NEUROSURGICAL FOCUS

Neurosurg Focus 49 (4):E17, 2020

Minimally invasive surgical treatment of intracranial meningiomas in elderly patients (≥ 65 years): outcomes, readmissions, and tumor control

Jai Deep Thakur, MD,[1–3] Regin Jay Mallari, BS,[1] Alex Corlin, BA,[1] Samantha Yawitz,[1] Weichao Huang, MD,[1] Amy Eisenberg, MSN, ARNP, CNRN,[1] Walavan Sivakumar, MD,[1,2] Howard R. Krauss, MD,[1,2] Chester Griffiths, MD,[1,2] Garni Barkhoudarian, MD,[1,2] and Daniel F. Kelly, MD[1,2]

[1]Pacific Neuroscience Institute, and [2]John Wayne Cancer Institute, Providence Saint John's Health Center, Santa Monica, California; and [3]University of South Alabama, Mobile, Alabama

OBJECTIVE Increased lifespan has led to more elderly patients being diagnosed with meningiomas. In this study, the authors sought to analyze and compare patients ≥ 65 years old with those < 65 years old who underwent minimally invasive surgery for meningioma. To address surgical selection criteria, the authors also assessed a cohort of patients managed without surgery.

METHODS In a retrospective analysis, consecutive patients with meningiomas who underwent minimally invasive (endonasal, supraorbital, minipterional, transfalcine, or retromastoid) and conventional surgical treatment approaches during the period from 2008 to 2019 were dichotomized into those ≥ 65 and those < 65 years old to compare resection rates, endoscopy use, complications, and length of hospital stay (LOS). A comparator meningioma cohort of patients ≥ 65 years old who were observed without surgery during the period from 2015 to 2019 was also analyzed.

RESULTS Of 291 patients (median age 60 years, 71.5% females, mean follow-up 36 months) undergoing meningioma resection, 118 (40.5%) were aged ≥ 65 years and underwent 126 surgeries, including 20% redo operations, as follows: age 65–69 years, 46 operations; 70–74 years, 40 operations; 75–79 years, 17 operations; and ≥ 80 years, 23 operations. During 2015–2019, of 98 patients referred for meningioma, 67 (68%) had surgery, 1 (1%) had radiosurgery, and 31 (32%) were observed. In the 11-year surgical cohort, comparing 173 patients < 65 years versus 118 patients ≥ 65 years old, there were no significant differences in tumor location, size, or outcomes. Of 126 cases of surgery in 118 elderly patients, the approach was a minimally invasive approach to skull base meningioma (SBM) in 64 cases (51%) as follows: endonasal 18, supraorbital 28, minipterional 6, and retrosigmoid 12. Endoscope-assisted surgery was performed in 59.5% of patients. A conventional approach to SBM was performed in 15 cases (12%) (endoscope-assisted 13.3%), and convexity craniotomy for non–skull base meningioma (NSBM) in 47 cases (37%) (endoscope-assisted 17%). In these three cohorts (minimally invasive SBM, conventional SBM, and NSBM), the gross-total/near-total resection rates were 59.5%, 60%, and 91.5%, respectively, and an improved or stable Karnofsky Performance Status score occurred in 88.6%, 86.7%, and 87.2% of cases, respectively. For these 118 elderly patients, the median LOS was 3 days, and major complications occurred in 10 patients (8%) as follows: stroke 4%, vision decline 3%, systemic complications 0.7%, and wound infection or death 0. Eighty-three percent of patients were discharged home, and readmissions occurred in 5 patients (4%). Meningioma recurrence occurred in 4 patients (3%) and progression in 11 (9%). Multivariate regression analysis showed no significance of American Society of Anesthesiologists physical status score, comorbidities, or age subgroups on outcomes; patients aged ≥ 80 years showed a trend of longer hospitalization.

CONCLUSIONS This analysis suggests that elderly patients with meningiomas, when carefully selected, generally have excellent surgical outcomes and tumor control. When applied appropriately, use of minimally invasive approaches and endoscopy may be helpful in achieving maximal safe resection, reducing complications, and promoting short hospitalizations. Notably, one-third of our elderly meningioma patients referred for possible surgery from 2015 to 2019 were managed nonoperatively.

https://thejns.org/doi/abs/10.3171/2020.7.FOCUS20515

KEYWORDS meningioma; elderly; intracranial; tumor; endoscopic; keyhole

ABBREVIATIONS ASA = American Society of Anesthesiologists; EBL = estimated blood loss; GTR = gross-total resection; KPS = Karnofsky Performance Status; LOS = length of hospital stay; NTR = near-total resection; SRS = stereotactic radiosurgery; STR = subtotal resection.

SUBMITTED June 1, 2020. **ACCEPTED** July 21, 2020.
INCLUDE WHEN CITING DOI: 10.3171/2020.7.FOCUS20515.

Intracranial meningiomas are the most common primary brain tumor, and in most adult surgical series, almost half of meningioma patients are ≥ 65 years old.[1] Secondary to improved life expectancy and advances in neurodiagnostics, there appear to be increasing numbers of elderly patients with intracranial meningiomas who are surgical candidates. Prior studies have assessed major risk factors and surgical outcomes in elderly patients; however, there are limited reports of studies in which stratification of elderly patients by age was performed, and there is a paucity of reports assessing outcomes in elderly patients undergoing keyhole or minimally invasive surgical approaches.[2–6] We analyzed the surgical indications, risk factors, outcomes, complications, readmission rates, and tumor control in elderly patients (≥ 65 years) undergoing a minimally invasive approach for the removal of skull base and non–skull base meningiomas. The primary goal of this study was to highlight surgical outcomes and the potential benefits and disadvantages of a minimally invasive strategy in elderly meningioma patients. As such, our outcomes are stratified separately for patients with skull base meningiomas undergoing a minimally invasive keyhole approach, those undergoing a conventional skull base approach, and patients with non–skull base meningiomas.[7] To emphasize the importance of patient selection and management of incidentally discovered meningiomas, we also present a comparator cohort of patients referred to our clinic for meningioma who were managed without surgery.[8,9]

