tumors despite recent advances in perioperative management. This study provides an overview over the full range of adverse events ions occurring within 30 days after neurosurgical treatment in a German brain tumor center, adjusting them to the current quality measures. In addition, it identifies predictors of these outcome variables.

Several quality indicators have been suggested for neurosurgery, as discussed before [38]. The identification of adverse events directly correlates with the outcome of quality metrics that are currently used and suggested for the field of neurosurgery. Therefore, finding predictors for complications leading to one of the measured quality indicators is very important in order to lower these rates and develop prevention strategies. Importantly, if adequately validated, such predictors, if unevenly distributed between centers, will allow adjusting unequal risks.

Unplanned readmission rates

Thirty days readmission rates have become an important metric for measuring the quality of care as they are a major contributor to high costs in the health care system [28]. In addition, recent studies showed that readmissions are strongly associated with poor survival in glioblastoma patients [14, 33]. We found a 30 days unplanned readmission rate of 5.7% for all tumor patients. Other studies presented data with readmission rates for patients with cranial tumors ranging from 7.5 to 17.3% [12, 14, 28, 31, 33, 41].

The discrepancy between these results might result from differences in study methods and definition of readmission rates. Most studies are based on data from local registries including hospitals in a certain area [28, 31, 33, 42], other studies—as ours—only analyzed readmission to the site of the index procedure [6, 14], whereas only one study analyzed nationwide readmission rates for brain tumor patients [16]. In order to compare readmission rates between hospitals, a homogenous definition of readmission rates is required. In addition, the readmission rate bases on the different services provided, local health policy, and discharge management in different countries. Since the incidence of complications depends on time from surgery (Fig. 1c, d), the length of hospitalization will directly influence readmission rates. Therefore, a shorter LOS (as, e.g., in the USA) might explain higher readmission rates as found in the literature in comparison to our results.

In our collective, 50% of all readmissions occurred within the first 7 days after discharge from index admission and within 17 days after index surgery (Fig. 1).

Consequently, especially the first 3 weeks after surgery are critical for the occurrence of adverse events.

Table 4 Multivariate logistic regression model predicting 30 days unplanned reoperation, readmission, nosocomial infection, length of stay, postoperative hemorrhage, and any complication

		OR	95%CI		*p* value	P (Ref)	RR	95%CI	
30 days unplanned readmission rate included variables: sex, age, and age-adj. CCI									
Sex	Female	Ref				40.8%			
	Male	1.502	1.064	2.121	0.021		1.257	1.037	1.455
Age	18–56	1.774	1.188	2.650	0.005		1.382	1.112	1.652
	> 56	Ref				36.6%			
30 days unplanned reoperation rate included variables: sex, cerebrovascular disease, dementia, hemiplegia, and leukemia									
Sex	female	Ref				44.4%			
	male	1.321	1.001	1.744	0.049		1.156	1.001	1.311
Hemiplegia		1.555	1.045	2.313	0.029	83.9%	1.061	1.006	1.101
Leukemia		6.184	1.045	20.338	0.022	98.7%	1.011	1.001	1.013
Nosocomial infection rate included variables: age, age-adj. CCI, congestive heart failure, cerebrovascular disease, dementia, chronic obstructive pulmonary disease (COPD), gastric ulcer, hemiplegia, renal disease, leukemia, lymphoma, liver disease, and metastatic solid tumor									
COPD		2.421	1.238	4.733	0.010	95.1%	1.03	1.01	1.04
Gastric ulcer		4.106	1.158	14.565	0.029	98.4%	1.012	1.002	1.015
Hemiplegia		1.894	1.304	2.751	0.001	81.0%	1.099	1.046	1.138
Renal disease		2.748	1.727	4.371	<0.001	88.5%	1.079	1.051	1.097
Leukemia		5.882	1.212	28.553	0.028	98.7%	1.011	1.002	1.013
Lymphoma		2.043	1.059	3.941	0.033	95.1%	1.026	1.003	1.038
Metastatic solid tumor		1.564	1.106	2.213	0.011	73.1%	1.107	1.026	1.173
Surgical site infections included variables: age-adj. CCI, neurosurgical diagnosis, and tumor									
Meningioma		3.313	1.169	9.386	0.024	90.9%	1.068	1.013	1.089
Length of stay > 8 days included variables: age, age-adj. CCI, congestive heart failure, peripheral arterial disease, cerebrovascular disease, dementia, gastric ulcer, diabetes, hemiplegia, renal disease, tumor, leukemia, lymphoma, and metastatic solid tumor									
Age	18–56	Ref				43.0%			
	> 56	1.241	1.016	1.515	0.034		1.124	1.009	1.24
Age-adj. CCI	0–3	Ref				41.8%			
	> 3	1.437	1.083	1.905	0.012		1.215	1.047	1.382
Congestive heart failure		8.908	2.054	38.641	0.003	97.4%	1.024	1.014	1.026
Hemiplegia		2.254	1.656	3.070	<0.001	83.6%	1.1	1.069	1.124
Renal disease		1.972	1.268	3.069	0.003	92.5%	1.038	1.016	1.053
Lymphoma		2.340	1.201	4.556	0.012	96.5%	1.02	1.006	1.028
Metastatic solid tumor		1.366	1.054	1.770	0.018	75.8%	1.069	1.013	1.118
Postoperative hemorrhage included variables: age, dementia, connective tissue disease, diabetes, and hemiplegia									
Diabetes		2.67	1.070	6.675	0.035	88.4%	1.077	1.008	1.107
Dementia		19.580	2.540	150.913	0.004	97.9%	1.02	1.013	1.021
Hemiplegia		2.318	1.384	3.884	0.001	77.9%	1.144	1.065	1.196
Connective tissue disease		5.000	1.386	18.035	0.014	96.8%	1.026	1.009	1.031
Any complication included variables: age-adj. CCI, sex, congestive heart failure, cerebrovascular disease, dementia, COPD, gastric ulcer, hemiplegia, renal disease, leukemia, and liver disease									
Sex	Female	Ref				46.0%			
	Male	1.236	1.025	1.490	0.027		1.115	1.013	1.216
Hemiplegia		1.731	1.277	2.347	< 0.001	84.6%	1.07	1.035	1.097
Renal disease		1.684	1.109	2.555	0.014	92.8%	1.03	1.007	1.046
Leukemia		6.894	1.294	36.731	0.024	99.2%	1.007	1.002	1.008
Liver disease		9.937	1.020	96.790	0.048	99.5%	1.005	1.000	1.005

