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Brain Tumor Surgery is Safe in Octogenarians and Nonagenarians: A Single-Surgeon 741 Patient Series

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■ OBJECTIVES: Elderly patients with surgically accessible brain tumors are often not offered clinically indicated brain tumor surgery (BTS) because of to assumptions of greater risk for perioperative morbidity and mortality. Because brain tumor incidence is highest in the geriatric population, and because the global population is aging, accurate understanding of BTS risk in elderly patients is critical. We aimed to compare safety of BTS in elderly patients with younger counterparts to better understand the risk—benefit profile of BTS for elderly patients.

■ METHODS: Retrospective cohort study of young (20—29 years), senior (60—79 years), and elderly (80+ years) patients who underwent BTS with a single neurosurgeon. Differences between pre- and postoperative modified Rankin score (ΔmRS), length of hospitalization (LOH), complication rate, and 30-day readmission rates (30DRR) were recorded.

■ RESULTS: A total of 741 patients (83 elderly, 570 senior, and 88 young) were identified. No significant difference in preoperative mRS between different age groups, $\chi^2 = 0.269$, $P = 0.874$. Elderly complication rate was 6.0%, not significantly different from young (4.5%, $P = 0.667$) or senior (7.2%, $P = 0.696$) complication rate. Elderly LOH was 1.93 ± SD 0.176 days; not significantly different from young (3.01 ± 0.384 days, $P = 0.081$) or senior (2.47 ± 0.144 days, $P = 0.881$). Statistical equivalence testing showed with 95% confidence that there was equivalence in ΔmRS among age groups.

■ CONCLUSIONS: Elderly patients did not have significantly different ΔmRS, LOH, 30DRR, or complication rates after BTS compared with younger counterparts. Therefore, in healthy patients, advanced age alone should not prevent patients from being offered BTS.

INTRODUCTION

Primary brain tumors present a growing public health concern, especially as the proportion of elderly patients in the population increases. More than 20,000 patients annually are diagnosed with a high-grade glioma, and there are an estimated 100,000 to 200,000 new cases of brain metastases each year.[1] This burden is especially apparent in aging patient populations, with an increased incidence of both intrinsic and metastatic brain tumors in the elderly.[2,3] Several factors influence the increasing risk for developing brain tumors in aging patients. The incidence of all types of brain tumor increases with age, and continually advancing chemotherapeutics for systemic cancers that improve mean survivability also increase the possibility of developing secondary brain metastases. This increased incidence of brain tumors in geriatric patients underscores the need to evaluate the relationship between age and outcome after aggressive surgical treatment for brain tumors, such as craniotomy or transsphenoidal endoscopic endonasal surgery (TEES) for tumor resection.

Previous literature has shown a relationship between surgical resection of brain tumors and mean survival rates in both intrinsic and metastatic brain tumors.[4,5] However, despite increasing

efficacy and safety of novel surgical and anesthetic techniques, there remains a consistent disparity in the rates of surgery for elderly patients.[6] This discrepancy seemingly stems from a belief that older patients are less able to tolerate long surgeries and thus have higher risk for morbidity and mortality associated with invasive tumor resection.[7-10] The evidence vindicating this belief remains controversial, partially arising from a lack of clear definition for what is considered "elderly" in surgical candidates. Whereas some studies have found that advanced age does not affect surgical outcomes,[11-14] many do find worse outcomes for elderly patients after craniotomy for resection of primary brain tumor.[15-21] Therefore, a large single-surgeon series comparing outcomes in elderly and non-elderly patients is sought to eliminate the confounding variable of heterogeneity of surgical technique and ancillary care provided.

The objective of this study was to compare immediate post-operative outcomes, including postoperative complications, neurologic deficits, length of stay, and 30-day postoperative emergency department visits and hospital readmissions, for a single surgeon's series of octogenarians and nonagenarians to the same surgeon's series of younger patients with similar preoperative indications.