Methods

Patient Population

All patients who underwent surgical removal of an intracranial meningioma between January 2008 and August 2019 were identified. All operations were performed by neurosurgeons (D.F.K. or G.B.) at the Pacific Neuroscience Institute/John Wayne Cancer Institute, and all surgeries performed were neither overlapping nor concurrent.[10] A retrospective analysis of a prospectively maintained database was done for consecutive meningioma patients from January 2008 to August 2019. This study was approved by the Institutional Review Board of the John Wayne Cancer Institute and Saint John's Providence Hospital, Santa Monica, California.

Minimally Invasive Approach

Since 2008, we have rarely utilized traditional open craniotomies for resection of skull base meningiomas at our institute. Instead, we have increasingly applied keyhole approaches, which we define as the use of a minimally invasive approach for a given tumor for which a conventional larger transcranial approach is often used instead. These keyhole approaches include 5 specific routes: the endoscopic endonasal route and 4 transcranial routes: supraorbital eyebrow, minipterional, and retromastoid approaches, and a gravity-assisted transfalcine approach. The specifics of these different approaches have been previously described by our group.[11–17] For the endonasal route, in 2008–2009 endoscope assistance was used, but since 2010 a fully endoscopic approach has been used with a binostril two-surgeon approach performed by a neurosurgeon and otolaryngologist (ENT).[16–18] For the keyhole craniotomies, no rigid brain retraction system was utilized.[11,16,17,19]

Patients with non–skull base convexity meningiomas and those with tentorial-based or falx-based meningiomas undergo a focused craniotomy with the bone flap following the smallest dimensions of the tumor, or a craniotomy that allows the most minimal amount of brain manipulation. In some instances, the ideal approach is a keyhole supraorbital or minipterional route to frontal and middle fossa meningiomas, or a gravity-assisted transfalcine approach to contralateral falx meningiomas (as we have previously described for brain metastases).[11]

Outcome and Statistical Analysis

Elderly patients were defined as ≥ 65 years old per the definition used by the WHO.[1] Preoperative American Society of Anesthesiologists (ASA) scores and comorbidities were noted for elderly patients undergoing removal of their intracranial meningioma. Patient demographic and tumor-related data were collected from the electronic medical record. Indications for surgery, including symptoms, tumor growth, mass effect, peritumoral edema, failed prior surgery, and/or radiation, were noted. Outcomes were dichotomized to short-term 90-day outcomes and long-term outcomes; 90-day outcomes primarily included all perioperative complications, return to the operating room, and readmissions. Surgical resection was categorized as follows: 1) gross-total resection (GTR), 2) near-total resection (NTR; ≥ 90% tumor resection with intentional residual tumor left over the neurovascular entity), or 3) subtotal resection (STR; < 90% tumor resection). Simpson resection classification was not used, given that in this series of meningiomas, a majority of patients had meningiomas with extension invasion into the cavernous sinus, Meckel's cave, optic canal, orbit, infratemporal fossa, and/or paranasal sinuses, where complete resection of the involved bone and dura is typically not possible. Length of hospital stay (LOS) and discharge to home or rehabilitation were also recorded. To assess long-term outcomes, elderly patients undergoing surgery were analyzed for progression of residual tumor or recurrence and its management and functional outcome (Karnofsky Performance Status [KPS] score).

Observational Cohort

From 2015 onward (when our electronic medical record became operational), to detail the patients' demographic information and clinical and imaging presentation, we collected data on all elderly patients referred to our clinic for a presumed meningioma who were managed conservatively, without surgery. Using the same time frame (2015–2019) used for the operated cohort, we determined the proportion of operated versus nonoperated patients and compared their clinical characteristics.

Statistical Analysis

Statistical comparison of the means in the data among different groups was performed using ANOVA and Student t-tests. For LOS and comparing medians, we used nonpara-

TABLE 1. Characteristics of 31 elderly patients with meningioma managed conservatively without surgery