In addition to the OR (odds ratio), the risk ratio (RR) was calculated. There were no significant associations for 30 days mortality rate in multivariate analysis

CI confidence interval, *P (Ref)* prevalence in reference group

Table 5 Risk ratio and attributable risk of different variables regarding the outcome measures

30 days unplanned readmission								
		Readmitted (*n* (%))	Not readmitted (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Age	18–56	90 (63.4%)	1181 (49.9%)	1.689	1.211	2.354	0.002	40.8%
	> 56	52 (36.4%)	1188 (50.1%)					
Sex	Male	84 (59.2%)	1169 (49.3%)	1.454	1.050	2.013	0.023	31.3%
	Female	58 (40.8%)	1200 (50.7%)					
Neurosurgical diagnosis	Glioma	71 (50.0%)	984 (41.5%)	1.380	1.003	1.899	0.047	26.9%
	Metastasis	15 (10.6%)	453 (19.1%)	0.516	0.305	0.872	0.011	− 48.4%
30 days unplanned reoperation								
		Reoperated (*n* (%))	Not reoperated (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Secondary diagnosis	Cerebrovascular disease	8 (3.6%)	28 (1.2%)	2.558	1.370	4.776	0.005	60.8%
	Dementia	2 (0.9%)	2 (0.1%)	5.672	2.112	15.235	0.004	82.4%
	Hemiplegia	36 (16.1%)	187 (8.3%)	1.681	1.205	2.345	0.002	40.7%
	Leukemia	3 (1.3%)	4 (0.2%)	4.878	2.055	11.581	0.002	79.5%
	Ulcer	3 (1.3%)	8 (0.3%)	3.099	1.171	8.202	0.032	67.8%
30 days mortality								
		Died (*n* (%))	Alive (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Neurosurgical diagnosis	Metastasis	11 (40.7%)	457 (18.4%)	3.001	1.402	6.424	0.003	66.7%
Secondary diagnosis	Congestive heart failure	2 (7.4%)	28 (1.1%)	6.616	1.640	26.684	0.003	85.1%
	Peripheral arterial disease	1 (3.7%)	14 (0.6%)	6.400	0.927	44.169	0.035	85.1%
	Cerebrovascular disease	2 (7.4%)	34 (1.4%)	5.500	1.353	22.352	0.009	82.1%
	Hemiplegia	7 (25.9%)	251 (10.1%)	3.056	1.305	7.158	0.007	66.7%
	Tumor	23 (85.2%)	1525 (61.4%)	3.577	1.241	10.312	0.011	73.3%
	Leukemia	1 (3.7%)	6 (0.2%)	13.758	2.154	87.888	0.001	93.0%
	Lymphoma	2 (7.4%)	49 (2.0%)	3.857	0.939	15.852	0.047	74.4%
	Metastatic solid tumor	10 (37.0%)	447 (18.0%)	2.644	1.219	5.736	0.011	72.7%
Age-adj. CCI	0–3	5 (18.5%)	1377 (55.4%)					
	> 3	22 (81.5%)	1107 (44.6%)	5.386	2.046	14.177	< 0.001	78.9%
Nosocomial infection rate								
		Infection (*n* (%))	No infection (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Age	18–56	132 (43.3%)	1139 (51.6%)					
	> 56	173 (56.7%)	1067 (48.4%)	1.343	1.086	1.662	0.006	25.7%
Neurosurgical diagnosis	Glioma	109 (35.7%)	946 (42.9%)	0.768	0.616	0.957	0.018	− 31.1%
	Meningioma	78 (25.6%)	441 (20.0%)	1.319	1.039	1.674	0.024	24.0%
	Metastasis	79 (25.9%)	389 (17.6%)	1.526	1.206	1.931	0.001	34.3%
Secondary diagnosis	Congestive heart failure	10 (3.3%)	20 (0.9%)	2.803	1.671	4.703	< 0.001	64.3%
	Cerebrovascular disease	10 (3.3%)	26 (1.2%)	2.331	1.361	3.989	0.004	57.2%
	Dementia	2 (0.7%)	2 (0.1%)	4.137	1.544	11.085	0.020	75.8%
	COPD	15 (4.9%)	33 (1.5%)	2.654	1.721	4.094	< 0.001	62.3%
	Gastric ulcer	5 (1.6%)	6 (0.3%)	3.788	1.966	7.300	0.001	73.6%
	Hemiplegia	58 (19.0%)	200 (9.1%)	2.051	1.588	2.647	< 0.001	51.1%
	Renal disease	35 (11.5%)	81 (3.7%)	2.676	1.985	3.608	< 0.001	62.6%
	Leukemia	4 (1.3%)	3 (0.1%)	4.754	2.481	9.108	< 0.001	78.9%
	Lymphoma	15 (4.9%)	36 (1.6%)	2.494	1.608	3.867	< 0.001	59.8%
	Severe liver disease	2 (0.7%)	2 (0.1%)	4.135	1.543	11.018	0.020	75.8%
	Metastatic solid tumor	82 (26.9%)	375 (17.0%)	1.653	1.311	2.084	< 0.001	39.1%
Age-adj. CCI	0–3	128 (42.0%)	1254 (56.8%)					
	> 3	177 (58.0%)	952 (43.2%)	1.693	1.367	2.095	< 0.001	40.8%
Surgical site infection rate								
		SSI	No SSI	Risk ratio	95%CI		*p* value	Attributable risk (%)
Neurosurgical diagnosis	Meningioma	47 (45.2%)	472 (19.6%)	3.165	2.178	4.600	< 0.001	68.1%
	Sellar tumor	0 (0%)	279 (11.6%)	1.049	1.039	1.059	< 0.001	0%
Secondary diagnosis	Tumor	51 (3.3%)	1497 (96.7%)	0.599	0.411	0.872	0.007	− 66.7%
Age-adj. CCI	0–3	70 (67.3%)	1312 (54.5%)	1.682	1.125	2.514	0.010	51.4%
	> 3	34 (32.7%)	1095 (45.5%)					
Length of stay (> 8 days)								
		> 8	≤ 8	Risk ratio	95%CI		*p* value	Attributable risk (%)
Age	18–56	463 (43.0%)	808 (56.3%)					
	> 56	613 (57.0%)	627 (43.7%)	1.357	1.238	1.488	< 0.001	26.3%
Neurosurgical diagnosis	Meningioma	192 (17.8%)	327 (22.8%)	0.834	0.737	0.942	0.002	− 20.0%
	Metastasis	274 (25.5%)	194 (13.5%)	1.491	1.358	1.637	< 0.001	32.8%
	Sellar tumor	92 (8.6%)	187 (13.0%)	0.748	0.629	0.890	< 0.001	33.6%
Secondary diagnosis	Congestive heart failure	28 (2.6%)	2 (0.1%)	2.210	1.987	2.457	< 0.001	54.8%
	Peripheral arterial disease	11 (1.0%)	4 (0.3%)	1.719	1.262	2.340	0.017	41.8%
	Cerebrovascular disease	23 (2.1%)	13 (0.9%)	1.502	1.170	1.928	0.010	33.5%
	Dementia	4 (0.4%)	0 (0%)	2.339	2.235	2.447	0.021	57.2%