METHODS

Patient Selection

This study was conducted and reported in accordance with STROBE guidelines.[22] After institutional review board approval, a retrospective chart review of the electronic medical record was conducted, reviewing patients aged 20–29 years (young group), 60–79 years (senior group), and 80+ years (elderly group), inclusive, who underwent initial elective craniotomy or initial TEES for resection of a brain tumor from August 2011 to April 2018. The patient consent process was waived as this was a retrospective study stripped of all patient identifying information. These age groups were chosen to assess the outcomes of elderly patients in comparison with those of slightly younger patients (60–79 years) and much younger counterparts (20–29 years) with similar surgical indications and preoperative functional status. Only patients with no significant preoperative medical comorbidities and with a modified Rankin Scale (mRS) score less than or equal to 3 were offered elective surgery, so only patients meeting these criteria were included. As such, patients who were unresponsive, unarousable, and intubated were excluded from this study. In addition, patients who underwent more minor surgeries such as ventriculoperitoneal shunt, stereotactic biopsy, or laser interstitial thermal therapy were excluded. Patients who underwent revision surgery, were outside the specified age ranges, and who had less than 4 weeks of follow-up were excluded. The medical records of all patients were searched to determine whether the patient expired within 30 days of surgery. This perioperative death was included even if the patient expired before clinical follow-up. Pertinent demographics including diagnosis, sex, age at surgery, tumor location, largest tumor diameter, and pathology were recorded, as were intraoperative variables such as whether awake craniotomy or motor-evoked potentials were used during surgery.

Outcomes of Interest

Outcome information recorded included intraoperative and postoperative complications, preoperative and postoperative neurologic deficits measured with mRS,[23] length of stay, 30-day mortality, and 30-day postoperative emergency department visits and hospital readmissions. Information was found by reviewing patient notes from the electronic medical record. Surgical complications were divided into 3 groups, as suggested by the Glioma Outcome Project: neurologic (hydrocephalus, neurological deficit, etc.), regional (wound infection, etc.), and systemic (pulmonary embolism, pneumonia, etc.).[24] Functional outcome was measured as the difference between preoperative and postoperative mRS scores (ΔmRS). Thirty-day readmission rate was defined as return to the emergency department or hospital readmission. Length of stay was defined as the number of days the patient remained in the hospital between dates of admission and discharge. Tumor size and preoperative mRS scores were compared among groups in order to evaluate for preoperative group homogeneity. All patients were reviewed and mRS scores were assigned by a single reviewer blinded to patient age in order to reduce inter-rater variability. Preoperative tumor size was estimated by utilizing the largest tumor diameter measured by a board-certified neuroradiology attending physician, as in the method of James et al.[25-27]

Statistical Analysis

Univariate and multivariate analyses were performed to assess for any relationship between age at surgery and postoperative outcome. P value less than 0.05 was considered statistically significant. IBM SPSS statistics software was used for all statistical analysis (version 24; IBM, Armonk, NY). Post hoc analysis of observed power was conducted using the statistical program G★Power 3.[28] For initial analysis, patients were stratified into young group (20–29 years), senior group (60–79 years), and elderly group (80+ years). The Kruskal-Wallis H test was used to compare ordinal data (mRS scores) between groups; the Pearson χ^2 test was used for analysis of categorical variables (readmission rates); one-way analysis of variance (ANOVA) was used for continuous variables (largest lesion diameter, ΔmRS). Postoperative outcome measurements were initially compared between the young, senior, and elderly groups. For further evaluation, patients were re-stratified. The young and senior groups were combined (combined group) and compared with the elderly patients. An independent samples t test was used to compare ΔmRS and postoperative stay length and a 2-tailed Z test was used to compare 30-day readmission rates between the 2 new groups.

