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Long-Term Outcomes Using Frameless Immobilization in Salvage Gamma Knife Radiosurgery for Meningioma

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Introduction

Traditional GKRS relies on rigid, pin-based stereotactic frames for immobilization, which can be uncomfortable and limit fractionated treatment.[1] The LGK Icon enables frameless, mask-based delivery with improved comfort, workflow, and support for fractionation.[2,3]

This represents the largest study to date evaluating long-term outcomes of frameless GKRS as salvage treatment for meningioma.

Objective

The objective of this study was to evaluate oncologic outcomes from frameless, mask-based salvage Gamma Knife radiosurgery (GKRS) treatment for intracranial meningiomas.

Methods and Materials

Patients were chosen from an IRB-approved prospective observational cohort and retrospectively analyzed. Patients with radiographically or histopathologically confirmed meningiomas treated with salvage Gamma Knife radiosurgery (GKRS) therapy using the frameless, mask-based fixation method were included in this study ; a parallel frame-based cohort was analyzed for reference. Clinical, treatment, and outcome data were abstracted from the electronic medical record. Local control was defined as absence of in-field or marginal progression (≤2 cm from the prescription isodose line). Progression-free survival (PFS) was measured from GKRS to intracranial progression or death and estimated using Kaplan-Meier methods. Factors associated with local control and PFS were evaluated using multivariable Cox proportional hazards models. Secondary outcomes included treatment-related toxicities such as radiation necrosis, seizures, and visual complications.

Table 1. Baseline characteristics of patients undergoing fixation with the frameless mask-based and the frame-based techniques

Variable	Frameless (N = 89)[1]	Frame (N = 53)[1]	Std diff[2]	p-value[2]
Sex				0.4
F	42 (58%)	30 (67%)		
M	31 (42%)	15 (33%)		
Age at GKRS (years)	65.9 [55.9, 76.5]	63.7 [52.4, 77.4]	-0.20	>0.9
Tumor grade				0.2
WHO I	25 (32%)	22 (42%)		
WHO II	51 (65%)	30 (58%)		
WHO III	3 (3.8%)	0 (0%)		
Prior brain RT	20 (28%)	8 (17%)		0.3
Prior surgery (any)	81 (91%)	53 (100%)		0.061
Extent of resection				0.8
GTR	44 (66%)	32 (70%)		
STR	23 (34%)	14 (30%)		
Treatment volume (cc)	3.8 [1.5, 9.0]	2.0 [0.7, 4.3]	1.4	0.003
Marginal dose (Gy)				<0.001
12	0 (0%)	1 (1.9%)		
13.5	0 (0%)	1 (1.9%)		
14	28 (31%)	37 (71%)		
16	29 (33%)	11 (21%)		
18	4 (4.5%)	2 (3.8%)		
25	18 (20%)	0 (0%)		
30	10 (11%)	0 (0%)		
Number of fractions				<0.001
1	61 (69%)	52 (100%)		
5	28 (31%)	0 (0%)		
Follow-up (months)	45.6 [22.3, 64.6]	75.0 [41.9, 95.9]	-27	<0.001
Tumor location				0.5
Non-skull base	56 (63%)	37 (70%)		
Skull base	33 (37%)	16 (30%)		

[1]n (%); Median [Q1, Q3]
[2]Pearson's Chi-squared test; Wilcoxon rank sum test; Fisher's exact test

Results

- 89 lesions undergoing frameless mask-based fixation, and 53 lesions undergoing frame-based fixation were included
- Median follow-up time for the frameless cohort was 45.6 months and 75.0 months for the frame-based cohort
- 1-, 3-, and 5-year PFS was 97,4%, 80.9% and 64.9% respectively for the frameless cohort and 98%, 75.3%, 68.0% respectively for the frame-based cohort
- 1-, 3-, and 5-year local control was 97.5%, 82.6% and 77.0% respectively for the frameless cohort and 98.0%, 78.9%, 73.5% respectively for the frame-based cohort
- Toxicity rates were low and comparable between frame-based and frameless GKRS
- Cox regression analyses identified tumor grade II/III as the only significant multivariable predictor of PFS

Figure 1. Kaplan-Meier curves for frameless cohorts showing local control (1a) and progression free survival (1b)

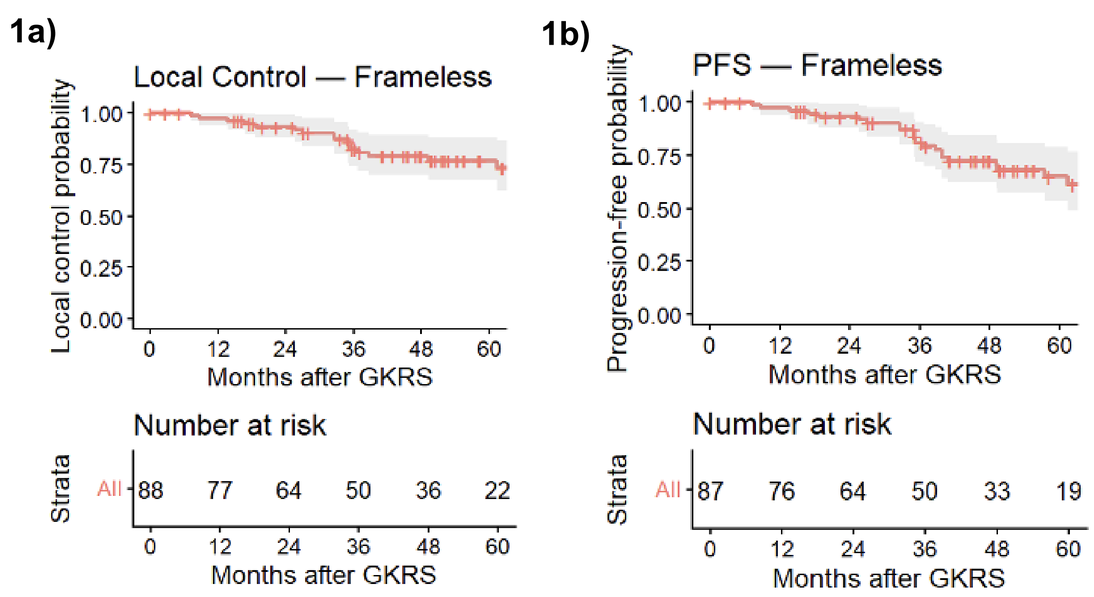

Table 2. Summary of 1-, 3-, and 5-year outcomes after GKRS by fixation method

Outcome	Cohort	1-year (%)	3-year (%)	5-year (%)
PFS	Frameless	97.4	80.9	64.9
PFS	Frame	98.0	75.3	68.0
Local control	Frameless	97.5	82.6	77.0
Local control	Frame	98.0	78.9	73.5
Overall survival	Frameless	100.0	94.6	92.9
Overall survival	Frame	100.0	94.0	91.8

Table 3. Toxicity profile after GKRS by fixation method

	Frameless GKRS			Frame-based GKRS		
Toxicity	Yes	No	Percent	Yes	No	Percent
Radionecrosis	2	72	2.7	1	29	3.3
New-onset Seizures	3	71	4.1	0	29	0.0
Optic Neuropathy	0	74	0.0	0	29	0.0
Visual Symptoms	0	73	0.0	0	29	0.0

Conclusions

Frameless, mask-based GKRS used in the salvage setting provides excellent local control and progression-free survival outcomes for intracranial meningiomas, with low toxicity rates comparable to traditional frame-based fixation. These findings support frameless GKRS as a safe, effective, and patient-centered salvage treatment option, particularly given its workflow efficiencies and suitability for fractionated treatments.

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