Pt No.	Age, Sex	Tumor Location	Max Tumor Diameter (mm)	Peritumoral Edema	Etiology for Imaging	FU	Latest FU Status
1	73, F	Convexity	30	No	Headaches	5 mos	Asymptomatic, stable
2	74, F	Convexity	33	Yes	Incidental, metastasis WU	12 mos	Asymptomatic, stable
3	76, F	Convexity	12	No	Dementia	50 mos	Asymptomatic, stable
4	77, M	Convexity	16	No	Incidental, trauma evaluation	6 mos	Asymptomatic, stable
5	80, F	Convexity	54	No	TIA	60 mos	Asymptomatic, stable
6	81, M	Convexity	31	Yes	Incidental, WU for IPH	24 mos	Interval growth, patient chose radiological FU
7	84, F	Convexity	17	No	Syncope	52 mos	Asymptomatic, stable
8	85, M	Convexity	32	No	Dementia	32 mos	Asymptomatic, stable
9	85, F	Convexity	30	No	Headaches	19 yrs	Asymptomatic, stable
10	89, M	Convexity	20	No	Dementia	No FU	
11	89, M	Convexity	11	Yes	Incidental, trauma WU	48 mos	Asymptomatic, stable
12	90, M	Convexity	38	No	Dementia	No FU	
13	93, M	Convexity	12	No	Ataxia	43 mos	Asymptomatic, stable
14	67, F	CPA	11	No	Incidental, CIDP WU	12 mos	Asymptomatic, stable
15	80, F	CPA	20	No	Syncope	120 mos	Asymptomatic, stable
16	69, F	CS	14	No	Intermittent diplopia	14 mos	Stable, intermittent diplopia
17	86, F	Middle fossa	17	No	Incidental, metastasis WU	24 mos	Asymptomatic, stable
18	72, F	Middle fossa, CS	38	No	Incidental, no neurological symptoms	84 mos	Asymptomatic, stable
19	75, F	Olfactory groove	26	No	Incidental, metastasis WU	43 mos	Asymptomatic, stable
20	67, F	Parafalcine	7	No	Incidental, vetigo WU	48 mos	Asymptomatic, stable
21	70, F	Parafalcine	12	No	Incidental, no neurological symptoms	12 mos	Asymptomatic, stable
22	74, F	Parafalcine	26	No	Incidental, no neurological symptoms	120 mos	Stable, intermittent headaches
23	75, M	Parafalcine	28	Yes	Incidental, no neurological symptoms	144 mos	Asymptomatic, stable
24	85, F	Parafalcine	12	No	Vision loss WU	4 mos	Asymptomatic, stable
25	87, F	Parafalcine	43	Yes	Incidental, no neurological symptoms	13 yrs	Asymptomatic, stable
26	68, F	Tentorial	15	No	Incidental, vertigo WU	3 mos	Asymptomatic, stable
27	69, F	Tentorial	23	No	Incidental, vertigo, syncope WU	31 mos	Asymptomatic, stable
28	74, F	Tentorial	19	No	Incidental, spine WU	72 mos	Asymptomatic, stable
29	87, F	Tentorial	21	No	Incidental, dehydration WU	No FU	
30	74, F	Tuberculum sellae	9	No	Blurry vision	12 mos	Stable, blurry vision not from tumor
31	69, F	Tentorial	28	Yes	Incidental, hearing loss WU	84 mos	SRS for tumor growth, no growth at 18-mo FU

CIPD = chronic inflammatory demyelinating polyneuropathy; CPA = cerebellopontine angle; CS = cavernous sinus; FU = follow-up; IPH = intraparenchymal hemorrhage; pt = patient; TIA = transient ischemic attack; WU = workup.

metric tests, including Kruskal-Wallis. Univariate analysis was done using chi-square studies, and if the number in one of the 2 × 2 grids was > 5, we used Fisher's exact test. Binomial multivariate analysis was done using multivariate regression analysis, and p values < 0.05 were considered statistically significant. Survival curves for testing binomial variables were plotted using Cox regression, and Kaplan-Meier survival curve graphs were plotted.

Results

Elderly Patients Managed Conservatively

From 2015 to 2019, of 97 patients seen in our clinic for presumed meningioma, 69% had surgery and 31% were observed. The 31 patients observed (Table 1) had a mean age of 78 ± 8.2 years, and tumor location was convexity in 13 patients, skull base in 7, parafalcine in 6, and tentorial in 5 patients. The mean maximal tumor diameter was 22.5 ± 11 mm. In comparison, the patients undergoing surgery had a mean age of 72 ± 6 years and mean tumor diameter of 35 ± 6 mm (p = 0.45). Follow-up data were available in 28 of 31 conservatively managed patients (range 3 months–19 years), and 26 of 28 patients were clinically stable with stable tumor diameter. One patient opted to continue monitoring despite tumor growth as he remained clinically stable. One patient opted for stereotactic radiosurgery (SRS; 2750 cGy over 5 fractions [550 cGy × 5]) after substantial growth of her tentorial me-

TABLE 2. Comparison of nonelderly and elderly patients undergoing surgery for meningioma

	Cases (n = 323 ops in 291 pts)		
	Nonelderly (n = 197 ops in 173 pts)	Elderly (n = 126 ops in 118 pts)	p Value
Age, yrs	<65	≥65	
Preop KPS score >70	165 (83.8)	92 (73)	0.02
Skull base	134 (68)	79 (62.7)	0.32
Mean max tumor diameter, mm	33	35	0.22
Invasion to Meckel's cave/CS/orbit/infratemporal fossa	51 (26)	29 (23)	0.56
Tumor w/ vascular encasement	116 (59)	71 (56.3)	0.65
Redo op	48 (24.4)	25 (20)	0.10
Prior radiation	32 (16.2)	11 (8.7)	0.053
Keyhole approach, total	132 (67)	70 (55.5)	0.40
Endoscopic endonasal	51 (38.5)	18 (25.7)	
Supraorbital	34 (25.7)	32 (45.7)	
Minipterional	11 (8.3)	7 (10)	
Retromastoid	33 (25)	12 (17.2)	
Transfalcine	3 (0.5)	1 (1.4)	
Endoscope use during op	98 (49.7)	55 (43.6)	0.42
GTR/NTR	132 (67)	90 (71.4)	0.40
Mean EBL, ml	332 ± 374	216 ± 326	0.7
Mean op duration, mins	337 ± 166	295.1 ± 138	0.01
Median LOS, days	3 (1–27)	3 (1–20)	0.55
LOS >5 days	15 (7.6)	16 (12.7)	0.13
Good functional outcome (improved/stable postop KPS score)	164 (83.2)	112 (88.2)	0.22
Major complication	16 (8)	11 (8.7)	0.62
Readmission w/in 90 days	11 (5.6)	5 (4)	0.51

Values are presented as number of operations (%), median (range), or mean ± SD, unless otherwise indicated.

ningioma over several years. Subsequently, at the time of this report, her tumor has remained stable for 18 months following SRS.