Two one-sided tests procedures were used to determine whether there existed a clinical non-equivalence in surgical outcome (ΔmRS) between patients aged 20–29, 60–79, and 80+ years. The difference in mRS needed to indicate a clinically relevant difference was defined as a single-point change in mRS and based on established literature.[29,30] Thus, two one-sided tests procedures using confidence intervals were used to determine equivalence of treatment effect and the zone of clinical indifference was set as ranging from −1 to +1.[31,32] Ninety percent confidence intervals were generated of the difference in mean ΔmRS between groups (Figure 1).
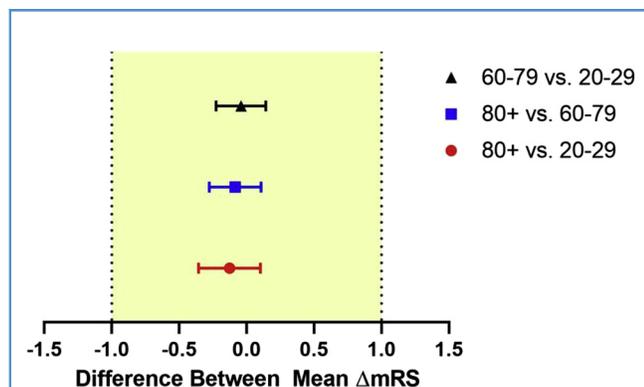
Figure 1. Two one-sided tests procedures to evaluate for equivalence in mean ΔmRS among age groups. Ninety percent confidence interval comparing the difference in ΔmRS between patients aged 20–29 and 80+ years old (*red circles*), 60–79 and 80+ year old (*blue squares*), and 60–79 and 20–29 years old (*black triangles*). All confidence intervals fall within the preset zone of clinical indifference (−1, +1); thus, we conclude that there is clinical equivalence with regard to functional outcome between the aforementioned age groups.

RESULTS

Patient Demographics

All patients underwent cranial surgery by the senior neurosurgeon (RJK) at a single academic medical center. Of 2792 patients who underwent cranial surgery by the senior surgeon from August 2011 to April 2018, 731 consecutive patients were identified that fit the inclusion and exclusion criteria (Tables 1 and 2). Eighty-three elderly group patients (range: 80–91 years), 84 young group patients (range: 20–29 years), and 564 senior group patients (range: 60–79 years) who underwent primary craniotomy or TEES for intrinsic brain tumor were identified (Table 1). Tumor pathology included pituitary adenoma (n = 128, 17.5%), glioblastoma multiforme and high-grade glioma (n = 173, 23.7%), low-grade gliomas (n = 45, 6.2%), meningiomas (n = 180, 24.6%), metastatic tumors (n = 153, 20.9%), and other pathologies (n = 52, 7.1%) (Table 1). All patients showed preoperative radiographic evidence of a mass lesion. All patients had a preoperative mRS score less than or equal to 3. The average maximal tumor diameter was 3.40 cm. Mean follow-up length was 15.83 days. Relevant descriptive statistics by group may be seen in Table 1. Quantitative data are expressed as mean value ± standard deviation.

Table 1. Patient Demographics and Oncological Data

Characteristic	Value (%)			
Age group, years	20–29	60–79	80+	Total
Number of patients	84	564	83	731
Male	35 (41.7)	273 (48.4)	40 (48.2)	348 (47.6)
Female	49 (58.3)	291 (51.6)	43 (51.8)	383 (52.4)
Pathology				
Pituitary adenoma	24 (28.5)	91 (16.1)	13 (15.7)	128 (17.5)
Glioblastoma	9 (10.7)	133 (23.6)	21 (25.3)	163 (22.3)
Low grade glioma	30 (35.7)	15 (2.7)	0 (0)	45 (6.2)
High grade glioma	2 (2.4)	8 (1.4)	0 (0)	10 (1.4)
Meningioma	4 (4.8)	149 (26.4)	27 (32.5)	180 (24.6)
Metastases	4 (4.8)	130 (23.1)	19 (22.9)	153 (20.9)
Other	11 (13.1)	38 (6.7)	3 (3.6)	52 (7.1)
Intraoperative data				
Total awake	16 (19)	68 (12.1)	7 (8.4)	91 (12.4)
Total motor evoked potentials	16 (19)	94 (16.7)	20 (24.1)	130 (17.8)
Mean tumor greatest diameter, cm	2.61 ± 1.78	3.52 ± 1.99	3.35 ± 1.71	3.39 ± 1.95
Mean length to follow-up, days	13.83 ± 8.36	16.23 ± 19.81	14.60 ± 2.33	15.83 ± 18.62
Values are presented as n (%) or mean ± SD.				