Table 5 (continued)

	Gastric ulcer	10 (0.9%)	1 (0.1%)	2.132	1.759	2.584	0.001	53.1%
	Diabetes	92 (8.6%)	69 (4.8%)	1.364	1.184	1.572	< 0.001	26.6%
	Hemiplegia	176 (16.4%)	82 (5.7%)	1.708	1.549	1.883	< 0.001	41.5%
	Renal disease	81 (7.5%)	35 (2.4%)	1.681	1.478	1.912	< 0.001	40.5%
	Tumor	725 (67.4%)	823 (57.4%)	1.285	1.164	1.418	< 0.001	51.6%
	Leukemia	7 (0.7%)	0 (0%)	2.342	2.238	2.451	0.002	57.3%
	Lymphoma	38 (3.5%)	13 (0.9%)	1.767	1.495	2.088	< 0.001	43.4%
	Metastatic solid tumor	260 (24.2%)	197 (13.7%)	1.432	1.301	1.576	< 0.001	30.2%
Age-adj. CCI	0–3	450 (41.8%)	932 (64.9%)					
	> 3	626 (58.2%)	503 (35.1%)	1.703	1.553	1.867	< 0.001	41.2%
Any complication								
		Any complication (*n* (%))	No complication (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Sex	Male	322 (54%)	931 (48.6%)	1.180	1.025	1.358	0.021	15.2%
	Female	274 (46%)	984 (51.4%)					
Secondary diagnosis	Congestive heart failure	14 (2.3%)	16 (0.8%)	1.989	1.348	2.936	0.003	49.7%
	Cerebrovascular disease	15 (2.5%)	21 (1.1%)	1.775	1.198	2.629	0.011	43.7%
	Dementia	3 (0.5%)	1 (0.1%)	3.171	1.793	5.608	0.016	68.4%
	COPD	18 (3.0%)	30 (1.6%)	1.598	1.101	2.318	0.024	37.3%
	Gastric ulcer	6 (1.0%)	5 (0.3%)	2.311	1.341	3.982	0.016	56.7%
	Hemiplegia	92 (15.4%)	166 (8.7%)	1.594	1.330	1.910	< 0.001	37.3%
	Renal disease	43 (7.2%)	73 (3.8%)	1.605	1.253	2.058	0.001	37.7%
	Leukemia	5 (0.8%)	2 (0.1%)	3.026	1.884	4.861	0.003	66.9%
	Severe liver disease	3 (0.5%)	1 (0.1%)	3.169	1.792	5.605	0.016	68.4%
Age-adj. CCI	0–3	299 (50.2%)	1083 (56.6%)	1.216	1.057	1.399	0.006	17.9%
	> 3	297 (49.8%)	832 (43.4%)					
Postoperative hemorrhage								
		Hemorrhage (*n* (%))	No hemorrhage (*n* (%))	Risk ratio	95%CI		*p* value	Attributable risk (%)
Secondary diagnosis	Cerebrovascular disease	4 (4.2%)	32 (1.3%)	3.022	1.174	7.780	0.02	66.7%
	Dementia	2 (2.1%)	2 (0.1%)	13.478	4.958	36.641	< 0.001	92.6%
	Connective tissue disease	3 (3.2%)	15 (0.6%)	4.516	1.577	12.935	0.004	77.8%
	Diabetes	11 (11.6%)	150 (6.2%)	1.911	1.040	3.506	0.036	47.1%
	Hemiplegia	21 (22.1%)	237 (9.8%)	2.478	1.553	3.954	< 0.001	59.3%
Age-adj. CCI	0–3	40 (42.1%)	1342 (55.5%)					
	> 3	55 (57.9%)	1074 (44.5%)	1.683	1.129	2.510	0.010	40.8%