Demographic and Preoperative Clinical Factors

The surgical cohort operated on between 2008 and 2019 included 291 patients (median age 60 years [range 24–93 years], 71.5% females, mean follow-up 36 months) who underwent 323 operations (23% redo, skull base, 213/323, 66%). Of these 323 operations, 126 (39%) were performed in 118 elderly patients (age 65–69 years, 46 operations; 70–74 years, 40 operations; 75–79 years, 17 operations; and ≥ 80 years, 23 operations). Of these operations, 25 of 126 (20%) were redo operations; 79 (63%) were for skull base meningiomas, and 47 (37%) were for non–skull base meningiomas. The number of patients with preoperative KPS score ≥ 70 was higher in the nonelderly cohort (165 [83.8%] vs 92 [73%], p = 0.02). There were no significant differences in tumor location, maximum tumor diameter, invasiveness to Meckel's cave/cavernous sinus/orbit/infratemporal fossa, and vascular encasement between the two groups (Table 2). In the elderly group, 92 cases (73%) had an ASA score of ≥ 3. Tumor pathology was WHO grade I in 106 tumors (84%), WHO grade II in 19 tumors (15%), and WHO grade III in 1 tumor (1%).

Indications for Surgical Management in the Elderly Cohort

Surgical indications for the elderly patients with meningiomas are stratified in Table 3. The most common indication for surgery in our series was tumor-related neurological symptoms with or without peritumoral edema (67/126, 53.2%). Among the patients undergoing surgery, 8 patients presented with their meningioma as an incidental finding. Of these 8 patients, peritumoral edema was noted in 4 patients; the mean maximal tumor diameter in the 4 patients without edema was 25 ± 15 mm.

Tumor Description, Intraoperative Characteristics, Complications, and Functional Outcomes in the Elderly Population

Skull Base Meningiomas: Minimally Invasive Approach

Of the total 126 operations performed in 118 patients, surgery for skull base meningioma was performed in 79 cases (63%) and, of these, 14 cases (17.7%) were redo operations and 5 of the patients had had previous radiation treatment. A minimally invasive approach was used in 64 skull base operations (81%) (endonasal 18, supraorbital 28, minipterional 6, retrosigmoid 12), and a conventional skull base approach was used in 15 (19%) (middle fossa 5, pterional 10). For the 64 operations with a minimally invasive approach, 50 (63.3%) were in patients with an ASA score ≥ 3, and ≥ 3 comorbidities were present in 39 of

TABLE 3. Indications for surgical intervention in elderly meningioma patients

Indications for Surgery	No. of Cases (%)
Clinical symptoms	34 (27)
Peritumoral edema and clinical symptoms	33 (26.2)
Tumor growth, peritumoral edema, clinical symptoms	13 (10.3)
Tumor growth	12 (9.5)
Tumor growth, clinical symptoms	10 (7.9)
Symptomatic recurrence	8 (6.3)
Tumor growth, peritumoral edema	7 (5.6)
Incidental, peritumoral edema	4 (3.2)
Incidental, patient preference	4 (3.2)
Staged surgery	1 (0.8)
Total	126

TABLE 4. Neurological complications, systemic complications, and readmissions

Complication	No. of Pts
Major neurological (n = 10, 7.9%)*	
Stroke	5
Hematoma	2
Worsening vision	4
Wound infection	0
Meningitis	0
CSF leak	0
Major systemic complications (n = 1, 0.8%)	
Aspiration pneumonia	1
DVT/PE/cardiac event	0
Readmissions (n = 5, 4%)	
SDH (managed conservatively)	2
Worsening brain edema	1
Seroma	1
Transient neurological decline	1

DVT = deep vein thrombosis; PE = pulmonary embolism; SDH = subdural hematoma.
* One patient had both postoperative hematoma and stroke.

these 64 patients (61%). The mean maximal tumor diameter was 31 ± 13 mm; tumors with a maximum diameter of > 3 cm were seen in 29 cases (45%), and invasiveness to Meckel's cave/cavernous sinus/orbit/infratemporal fossa was seen in 28 of the 79 skull base meningioma cases (35.4%). In these 79 cases, GTR was achieved in 33 cases (41.8%) and GTR/NTR combined was achieved in 47 cases (59.5%). Of the 64 cases in which a minimally invasive approach was used for skull base meningiomas, 40 (62.5%) had one of the following resectability-limiting features: 1) invasiveness to Meckel's cave/cavernous sinus/orbit/infratemporal fossa, 2) redo operation, or 3) lack of an arachnoid plane and adherence to neurovascular structures. The GTR/NTR rates in patients with these limiting factors in comparison to the rates in patients lacking these risk factors were 35% (14/40) versus 100% (24/24) ($p < 0.001$).

Apart from the 18 patients with skull base meningiomas who underwent an endoscopic endonasal approach, endoscopy was utilized in 29 of the 47 nonendonasal skull base cases (62%). Endoscopy was deemed helpful in achieving additional tumor removal in 12 patients (41.4%). Of the 29 craniotomy cases for which an endoscope was useful for additional removal, in 5 of 12 cases (41.7%) NTR was converted to GTR with the use of endoscopy.

The mean duration of surgery for the overall cohort was 326 ± 137 minutes, the mean estimated blood loss (EBL) was 291.5 ± 287 ml, and the mean and median LOS were 3.7 and 3 days. LOS > 5 days in the young versus elderly cohort occurred in 7.6% versus 12.7% of patients, respectively ($p = 0.13$). Major complications occurred in 8 of 64 cases (12.5%) and are detailed in Table 4. There was 1 readmission within 90 days for a chronic subdural hematoma that was managed conservatively. Improved or stable KPS scores were seen in 57 of 64 cases (89.1%) at the latest follow-up.