Table 2. Changes in Preoperative and Postoperative modified Rankin Score

Characteristic	Value (%)		
Age group, years	20—29	60—79	80+
Preoperative mRS			
0	17 (20.2)	149 (26.6)	19 (22.9)
1	66 (78.6)	348 (61.8)	53 (63.9)
2	1 (1.2)	45 (8)	8 (9.6)
3	0 (0)	20 (3.6)	3 (3.6)
4	0 (0)	0 (0)	0 (0)
5	0 (0)	0 (0)	0 (0)
6	0 (0)	0 (0)	0 (0)
Postopoperative mRS			
0	79 (94.0)	458 (81.3)	69 (83.1)
1	6 (6.0)	77 (13.7)	5 (6.0)
2	0 (0)	22 (3.9)	8 (9.6)
3	0 (0)	6 (1.1)	1 (1.2)
4	0 (0)	0 (0)	0 (0)
5	0 (0)	0 (0)	0 (0)
6	0 (0)	1 (0.2)	0 (0)
Mean mRS Δ (postop mRS — preop mRS)	−0.75 ± 0.46	−0.65 ± 0.50	−0.64 ± 0.49

Values are presented as n (%) or mean ± SD.
mRS, modified Rankin scale score.

Table 3. Patient Postoperative Morbidity and Mortality Data

Characteristic	Value (%)		
Age group, years	20—29	60—79	80+
Mean postoperative stay length, days	3.00 ± 3.64	2.39 ± 3.31	2.16 ± 2.33
Complications	4 (4.7)	41 (7.3)	5 (6.0)
Neurologic	2 (50)	16 (39)	0 (0)
Regional	2 (50)	10 (24.4)	5 (100)
Systemic	0 (0)	15 (36.6)	0 (0)
30-day morbidity and mortality			
Readmission rate	4 (4.8)	36 (6.4)	4 (4.8)
Mortality rate	1 (1.2)	7 (1.2)	1 (1.2)
Average follow-up, months	14.44 ± 10.54	14.60 ± 16.75	16.23 ± 19.81

Values are presented as n (%) or mean ± SD.

Preoperative Assessment

mRS was used to assess each patient's preoperative neurological baseline. In all age groups, the median preoperative mRS was 1. Median postoperative mRS in all groups was 0 (Table 2). A Kruskal-Wallis H test showed that there was no statistically significant difference in preoperative mRS between different age groups, $\chi^2 = 0.789$, df = 2, $P = 0.674$. Preoperative lesion greatest diameter was also measured. Mean tumor greatest diameter was 2.61 cm, 3.52 cm, and 3.35 cm for the young, senior, and elderly groups, respectively. A 1-way ANOVA test with Tukey post hoc test showed significantly smaller preoperative tumor greatest diameter in the young group compared with the senior and elderly patients ($P < 0.001$, $P = 0.032$, respectively).

Postoperative Assessment

Elderly patients had improved ΔmRS (−0.64 ± 0.49), not statistically significantly different than for young (−0.75 ± 0.46, $P = 0.158$) or senior (−0.65 ± 0.50, $P = 0.825$) patients.

Functional Outcome

Functional outcome of each patient was measured as the difference between preoperative and postoperative mRS scores (ΔmRS) (Table 2). The length of hospitalization and 30-day morbidity and mortality rates were also used to evaluate surgical outcome

(Table 3). One-way ANOVA with Tukey HSD post hoc tests were used to compare ΔmRS and postoperative stay length between groups. Mean ΔmRS was −0.75 for young patients, −0.65 for senior patients, and −0.64 for elderly patients (Table 2). These differences were not statically significant, $P = 0.117$. Post-hoc power analysis showed an observed power of 0.4. It should be noted, however, that when a non-significant effect is observed, a post hoc power analysis will inevitably show a low observed power due to existing low effect size.[33] For retrospective studies, it may be more appropriate to report how likely it may be to observe a significant effect for a given sample size and small effect size. In this study, with a total sample size of 730 patients, there was 0.80 power to detect an effect size of f = 0.115 at an alpha of 0.05.