Overall, the most common causes for unplanned readmission in our cohort were tumor progression (21.1%) and surgical site infections (22.4%). In the literature, neurological deterioration (30.2%), seizures (20.9%), thromboembolic complications (19.7%), and infectious complications (11.9–51.19%) accounted for unplanned readmissions [28, 33, 42].

When analyzing readmission rates, the identification of possible predictors is of great importance. In previous studies, LOS [28], male sex [12, 31], ASA score [12] type of insurance [16, 28, 31], initial emergency admission [31], loss of function [12, 16], patients with comorbidities [16, 28, 31], hydrocephalus [28], and in general complications that established postoperatively during the index admission [16, 28] were associated with readmission.

In contrast, our study only found male sex (OR 1.5) and younger age (OR 1.8) as independent risk factors.

Unplanned reoperation

Reoperation rates have been increasingly used as indicators evaluating the quality of care. [11]. The unplanned 30-days reoperation rate in our collective was 10.0%, whereas resection was performed in 16.1% ($n = 36$) either due to residual tumor or to tumor progression. In 83.9% ($n = 187$), reoperation was done for a surgical complication.

Postoperative hemorrhage was the leading reason for reoperation within 30 days and the fourth most common adverse event in our study. The consequences of intracranial hematomas are often devastating with a mortality rate of up to 32% [34]. We found a postoperative hemorrhage rate of 3.8% in our series. Other studies have reported a rate of 0.8% up to 7.1% [2, 17, 18, 22, 23, 26]. Advanced age and diabetes were significantly associated with a higher risk for postoperative hemorrhage. These findings have been attributed to tissue fragility in elderly and diabetes-induced atherosclerosis and changing of microcirculations [26, 35]. We did not find any significant association between tumor histology and risk of postoperative bleeding, whereas other authors described an increased risk for meningioma patients [18, 34].

Surprisingly, resection of residual tumor was identified as the third most common reason of reoperation in our collective, similar to the results of Senders et al. [39]. Extent of resection has gained more attention during the last years, as it influences survival in glioma patients [19, 41].

Overall, differences in readmission and/or reoperation rates will strongly be influenced by standards in surgical decision making or center-dependent rules policies. Most neurosurgical centers will be cautious and have a liberal readmission policy, but centers will not uniformly advocate early reoperations for residual tumor and not consistently re-operations for hematomas.

Predictors for reoperation were male sex (OR 1.32), hemiplegia (OR 1.55) and leukemia (OR 6.18) in our collective. Further risk factors described in the literature were older age [26], preoperative thrombocytopenia [10], operative time > 300 min [11], emergent operation [11], hypertension [11], and preoperative leukozytosis [11]. Palmer et al. showed that two thirds of identifiable coagulopathy risk factors could be modified preoperatively [34]. Therefore, an adequate management of patients with those risk factors is indispensable.

Surgical site infections

Postoperative wound infections were documented in 4.1% of all patients. Other studies report SSI rates after craniotomy between 0.5 and 6.6% [13, 25, 26, 32, 39].

In our collective, surgical site infections were the second most reason for reoperations and accounted for 22.4% of all readmission. Besides influencing readmission and reoperation rates, surgical site infection can be seen as a quality indicator for itself [37].

It is well-known that brain tumor patients have a predilection for infectious complications, in particular due to adjuvant oncological treatment [4, 11] and long-term use of glucocorticoids [43].

Meningioma patients had the highest incidence of SSIs. Our results are in accordance with the results by Lassen et al., showing that meningioma patients had an almost six times higher risk for developing SSIs than glioma patients [26]. This phenomenon has been attributed to hemostasis and closure difficulties in meningioma surgery [25, 26].

Although in previous studies, there were significant associations between occurrence of SSI and number of previous surgeries [37], male sex [26, 29], length of surgery [11, 25, 29], and chemotherapy [29], we only observed that the surgery of meningioma was an independent risk factors for SSIs.

Nosocomial infections

Nosocomial infections are frequent complications in neurosurgical patients. The total incidence of nosocomial infections in our collective was 12.1%. Studies showed that especially patients with intracranial tumors are at higher risk for infectious complications in comparison to other neurosurgical patients [1]. The nosocomial infection rate in our patient collective was mainly influenced by secondary diagnoses of the patient present at admission. Therefore, these "high-risk" patients should be under close surveillance for infectious complications.

30-days mortality rate

Twenty-seven patients (1.1%) died within 30 days after index neurosurgical admission. This rate was lower in comparison to other studies describing mortality rates ranging from 2.3 to 3.2% [12, 26, 28, 39] after brain tumor surgery.

Patients with the diagnosis of cerebral metastasis were at higher risk for dying within 30 days after surgery with a risk ratio of 3 compared to patients with other brain tumors. Our observations are confirmed by Lassen et al., who found a 30-days mortality rate for patient with cerebral metastasis of 4.5% [26].