Skull Base Meningiomas: Conventional Approach

Of 15 patients who underwent a conventional surgical approach (middle fossa 5, pterional 10), 11 patients (73%) had an ASA score of ≥ 3, and 8 patients (53.3%) had ≥ 3 comorbidities. The mean maximum tumor diameter was 37 mm. GTR was achieved in 7 of 15 patients (46.6%) and GTR/NTR was achieved in 9 of 15 patients (60%). GTR/NTR rates in patients with limiting factors (as mentioned above) in comparison with the rates in patients without these risk factors were 45.5% (5/11) versus 100% (4/4) ($p = 0.05$). Endoscope assistance was used in 2 patients and was helpful in removing additional tumor in 1 patient. The mean duration of surgery was 239 ± 79 minutes. The mean EBL was 367 ± 362 ml, and the mean and median LOS were 4.8 and 4 days, respectively. Major complications were seen in 2 cases (13%), including 1 hospital readmission within 90 days for a chronic subdural hematoma that was managed conservatively. An improved or stable KPS score was seen in 13 patients (86.7%) at the latest follow-up.

Non–Skull Base Meningiomas

Of the total 47 operations in 43 patients for non–skull base (predominantly convexity) meningiomas, 7 cases (15%) were redo operations, of which 4 cases had been treated with prior radiation, and ASA scores ≥ 3 were found in 42 cases (89%) and ≥ 3 comorbidities in 23 cases (48.9%). The mean maximum tumor diameter was 42 mm. Of the 47 non–skull base operations, 6 (13%) were performed via keyhole approaches. Of the 41 conventional nonkeyhole skull base approaches, GTR was achieved in 28 of 41 cases (68.2%) and GTR/NTR was achieved in 37 of 41 cases (90.2%). Endoscopy was used in 8 of 47 cases (17%) (a supraorbital approach for anterior frontobasal meningioma in 4 cases, frontal craniotomy for parafalcine meningioma in 2 cases, minipterional for frontal convexity meningioma in 1 case, and gravity-assisted transfalcine for parafalcine meningioma in 1 case). Use of the endoscope allowed for additional tumor removal in

TABLE 5. Elderly meningioma patient characteristics and surgical outcomes, stratified by age group

	Age Group, Yrs				p Value
	65–69	70–74	75–79	≥80	
Total no. of ops (n = 126)	46	40	17	23	
ASA score ≥3 (n = 92)	28 (61)	30 (75)	15 (88.2)	19 (82.6)	0.08
≥3 comorbidities	18 (39)	15 (37.5)	11 (64.7)	18 (78.3)	0.004
KPS score stable/improved	42 (91.3)	33 (82.5)	15 (88.2)	21 (91.3)	0.59
Redo op (n = 21)	5 (11)	8 (20)	3 (17.6)	5 (21.7)	0.60
Skull base tumor (n = 79)	28 (61)	27 (67.5)	10 (58.8)	14 (61)	0.89
GTR/NTR	35 (76)	28 (70)	13 (76.5)	14 (61)	0.57
Max tumor diameter, mm	32	34.6	35.7	41.8	0.12
Mean EBL, ml	287	310	207	455	0.19
Mean op duration, mins	296	296	300	286	0.99
Mean LOS, days*	3.4	3.4	3.3	3.9	0.88

Values are presented as number of patients (%) unless otherwise indicated.
* Median LOS 3 days in all groups.

7 of 8 cases (87.5%), and in 6 of 7 cases (86%) NTR was converted to GTR with endoscopy. The mean duration of surgery was 237 ± 121 minutes, the mean EBL was 354 ± 488 ml, and the mean and median LOS were both 3 days. Major complications occurred in 5 of the 47 cases (11%), and there were 3 readmissions within 90 days. Improved or stable KPS scores were seen in 41 cases (87.2%) at the latest follow-up.

LOS and Complications

In the overall cohort of 118 elderly patients, LOS > 5 days, which occurred in 16 cases (12.7%), did not significantly differ in patients with an ASA score of ≥ 3 or more, more comorbidities (≥ 3), higher preoperative KPS score (> 70), good functional outcome, history of prior radiation or surgery, larger tumor diameter (≥ 3 cm), or GTR versus NTR resection. However, among the elderly patients (≥ 65 years old) the analysis showed longer LOS in patients aged ≥ 80 (12/39, 30.8%) or 70–74 (12/39, 30.8%) years than in patients aged 65–69 (9/39, 23.1%) or 75–79 (6/39, 15.4%) years. Multivariate regression analysis, when controlled for ASA score and comorbidities, did not show significant differences within the groups but showed a trend of longer LOS in the group of patients aged ≥ 80 years. Similarly, multivariate analysis showed no statistically significant association of ASA score or comorbidities with achievement of a good functional outcome in the elderly subgroups.

Overall, major neurological complications were seen in 10 of the patients (7.9%), a major systemic complication in 1 patient, and readmission in 5 patients (Table 4). Of the 5 patients who had strokes, none were neurologically devastated, all had improvement of symptoms and maintained good quality of life at last follow-up, and none of them had a KPS score decline to < 80.