After statistical equivalence testing, none of the 90% confidence intervals fell outside our predetermined zone of clinical indifference. Thus, we concluded with 95% confidence[31,32] that there was equivalence in ΔmRS among age groups.

Average postoperative length of stay was 3.00, 2.39, and 2.16 days for the young, senior, and elderly groups, respectively. Stay length did not significantly differ between groups, $P = 0.192$, with an observed statistical power of 0.53. There were 4 (4.8%), 36 (6.4%), and 4 (4.8%) instances in which patients were readmitted within 30 days after discharge in the young, senior, and elderly patient groups, respectively. A χ^2 test showed no significant association between these readmission rates and age at surgery, $\chi^2 = 0.388$, $P = 0.534$. There were 4, 41, and 5 instances of complication in the young, senior, and elderly groups, respectively. In young patients, there were 2 incidences of regional complications (1 cerebrospinal fluid leak and 1 wound infection) and 2 incidences of neurologic complication (both hydrocephalus). In senior patients, there were 16 instances of neurologica complication (6 seizures, 4 cerebral infarctions, 5 hydrocephalus, 1 subdural hematoma), 10 regional complications (6 wound infections, 4 cerebrospinal fluid leaks), and 15 systemic complications (2 thromboembolic disease, 1 angioedema, 2 severe hyponatremia, 1 hyperglycemia, 1 panhypopituitarism, 1 myocardial

Table 4. Summary of Statistics (Compared to 80+ Years Old Group)

Characteristic	P Value		
Age group, years	20—29	60—79	20—29 + 60—79
Parametric tests (t test for independent samples)			
Mean mRS Δ (postop mRS — preop mRS)	0.158	0.825	0.963
Mean postoperative stay length	0.074	0.428	0.411
Mean length to follow-up	0.94	0.478	0.523
Mean tumor greatest diameter	0.006	0.459	0.832
Nonparametric tests (z test for independent samples)			
Complications	0.691	0.808	0.878
Neurologic	0.018	0.067	0.051
Regional	0.018	0.001	0.001
Systemic	-	0.082	0.105
30-day morbidity and mortality			
Readmission rate	0.959	0.581	0.63
Mortality rate	0.992	0.976	0.984

mRS, modified Rankin scale score.

infarction, 7 systemic infections). In elderly patients, there were 5 instances of regional complication (4 cases of wound infection and 1 case of cerebrovascular injury on surgical approach). There was no association between incidence of perioperative complications and age, $\chi^2 = 0.565$, P = 0.754; among complications, the relative rate of neurological and systemic complications did not differ by age ($\chi^2 = 5.423$, P = 0.066; $\chi^2 = 5.218$, P =0.074, respectively). However, the relative rate of regional complications did ($\chi^2 = 10.844$; P = 0.004). Thirty-day mortality rates were 1.1%, 1.2%, and 1.2% for the young, senior, and elderly group, respectively, and were not significantly associated with age ($\chi^2 = 0.005$, P = 0.997). In addition, 30-day readmission rates, total rate of complication, and rates of complication subtypes (neurologic, regional, systemic) were compared between groups with 2-sample Z tests (Table 4).

Re-stratification and Assessment

To further explore possible age-related differences in surgical outcome by broadening age range and increasing sample size, patients were re-stratified into 2 new groups: patients younger than 80 years and patients 80 years and older. Functional outcomes were again compared between these 2 groups. An independent sample t test showed there was no significant difference in ΔmRS and postoperative stay length (P = 0.963, power = 0.054; P = 0.411, power = 0.234). Two-tailed Z test showed no significant difference in 30-day readmission rates, incidence of perioperative complications, or 30-day mortality rates between the two new groups (P = 0.63, P = 0.878, P = 0.984, respectively). A summary of all relevant statistics and P values is shown in **Table 4**.

Quantitative data are expressed as mean ± standard deviation. Nominal data are expressed in proportions.