Length of stay

The median LOS in our collective was 8 days. The deviation in LOS in comparison to other studies, especially from the USA, is attributed to differences in the national health care systems. We found that patients with metastasis were hospitalized significantly longer (median 9 days, range 1–33) ($p < 0.001$). Mainly baseline patient characteristics like higher age, congestive heart failure, renal disease, etc. were associated with a longer LOS. Other studies revealed higher age, ASA class > 3, dependent functional status, diabetes, hematological comorbidities, and in general the number of comorbidities as independent risk factors for prolonged LOS [3, 9]. The occurrence of postoperative complications leads to prolonged hospitalization. We showed that reoperation ($p < 0.001$), postoperative hemorrhage ($p = 0.038$), tumor progression ($p < 0.001$), hydrocephalus ($p = 0.046$), nosocomial infections ($p < 0.001$), SSIs ($p < 0.001$), and CSF leakage were associated with longer LOS in univariate analysis. LOS is influenced both by premorbid conditions and postoperative complications.

Any complication

In our cohort, 23.7% of patients experienced at least one minor or major complication. Senders et al. found a major complication rate of 12.9%, which is comparable to our results, when stratifying into major and minor complications [39]. It was shown that the ASA score significantly correlated with postoperative unfavorable outcome in patients with malignant gliomas [39]. The ASA classification reflects the comorbidities of patients before surgery [44]. These data indicate that most predictors of short-term complications are not modifiable by neurosurgeons.

Age-adjusted Charlson Comorbidity Index

In our study, the CCI could not be determined to be highly and independently predictive of outcome regarding quality metrics. Patients with a CCI > 3 were more likely to have a longer LOS (> 8 days) (OR 1.4). In contrast, other countries, e.g., the UK uses the variables from the CCI for risk adjustment regarding mortality in their National Neurosurgical Audit Programme (NNAP). It must be kept in mind that the CCI was developed 30 years ago, and medical progress might have influenced the weighting and relevance of the single comorbidity items limiting its present validity, at least for our cohort.

Risk adjustment

We found several risk factors to predict our outcome variable that can be used for risk-adjustment. Most studies only evaluated the odds ratio. However, the OR often exaggerates the effect if the outcome is common (> 10% of the reference group) [36], as it is in many of the assessed quality indicators. Therefore, we provided the risk ratio as well. The risk ratio might be helpful in developing risk adjustment scores. Especially male patients hat an increased risk ratio for several adverse outcomes. In addition, when discussing methods of risk adjustment, the attributable risk of each potential risk factor gives further information, especially regarding possible preventable adverse events.

Limitations

This single-institutional observational study provides an overview on short-term complications that a German brain tumor center is confronted with. However, due to the retrospective nature of this study, the study has limited power to draw conclusions on a national level.

Our study did not enable capturing readmissions to other hospitals. Therefore, lower readmission and outcome rates might be attributed in part to a systematic underestimation bias.

Analysis relies on the usage of administrative data and ICD-10 codes. Coding is frequently not performed by experienced clinicians, often resulting in inaccuracies. However, by analyzing the patients' medical records in addition, we were able to optimize clinical accuracy.

A further aspect is that patient selection and determination of various treatment options is an important factor when analyzing these results. All our tumor cases were discussed in a multidisciplinary tumor board, and alternatives like radiation for metastasis or meningiomas and palliation in case of very poor prognosis were discussed with the patient. Still, due to the dependence of complications on patient factors, as demonstrated here, complication rates can be lowered simply by considering non-surgical therapies for high-risk patients, for example palliation, radiotherapy, or radiosurgery for selected patients with metastasis, malignant gliomas, or meningiomas.

Conclusions

We provide a large dataset on short-term complications and current quality metrics in a brain tumor center. We found that most predictors of adverse events and outcome rates are based on preoperative underlying medical conditions of the patient and are not modifiable by the surgeon. However, identifying patient related factors associated with adverse events after brain tumor resection aids in identifying patients at high risk for complications. These data can be used for risk-specific tailoring of postoperative management.

Of course, further studies are needed to identify and develop effective prediction models for complications in brain tumor patients that include additional clinical, treatment-, tumor-, and hospital-specific factors. This is of great importance, as adverse events directly influence the patient's outcome on the one hand, and on the other hand have a great impact on the currently used quality metrics, which have a growing relevance for reimbursement in health care.

We showed that the CCI is no longer an adequate predictor for mortality and outcome in neurosurgical tumor patients. In addition, our analysis and literature discussion emphasize the fact that a direct comparison of outcome rates between different health-care providers on an international basis is challenging, as the outcome measures are strongly influenced by standards in local and national health-care policy and surgical decision making. Therefore, we conclude that each health-care system has to develop own metrics for risk adjustment and assessment of outcome variables that require regular reassessment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the local ethic committee. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all participants included in the study.