A subgroup analysis among the elderly population revealed no significant differences in any of the patient/tumor/intraoperative/functional outcome features, except that the ≥ 80-year age group had a higher number of comorbidities (Table 5). In total, 83.4% of patients were discharged home, while 16.6% went to a short-term rehabilitation center/skilled nursing facility. Table 6 highlights the resection rates, complications, and LOS for different surgical approaches and compares the minimally invasive approaches with the conventional approaches. Notably, no endonasal approaches resulted in GTR, because in

TABLE 6. Meningioma resection rates, complication rates, and LOS by minimally invasive and conventional surgical approaches

	Endonasal (n = 18)*	Supraorbital (n = 32)	Minipterional (n = 7)	Retrosigmoid/Suboccipital (n = 12)	Transfalcine (n = 1)	p Value
GTR	0 (0)	17 (53)	5 (71.4)	9 (75)	0 (0)	<0.001
GTR/NTR	1 (5.6)	25 (78)	6 (85.7)	11 (91.7)	1 (100)	<0.001
Complications	1 (5.6)	6 (18.8)	1 (14.3)	0 (0)	0 (0)	0.34
Median LOS, days	2	3	2	2	3	0.16
LOS >5 days	4 (22.2)	4 (12.5)	0 (0)	1 (8.3)	0 (0)	0.53
	Pterional Skull Base (n = 10)	Middle Fossa Skull Base (n = 5)	Pterional Non–Skull Base (n = 3)	Convexity/Parafalcine (n = 38)	—	p Value
GTR	4 (40)	3 (71.4)	3 (100)	25 (65.8)	—	<0.001
GTR/NTR	5 (50)	4 (80)	3 (100)	34 (89.5)	—	<0.001
Complications	1 (10)	0 (0)	0 (0)	1 (2.6)	—	0.34
Median LOS, days	4	2	2	2.5	—	0.16
LOS >5 days	3 (30)	1 (20)	0 (0)	3 (8)	—	0.53

Values are presented as number of cases (%) unless otherwise indicated.
* Sixteen of 18 cases had extensive cavernous sinus/Meckel's cave invasion, and surgical goals in these patients were tumor debulking and bony decompression; 2 of 18 cases had dense adhesions to neurovascular structures.

TABLE 7. Meningioma recurrence and progression for different patient cohorts and clinical variables

	Recurrence/Progression (n = 15)	p Value
Age, yrs		0.03
65–69	2 (1.7)	
70–74	6 (5.1)	
75–79	1 (0.8)	
≥80	6 (5.1)	
Redo cases	4 (3.4)	0.14
First op cases	11 (9.3)	
Skull base	11 (9.3)	0.2
Non–skull base	4 (3.4)	
GTR	4 (3.4)	0.03
Non-GTR	11 (9.3)	
GTR/NTR	9 (7.6)	0.2
STR	6 (5.1)	

Values are presented as number of cases (%).

16 of 18 cases the patients had extensive cavernous sinus or Meckel's cave invasion and the goals of surgery were tumor debulking and bony decompression, and the 2 additional patients had dense neurovascular adhesions precluding GTR.

Tumor Control

Of the 118 elderly patients, follow-up of ≥ 3 months was available in 102 patients (mean 35.3 months, range 3–126 months). Of these 102 patients, recurrence was seen in 4 patients (3.9%) and progression of residual tumor was noted in 11 patients (10.8%). Of these 15 patients, pathology was grade I in 11 patients (73.3%) and grade II in 4 patients (26.7%). The mean time to recurrence was 19 months and to progression was 28 months. Univariate analysis showed that the 70- to 74-year and ≥ 80-year age groups had relatively higher recurrence/progression rates than the other age groups (Table 7). The mean times to progression or recurrence for different elderly cohorts were +18 months for the 65- to 69-year age group; 28 months for the 70- to 74-year age group; 5 months for the 75- to 79-year age group; and 17.3 months for the ≥ 80-year age group. Further associations of tumor control with redo surgery, skull base location, and GTR are depicted in Kaplan-Meier curves (Fig. 1).

Multivariate regression analysis, when controlled for the above clinical factors, including ASA score and comorbidities, did not reveal statistical significance in recurrence or progression rates between the elderly patient groups. Of the 15 patients with recurrence/progression, 8 were managed with stereotactic radiation therapy, 2 with medical management (chemotherapy), 2 with repeat surgery, and 1 with a combination of radiotherapy and surgery. Of these 15 patients, 3 patients had another recurrence, which required further treatment with surgery, surgery + stereotactic radiotherapy, and chemotherapy, respectively (Supplemental Table 1).

Discussion

Decision for Surgery and Preoperative Evaluation

Intracranial meningiomas are the most common primary brain tumors, as recognized by the CBTRUS (Central Brain Tumor Registry of the United States), whose recent report showed that 49% of meningioma patients were ≥ 65 years old.[1] Considering that most meningiomas are benign (typical) and have the highest incidence, neurosurgeons frequently encounter these patients in their practices. Numerous prior articles have questioned whether elderly patients should be offered surgery and what the key criteria are for surgery, radiation/radiosurgery versus conservative management.[5,18–22] As shown in this cohort, we propose that similar to younger patients, elderly patients with symptomatic meningiomas, those with significant mass effects with or without peritumoral edema, and those with MRI-documented tumor progression are reasonable candidates for surgery.[25] However, surgery is clearly not warranted in all patients with meningiomas, and many patients > 65 years can be observed, which was the case in our cohort from 2015 to 2019, when almost a third of patients we saw in our clinic were counseled against surgery and instead recommended watchful waiting with serial MRI studies.[8,9]

Notably, some symptomatic elderly patients who have significant preexisting conditions, who are at a higher risk of general anesthesia, and/or who have primary cavernous sinus meningiomas or smaller growing meningiomas can potentially be managed safely with stereotactic radiotherapy or radiosurgery alone.[22,23,26,27] Giving patients this option is an important part of the informed consent process and was the treatment opted for by 1 patient with an incidental but growing posterior fossa convexity/tentorial meningioma, who was doing well at the time of this report, 18 months after SRS, and was without further tumor growth.

Preoperative and Anesthesia Considerations

All of our patients undergo thorough medical clearance and further subspecialty clearance as recommended by the medicine physician, clearance that is further evaluated by our neuro-anesthesia team before surgery. Any systemic concerns or patients with ASA scores of 4 are extensively discussed in a multidisciplinary fashion, and then we proceed with surgery once the patient's safety is established. The type of general anesthesia, especially in elderly patients, likely plays an important role in the recovery process. Our neuro-anesthesia team uses propofol-based total intravenous anesthesia as it has been shown to decrease the risk of postoperative cognitive dysfunction.[28]

Do Patients Benefit From a Minimally Invasive Approach?