DISCUSSION

The disparity in the rate of clinically indicated cranial surgery offered to geriatric patients is in part due to the general neurosurgical assumption that elderly patients are at greater risk of postoperative complications and mortality after long, invasive surgeries.[12] Some authors argue that this discrepancy is due to preoperative risk factors and comorbidities more closely associated with aging patients and chronic disease, rather than age alone.[34] The association between age and craniotomy outcome remains unclear in part because of a reluctance to enroll elderly patients in clinical trials. Indeed, recent studies have shown that patients 65 years or older are underrepresented in clinical trials by as much as 38% compared with younger patients.[35-37]

Although many studies find worse perioperative outcomes for elderly patients after craniotomy for resection of primary brain tumor,[15-21] some have found that advanced age does not affect perioperative morbidity.[11-14] The discrepancy in these results may be due in part to reliance on data from national databases.[12,15,16,19-21,38] The majority of these studies demonstrate an association between increasing age and risk for morbidity and mortality with surgical resection.[15,16,19-21] Although they provide large sample sizes, national database studies are limited because their data set is created from administrative and financial input, which may not accurately correlate with health status from a medical perspective. Additionally, national database studies are constrained by inherent bias such as intersurgeon and intercenter variability. Specifically, data sourced from low-volume centers and inexperienced surgeons may skew outcome results, as individual surgeon volume has been correlated with patient 30-day mortality and high-volume hospitals have significantly lower morality rates for craniotomies.[16,20,39-41] Thus, the results of these studies must be interpreted with caution.

Other studies are similarly limited by utilization of departmental data from many neurosurgeons at 1 center, which may bias results.[13,14,17,18,42,43] Two multisurgeon single-institution studies investigating craniotomy outcomes for intrinsic and metastatic brain neoplasms found that increased age was an associated risk factor for regional and systemic complications.[8,10] Both studies were conducted with over 200 patients but were published over 15 years ago. One of the studies, performed by Brell et al., also found that severe concomitant disease was an associated risk factor for systemic complications post-craniotomy.[8] Increased disease progression and associated risk factors in older patients may explain the association between age and surgical comorbidity, but this relationship was not explored. Other studies suggest that craniotomy is a well-tolerated procedure in even elderly patients,[8,24,42,44] thus highlighting the discrepancies of the current literature.

Single-surgeon series comparing outcomes in young and elderly patients with similar pathologies may eliminate the confounding variables of intersurgeon and intercenter variability. Here, we present the largest single-surgeon series analyzing perioperative and postoperative outcomes in octogenarian and nonagenarian

patients after brain tumor surgery. We find that craniotomy or TEES outcome does not significantly differ between "elderly" patients (defined as octogenarians and nonagenarians), and "young" patients (defined as those aged 20—29 years) and "senior" patients (defined as those aged 60—79 years) when performed by a single surgeon at a high-volume medical center. We similarly found no significant association between postoperative outcome or 30-day complication rates and age at surgery. Furthermore, our age groups showed statistical homogeneity and were not significantly different in preoperative mRS score or variability in functional outcome. These factors were evaluated because higher mRS scores at presentation have been associated with worse postoperative outcome.[45-47] Thus, our findings are congruent with previous single and multi-institution studies that suggest there is no effect of age on 30-day morbidity and mortality rates when risk factors are controlled for in statistical analyses.[12,42] Therefore, our findings suggest that preoperative age, by itself, is not an independent predictor for postoperative outcome.

Several studies have identified preoperative risk factors for complications that should be considered when evaluating an elderly candidate for surgery. Reponen et al. reported that a composite score of age, American Society of Anesthesiologists (ASA) score, and C-reactive protein level were associated with increased probability of systemic infection postoperatively.[18] However, associations for each individual risk factor was not explored.[18] Other studies have found that worse preoperative mRS and Karnofsky Performance Status (KPS)[48] scores predicted increased length of stay and mortality.[47,49] Although we did not record KPS or ASA scoring in our study, we did not find a significant difference in preoperative mRS scores between our age groups. However, we only offer elective surgery to patients with mRS score less than or equal to 3, so good preoperative functional status does weigh heavily into our preoperative decision-making. Preoperative body mass index and history of previous brain operation have also been found to predict risk of postoperative infection.[50] These factors should be considered when evaluating elderly patients for craniotomy and controlled for in future research evaluating surgical outcome in aging patient populations.