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Appendix

Table 6 Univariate analysis

30 days unplanned readmission				
		Readmitted (*n* (%))	Not readmitted (*n* (%))	*p* value
Age		51.65 (SD 14.36)	55.61 (SD 15.71)	0.003
Sex	Male	85 (6.8%)	1168 (93.2%)	0.019
	Female	58 (4.6%)	1200 (95.4%)	
Neurosurgical diagnosis	Glioma	72 (7.6%)	983 (93.2%)	0.308
	Meningioma	28 (5.4%)	491 (94.6%)	
	Metastasis	15 (3.2%)	453 (96.8%)	
	Sellar tumor	17 (6.1%)	262 (93.9%)	
	Vestibular schwannoma	6 (4.7%)	121 (95.3%)	
	Other benign brain tumors	5 (7.9%)	58 (92.1%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.3%)	0.547
	Congestive heart failure	0 (0%)	30 (1.3%)	0.176
	Peripheral arterial disease	1 (0.7%)	14 (0.6%)	0.871
	Cerebrovascular disease	2 (1.4%)	34 (1.4%)	0.971
	Dementia	0 (0%)	4 (0.2%)	0.623
	COPD	2 (1.4%)	46 (1.9%)	0.645
	Connective tissue disease	1 (0.7%)	17 (0.7%)	0.980
	Gastric ulcer	1 (0.7%)	10 (0.4%)	0.626
	Liver disease	0 (0%)	7 (0.3%)	0.515
	Diabetes	10 (7.0%)	151 (6.4%)	0.771
	Hemiplegia	19 (13.3%)	239 (10.1%)	0.222
	Renal disease	6 (4.2%)	110 (4.6%)	0.804
	Diabetes with end organ damage	1 (0.7%)	26 (1.1%)	0.645
	Tumor	88 (61.5%)	1460 (61.7%)	0.978
	Leukemia	1 (0.7%)	6 (0.3%)	0.326
	Lymphoma	1 (0.7%)	50 (2.1%)	0.245
	Severe liver disease	1 (0.7%)	3 (0.1%)	0.096
	Metastatic solid tumor	20 (14.0%)	437 (18.5%)	0.179
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	3 (0–16)	3 (0–18)	n.s.
30 days unplanned reoperation				
		Reoperated (*n* (%))	Not reoperated (*n* (%))	*p* value
Age		54.73 (SD 16.02)	55.37 (SD 15.65)	0.272
Sex	Male	127 (11.4%)	988 (88.6%)	0.047
	Female	99 (8.7%)	1043 (88.6%)	
Neurosurgical diagnosis	Glioma	102 (10.9%)	836 (89.1%)	0.180
	Meningioma	46 (9.6%)	431 (90.4%)	
	Metastasis	40 (10.0%)	362 (90.0%)	
	Sellar tumor	28 (10.7%)	233 (89.3%)	
	Vestibular schwannoma	8 (6.5%)	115 (93.5%)	
	Other benign brain tumors	2 (3.6%)	54 (96.4%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	5 (0.2%)	0.441
	Congestive heart failure	0 (0%)	28 (1.4%)	0.083
	Peripheral arterial disease	2 (0.9%)	12 (0.6%)	0.557
	Cerebrovascular disease	8 (3.5%)	23 (1.1%)	0.005
	Dementia	2 (0.9%)	2 (0.1%)	0.004

Table 6 (continued)

	COPD	3 (1.3%)	42 (2.1%)	0.502
	Connective tissue disease	3 (1.3%)	12 (0.6%)	0.254
	Gastric ulcer	3 (1.3%)	8 (0.4%)	0.034
	Liver disease	0 (0%)	7 (0.3%)	0.405
	Diabetes	14 (6.2%)	129 (6.4%)	0.888
	Hemiplegia	36 (15.9%)	184 (9.1%)	0.003
	Renal disease	13 (5.8%)	96 (4.7%)	0.395
	Diabetes with end organ damage	2 (0.9%)	24 (1.2%)	0.771
	Tumor	146 (64.6%)	1217 (59.9%)	0.339
	Leukemia	3 (1.3%)	4 (0.2%)	0.002
	Lymphoma	3 (1.3%)	47 (2.3%)	0.432
	Severe liver disease	1 (0.4%)	3 (0.1%)	0.264
	Metastatic solid tumor	44 (19.5%)	346 (17.0%)	0.604
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	3 (0–18)	3 (0–18)	0.272
30 days unplanned mortality				
		Died (*n* (%))	Alive (*n* (%))	*p* value
Age		61.41 (SD 15.96)	55.32 (SD 15.65)	0.044
Sex	Male	11 (0.9%)	1242 (99.1%)	0.339
	Female	16 (1.3%)	1242 (98.7%)	
Neurosurgical diagnosis	Glioma	13 (1.2%)	1042 (98.8%)	0.164
	Meningioma	2 (0.4%)	517 (99.6%)	
	Metastasis	11 (2.4%)	457 (97.6%)	
	Sellar tumor	1 (0.4%)	278 (99.6%)	
	Vestibular schwannoma	0 (0%)	127 (100%)	
	Other benign brain tumors	0 (0%)	63 (100%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.2%)	0.789
	Congestive heart failure	2 (7.4%)	28 (1.1%)	0.003
	Peripheral arterial disease	1 (3.7%)	14 (0.6%)	0.035
	Cerebrovascular disease	2 (7.4%)	34 (1.4%)	0.009
	Dementia	0 (0.0%)	4 (0.2%)	0.835
	COPD	1 (3.7%)	47 (1.9%)	0.494
	Connective tissue disease	1 (3.7%)	17 (0.7%)	0.064
	Gastric ulcer	0 (0.0%)	11 (0.4%)	0.729
	Liver disease	0 (0.0%)	7 (0.3%)	0.782
	Diabetes	0 (0.0%)	161 (6.5%)	0.171
	Hemiplegia	7 (25.9%)	251 (10.1%)	0.007
	Renal disease	3 (11.1%)	113 (4.5%)	0.106
	Diabetes with end organ damage	1 (3.7%)	26 (1.0%)	0.183
	Tumor	23 (85.2%)	1525 (61.4%)	0.011
	Leukemia	1 (3.7%)	6 (0.2%)	0.001
	Lymphoma	2 (7.4%)	49 (2.0%)	0.047
	Severe liver disease	0 (0.0%)	4 (0.2%)	0.835
	Metastatic solid tumor	10 (37.0%)	447 (18.0%)	0.011
	AIDS	0 (0.0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	8 (2–15)	3 (0–18)	< 0.001
Nosocomial infection rate				
		Infection (*n* (%))	No infection (*n* (%))	*p* value
Age		58.69 (SD 15.31)	54.92 (SD 15.65)	< 0.001
Sex	Male	160 (12.8%)	1093 (87.2%)	0.341