Ekşi et al. recently published an extensive review of literature on complications encountered during surgery of elderly patients with intracranial meningiomas.[29] The review reported an overall postsurgical complication rate in elderly patients of 33.64%. Further, studies that reported neurological and systemic complications separately demonstrated 18.3% and 16.4% complication rates, respectively.[29] Thirty-day mortality was 4.3% (range 0%–55%). In addition to the reported outcomes, we reviewed the in-

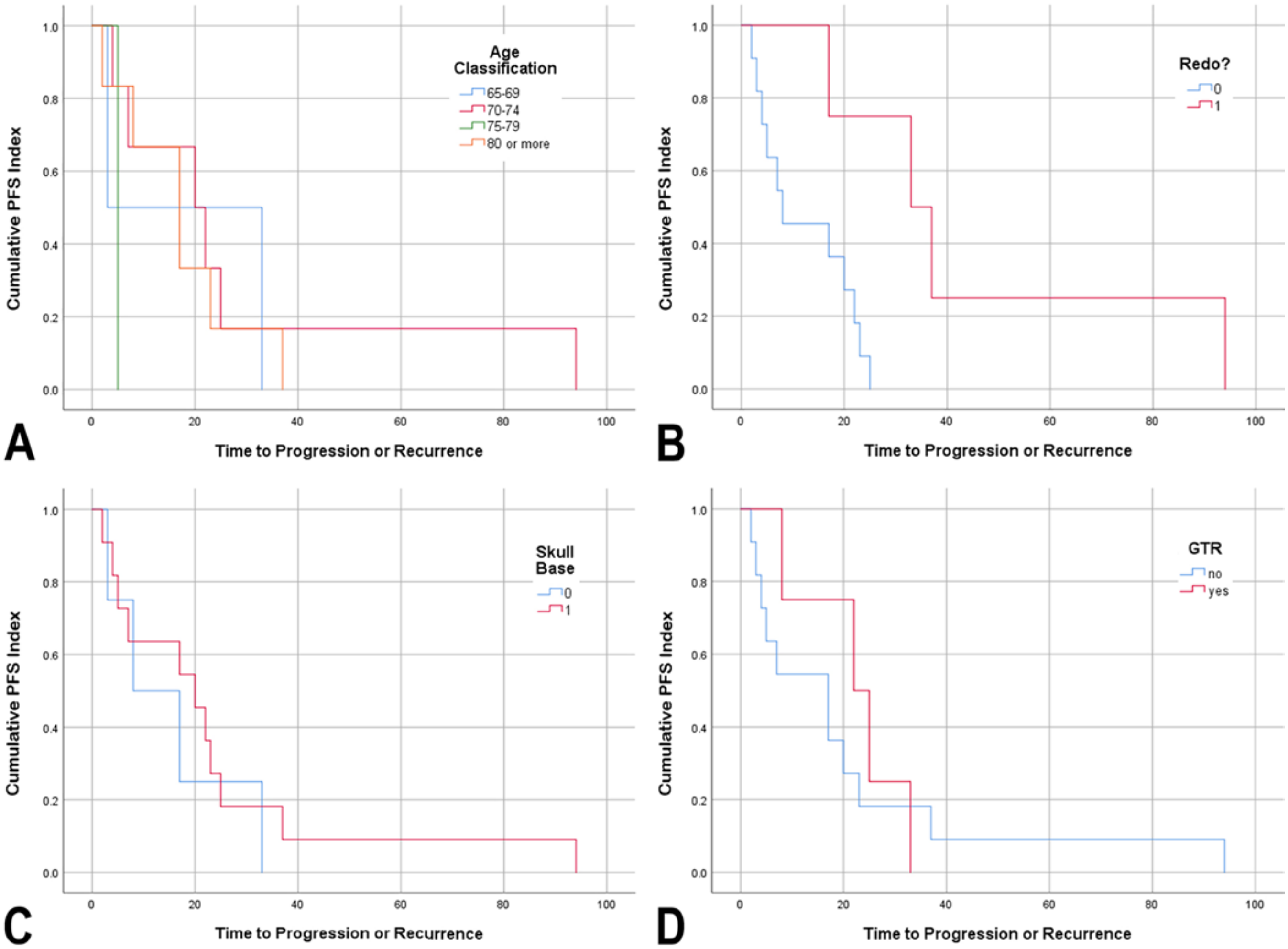

FIG. 1. Mean times to progression or recurrence in the elderly patient cohort. **A:** By age: 65–69 years, 18 months; 70–74 years, 28 months; 75–79 years, 5 months; and ≥ 80 years, 17.3 months. **B:** First-time cases, 12.3 months; redo cases, 45.2 months ($p = 0.01$). **C:** Skull base meningiomas, 15 months; non–skull base meningiomas, 23 months. **D:** GTR cases, 22 months; non-GTR cases, 20.8 months. PFS = progression-free survival.

cluded studies by Ekşi et al. and noted that the mean LOS was reported in 9 studies[5,20,30–36] and ranged between 4 and 25.7 days, with a mean LOS of 14.3 days. Of the 9 studies that reported LOS, 8 studies (89%) had a mean LOS > 5 days. Our mean and median LOS were 3.7 and 3 days, respectively, for the minimally invasive skull base approach cohort, and only 12.7% of our patients had an LOS > 5 days. A small proportion of our patients required narcotics at discharge, and no patients were prescribed narcotics beyond postoperative days (PODs) 10–14.