Limitations

First, it is possible that preoperative functional status and health status are confounding variables; that is, the elderly patients in this study may have been healthier preoperatively than the younger patients, thus biasing the results. We believe this effect is negligible, as only patients with a mRS less than or equal to 3 and no major medical comorbidities were offered elective surgery and were thus included in the study. Further, preoperative mRS score was found to not vary significantly among groups.

Second, assessing information from patient chart review is limited by the retrospective nature of the study. We attempted to reduce inter-rater variability by having 1 patient age—blinded researcher assess all patient records and assign mRS values.

The heterogeneity in tumor pathology between groups is worthy of discussion. This may seemingly confound our hypothesis, considering that patient outcome may be related to tumor pathology. However, we focused primarily on the perioperative outcome of invasive craniotomy, with a mean length to follow-up of 15.7 days. Within this time period immediately following surgery, patient outcome has not been shown to significantly differ by pathology.[51,52] Thus, as our intention was to assess immediate postoperative safety of craniotomy in this cohort, we believed it acceptable to compare these patients despite the heterogeneity in tumor pathology. In future studies we will explore long-term outcomes between age groups with subsequent subgroup analysis of individual tumor pathologies.

There was some variability among the age groups regarding case mix. The younger group had a greater percentage of transphenoidal surgery for pituitary adenomas, and the older groups had a greater percentage of open craniotomies for pathologies such as glioblastoma, meningioma, and brain metastasis. Although this case mix variability may be a potential source of bias, if anything this makes our results more clinically significant, as we would expect to have better perioperative outcomes with minimally invasive endoscopic surgery for benign tumors (as were more common in the younger group) than for more invasive open craniotomies for malignant tumors (as were more common in the older group). The fact that we demonstrated statistical equivalence among groups speaks to the fact that healthy elderly patients had similar outcomes to those of younger patients.

In addition, as in the case in many retrospective clinical reports, the observed power of our study is not ideal. Some investigators have suggested this may be due to a lack of sufficient sampling or low effect size.[53] Rather, this is most likely due to a post hoc rather than a priori calculation of observed power. It is well known in the statistical literature that there exists an inverse relationship between post hoc power and P value.[53,54] As explained by Hoenig and Heisey, nonsignificant P values always parallel low powers.[33] Although we reported power for transparency, we also reported the minimum effect size detectable for a power of 0.80 given our study's sample size, as suggested by Helminen and Reito.[54]

Moreover, all surgeries were performed by a single neurosurgical oncologist with extensive expertise in brain tumor surgery at a high-volume center. Thus, our results may not be generalizable to less experienced surgeons or institutions. Additionally, we used a relatively simple 1-dimensional method of estimating preoperative tumor size. Although this method may over- or underestimate actual tumor volume, the method was validated by James et al.[25] Lastly, the data in our study are subject to an inherent selection bias by the lead surgeon (i.e., elderly functional patients were elected for surgical resection whereas functionally dependent patients may have been stratified for stereotactic biopsies, observation and so forth). Therefore, some caution must be taken when extrapolating the data in our study to other institutions.

CONCLUSIONS

Our results suggest that age alone should not prevent clinically viable patients from undergoing craniotomy or TEES for resection of brain tumors with experienced neurosurgeons at high-volume centers. To our knowledge, this is the largest single surgeon study evaluating the effect of age in geriatric patients on outcome after craniotomy or TEES for tumor resection. We believe other age-associated risk factors and variability in surgical experience and institutional output in

brain tumor resection may play a role in discrepancies in the scientific literature. The groups in our study showed significant preoperative homogeneity. Thus, our findings suggest that in appropriately selected patients with good preoperative functional status and no significant medical comorbidities, advanced age alone should not preclude patients from clinically indicated craniotomy or TEES for resection of primary brain tumors when treated at high-volume expert centers.

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