Table 6 (continued)

	Female	145 (11.5%)	1113 (88.5%)	
Neurosurgical diagnosis	Glioma	109 (10.3%)	946 (89.7%)	0.404
	Meningioma	78 (15.0%)	441 (85.0%)	
	Metastasis	79 (16.9%)	389 (83.1%)	
	Sellar tumor	25 (9.0%)	254 (91.0%)	
	Vestibular schwannoma	9 (7.1%)	118 (92.9%)	
	Other benign brain tumors	5 (7.9%)	58 (92.1%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.3%)	0.362
	Congestive heart failure	10 (3.3%)	20 (0.9%)	< 0.001
	Peripheral arterial disease	4 (1.3%)	11 (0.5%)	0.084
	Cerebrovascular disease	10 (3.3%)	26 (1.2%)	0.004
	Dementia	2 (0.7%)	2 (0.1%)	0.020
	COPD	15 (4.9%)	33 (1.5%)	< 0.001
	Connective tissue disease	1 (0.3%)	17 (0.8%)	0.390
	Gastric ulcer	5 (1.6%)	6 (0.3%)	0.001
	Liver disease	1 (0.3%)	6 (0.3%)	0.862
	Diabetes	25 (8.2%)	136 (6.2%)	0.175
	Hemiplegia	58 (19.0%)	200 (9.1%)	< 0.001
	Renal disease	35 (11.5%)	81 (3.7%)	< 0.001
	Diabetes with end organ damage	6 (2.0%)	21 (1.0%)	0.107
	Tumor	187 (61.3%)	1361 (61.7%)	0.897
	Leukemia	4 (1.3%)	3 (0.1%)	< 0.001
	Lymphoma	15 (4.9%)	36 (1.6%)	< 0.001
	Severe liver disease	2 (0.7%)	2 (0.1%)	0.020
	Metastatic solid tumor	82 (26.9%)	375 (17.0%)	< 0.001
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	4 (0–18)	3 (0–18)	< 0.001
Surgical site infection rate				
		SSI	No SSI	*p* value
Age		54.40 (SD 13.54)	55.42 (SD 15.74)	0.515
Sex	Male	56 (4.5%)	1197 (95.5%)	0.411
	Female	48 (3.8%)	1210 (96.2%)	0.045
Neurosurgical diagnosis	Glioma	36 (3.4%)	1019 (96.6%)	
	Meningioma	47 (9.1%)	472 (90.9%)	
	Metastasis	16 (3.4%)	452 (96.6%)	
	Sellar tumor	0 (0%)	279 (100%)	
	Vestibular schwannoma	4 (3.1%)	123 (96.9%)	
	Other benign brain tumors	1 (1.6%)	62 (98.4%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.2%)	0.610
	Congestive heart failure	0 (0%)	30 (1.2%)	0.252
	Peripheral arterial disease	1 (1.0%)	14 (0.6%)	0.623
	Cerebrovascular disease	1 (1.0%)	35 (1.5%)	0.679
	Dementia	0 (0%)	4 (0.2%)	0.677
	COPD	2 (1.9%)	46 (1.9%)	0.993
	Connective tissue disease	0 (0%)	18 (0.7%)	0.376
	Gastric ulcer	0 (0%)	11 (0.5%)	0.490
	Liver disease	0 (0%)	7 (0.3%)	0.582
	Diabetes	2 (1.9%)	159 (6.6%)	0.056
	Hemiplegia	11 (10.6%)	247 (10.3%)	0.917
	Renal disease	4 (3.8%)	112 (4.7%)	0.701

Table 6 (continued)