In our study, good functional outcomes (stable or improved KPS scores) were seen in 88% of cases. Neurological complications were seen in 12 cases (10%), a systemic complication (aspiration pneumonia) was seen in 1 patient (0.8%), and readmissions occurred in 5 cases (4%). No prior study to our knowledge has reported readmission rates in an elderly patient population undergoing meningioma resection. Our 90-day mortality rate was 0%. Notably, we counsel our patients and their families prior to surgery that they will likely be able to leave the hospital by POD 2, mentally preparing them for a relatively short hospital stay; 83.4% of our patients were discharged to home in this series.

Steinberger et al. evaluated the American College of Surgeons National Surgical Quality Improvement Program database to determine the safety of meningioma resection in 1568 patients.[24] These investigators found that octogenarians had a 30-day mortality rate of 8.6% and an overall complication rate of 31.2%. Compared with younger patients, octogenarians had a 16-fold increase in the odds of death within 30 days, a 2-fold increase in the odds of experiencing any complication, and a 3-fold increase in prolonged LOS. In the present study, overall outcomes, complication rates, and LOS in patients > 80 years were similar to those in other elderly populations.

Surgical Philosophy for Meningiomas

The use of minimally invasive approaches for intracranial meningiomas is based in a philosophy and practice of minimal brain exposure and manipulation that includes

working through smaller corridors without static brain retractors and augmenting visualization by endoscopic views when needed, with the ultimate goal of achieving maximal safe tumor removal.[12–14,16,17,19,37] In our experience, for both young and old patients, use of smaller incisions, more focused craniotomies, and less expansive brain exposure not only promotes a greater likelihood of operative site healing and excellent cosmesis, but also is associated with less postoperative pain and a greater willingness by patients to mobilize and leave the hospital. Given that meningiomas are predominantly benign, radiosensitive tumors, we feel that the key goals of surgery, especially in older patients, should be maximal safe removal, restoration of quality of life, and avoidance of complications. The aggregate results presented here in terms of extent of resection, complications, and LOS would appear to support this approach. Prior studies and our current experience demonstrate a surgical reality, that complication rates and LOS are inextricably linked; simply put, complications beget longer, more intensive hospitalizations and reoperations, especially in older patients.[29,36,38–40]

Regarding extent of resection, our reported GTR and NTR rates for skull base and non–skull base meningiomas, as well as long-term tumor control rates (albeit with short follow-up), are similar to those reported for many prior series.[3,29,36,38–40] However, our rates of poor functional outcomes, surgical complications, and LOS are considerably lower than those of most prior series of elderly meningioma patients.[3,29,36] We attribute these quantitative and qualitative differences at least in part to the use of minimally invasive keyhole surgical approaches in the current study. In total, of all the approaches performed, 70 of 126 total operations (56%) were minimally invasive/keyhole and 55 (78.5%) included the use of endoscopy, which aided in additional tumor removal in 37 cases (67%).

Study Limitations

There is an overall study sample bias inherent to the retrospective nature of the study; however, prospective data collection was intended to lower this bias. Additionally, our philosophy, while primarily managing symptomatic meningiomas, is to favor surgical resection over the use of radiosurgery; hence, there is a selection bias for surgery. Overall, the cohort had a median 3-year follow-up, which is relatively short for patients with predominantly grade I meningiomas.

Conclusions

Approximately one-third of elderly patients seen for a presumed meningioma in our neurosurgical clinical practice over a 5-year period were managed with observation. Over the entire 11-year study period, for those elderly patients with symptomatic or growing meningiomas whose tumors did warrant surgery, our results indicate that excellent overall outcomes can be achieved with low risks of morbidity and mortality. Utilization of minimally invasive intracranial approaches with reasonable surgical goals may help improve clinical and functional outcomes and promote a shorter LOS after surgical treatment of meningioma in elderly patients.

Acknowledgments

The authors would like to acknowledge the Pacific Neuroscience Institute Foundation and Saint John's Health Center Foundation for their support.

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Disclosures

Dr. Sivakumar reports receiving honoraria from Zeiss and being a consultant for Stryker. Dr. Barkhoudarian reports being a consultant for Vascular Technologies Inc. Dr. Kelly reports receiving royalties from Mizuho Inc.

Author Contributions

Conception and design: Kelly, Thakur, Mallari, Barkhoudarian. Acquisition of data: Thakur, Eisenberg, Sivakumar. Analysis and interpretation of data: Kelly, Thakur, Mallari, Eisenberg, Sivakumar, Krauss, Griffiths, Barkhoudarian. Drafting the article: Kelly, Thakur, Mallari, Corlin, Yawitz, Huang, Eisenberg, Sivakumar, Barkhoudarian. Critically revising the article: Kelly, Thakur, Mallari, Sivakumar, Krauss, Griffiths, Barkhoudarian. Reviewed submitted version of manuscript: Kelly, Thakur, Mallari, Barkhoudarian. Approved the final version of the manuscript on behalf of all authors: Kelly. Statistical analysis: Kelly, Thakur, Mallari, Barkhoudarian. Administrative/technical/material support: Kelly, Barkhoudarian. Study supervision: Kelly, Barkhoudarian.

Supplemental Information

Online-Only Content

Supplemental material is available online.

Supplemental Table 1. https://thejns.org/doi/suppl/10.3171/2020.7.FOCUS20515.

Previous Presentations

A portion of this work was submitted for consideration in abstract form at the 14th Annual AANS/CNS Tumor Satellite Symposium, September 11–12, 2020, and has been awarded a Gold Award in the research for meningioma category.

Correspondence

Daniel F. Kelly: Pacific Neuroscience Institute, Santa Monica, CA. dkelly@pacificneuro.org.