	Diabetes with end organ damage	1 (1.0%)	26 (1.1%)	0.909
	Tumor	51 (49.0%)	1497 (62.2%)	0.007
	Leukemia	1 (1.0%)	6 (0.2%)	0.177
	Lymphoma	2 (1.9%)	49 (2.0%)	0.936
	Severe liver disease	0 (0%)	4 (0.2%)	0.677
	Metastatic solid tumor	15 (14.4%)	442 (18.4%)	0.308
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	2 (0–15)	3 (0–18)	0.027
Length of stay (> 8days)				
		> 8	≤ 8	*p* value
Age		58.24 (SD15.27)	53.24 (SD 15.61)	< 0.001
Sex	Male	521 (41.6%)	732 (58.4%)	0.199
	Female	555 (44.1%)	703 (55.9%)	
Neurosurgical diagnosis	Glioma	439 (41.9%)	616 (58.4%)	0.696
	Meningioma	192 (37.0%)	327 (63.0%)	
	Metastasis	274 (58.5%)	194 (41.5%)	
	Sellar tumor	92 (33.0%)	187 (67.0%)	
	Vestibular schwannoma	54 (42.5%)	73 (57.5%)	
	Other benign brain tumors	25 (39.7%)	38 (60.3%)	
Secondary diagnosis	Myocardial infarction	4 (0.4%)	2 (0.1%)	0.238
	Congestive heart failure	28 (2.6%)	2 (0.1%)	< 0.001
	Peripheral arterial disease	11 (1.0%)	4 (0.3%)	0.017
	Cerebrovascular disease	23 (2.1%)	13 (0.9%)	0.010
	Dementia	4 (0.4%)	0 (0%)	0.021
	COPD	23 (2.1%)	25 (1.7%)	0.474
	Connective tissue disease	8 (0.7%)	10 (0.7%)	0.891
	Gastric ulcer	10 (0.9%)	1 (0.1%)	0.001
	Liver disease	4 (0.4%)	3 (0.2%)	0.444
	Diabetes	92 (8.6%)	69 (4.8%)	< 0.001
	Hemiplegia	176 (16.4%)	82 (5.7%)	< 0.001
	Renal disease	81 (7.5%)	35 (2.4%)	< 0.001
	Diabetes with end organ damage	15 (1.4%)	12 (0.8%)	0.180
	Tumor	725 (67.4%)	823 (57.4%)	< 0.001
	Leukemia	7 (0.7%)	0 (0%)	0.002
	Lymphoma	38 (3.5%)	13 (0.9%)	< 0.001
	Severe liver disease	2 (0.2%)	2 (0.1%)	0.773
	Metastatic solid tumor	260 (24.2%)	197 (13.7%)	< 0.001
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	4 (0–18)	2 (0–18)	< 0.001
Any complication				
		Any complication (*n* (%))	No complication (*n* (%))	*p* value
Age		55.83 (SD 16.01)	55.24 (SD 15.55)	0.427
Sex	Male	322 (25.7%)	931 (74.3%)	0.021
	Female	274 (31.8%)	984 (78.2%)	
Neurosurgical diagnosis	Glioma	244 (23.1%)	811 (76.9%)	0.645
	Meningioma	129 (24.9%)	390 (75.1%)	
	Metastasis	114 (24.4%)	354 (75.6%)	
	Sellar tumor	76 (27.2%)	203 (72.8%)	
	Vestibular schwannoma	22 (17.3%)	105 (82.7%)	
	Other benign brain tumors	11 (17.5%)	52 (82.5%)	

Table 6 (continued)

Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.3%)	0.171
	Congestive heart failure	14 (2.3%)	16 (0.8%)	0.003
	Peripheral arterial disease	4 (0.7%)	11 (0.6%)	0.789
	Cerebrovascular disease	15 (2.5%)	21 (1.1%)	0.011
	Dementia	3 (0.5%)	1 (0.1%)	0.016
	COPD	18 (3.0%)	30 (1.6%)	0.024
	Connective tissue disease	5 (0.8%)	13 (0.7%)	0.686
	Gastric ulcer	6 (1.0%)	5 (0.3%)	0.016
	Liver disease	1 (0.2%)	6 (0.3%)	0.556
	Diabetes	44 (7.4%)	117 (6.1%)	0.269
	Hemiplegia	92 (15.4%)	166 (8.7%)	< 0.001
	Renal disease	43 (7.2%)	73 (3.8%)	0.001
	Diabetes with end organ damage	9 (1.5%)	18 (0.9%)	0.239
	Tumor	361 (60.6%)	1187 (62.0%)	0.535
	Leukemia	5 (0.8%)	2 (0.1%)	0.003
	Lymphoma	16 (2.7%)	35 (1.8%)	0.196
	Severe liver disease	3 (0.5%)	1 (0.1%)	0.016
	Metastatic solid tumor	121 (20.3%)	336 (17.5%)	0.128
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	3 (0–18)	3 (0–18)	0.002
Postoperative hemorrhage				
		Hemorrhage (*n* (%))	No hemorrhage (*n* (%))	*p* value
Age		57.84 (SD 16.84)	55.29 (SD 15.61)	0.119
Sex	Male	56 (4.5%)	1197 (95.5%)	0.072
	Female	39 (3.1%)	1219 (96.9%)	
Neurosurgical diagnosis	Glioma	44 (4.2%)	1011 (95.8%)	0.218
	Meningioma	23 (4.4%)	496 (95.6%)	
	Metastasis	14 (3.0%)	454 (97.0%)	
	Sellar tumor	9 (3.2%)	270 (96.8%)	
	Vestibular schwannoma	5 (3.9%)	122 (96.1%)	
	Other benign brain tumors	0 (0%)	63 (100%)	
Secondary diagnosis	Myocardial infarction	0 (0%)	6 (0.2%)	0.627
	Congestive heart failure	0 (0%)	30 (1.2%)	0.275
	Peripheral arterial disease	1 (1.1%)	14 (0.6%)	0.557
	Cerebrovascular disease	4 (4.2%)	32 (1.3%)	0.02
	Dementia	2 (2.1%)	2 (0.1%)	< 0.001
	COPD	48 (2.0%)	0 (0%)	0.166
	Connective tissue disease	15 (0.6%)	3 (3.2%)	0.004
	Gastric ulcer	1 (1.1%)	10 (0.4%)	0.355
	Liver disease	0 (0%)	7 (0.3%)	0.599
	Diabetes	11 (11.6%)	150 (6.2%)	0.036
	Hemiplegia	21 (22.1%)	237 (9.8%)	< 0.001
	Renal disease	6 (6.3%)	110 (4.6%)	0.422
	Diabetes with end organ damage	1 (1.1%)	26 (1.1%)	0.983
	Tumor	60 (3.9%)	1488 (61.6%)	0.758
	Leukemia	1 (1.1%)	6 (0.2%)	0.145
	Lymphoma	0 (0%)	51 (2.1%)	0.153
	Severe liver disease	0 (0%)	4 (0.2%)	0.692
	Metastatic solid tumor	15 (15.8%)	442 (18.3%)	0.535
	AIDS	0 (0%)	0 (0%)	–
Age-adjusted CCI	Median (range)	4 (0–16)	3 (0–18)	0.184

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