

Sustained Utilization of Gamma Knife Across Four Technological Generations

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PURPOSE

This study aimed to characterize longitudinal Gamma Knife radiosurgery (GKRS) utilization across four platform generations at a single institution. We evaluated whether utilization trends were driven predominantly by first-time treatments, repeat treatments, or specific disease indications, and examined treatment-volume patterns across platform eras while accounting for collinearity between calendar time and technology adoption.

MATERIAL & METHODS

- Treatments were classified as **first-time** or **repeat procedures** using matched patient identifiers and treatment chronology.
- Gamma Knife platform eras (**Model B, Model C, Perfexion, ICON**) were assigned according to institutional acceptance testing and commissioning dates.
- Annual treatment counts were analyzed using **negative binomial regression** to model over dispersed count data and estimate longitudinal utilization trends (Table 1).
- Newey–West standard errors** were applied to account for potential serial correlation in yearly treatment counts, improving robustness of statistical inference for time-series observations.
- Platform-adjusted models** were used to evaluate temporal trends while accounting for the close relationship between calendar year and GK platform era.
- Piecewise segmented regression** of monthly treatment counts assessed changes in utilization trajectories at platform transition years (2002, 2008, and 2017), estimating both immediate level changes and changes in growth rates across eras (Figure 3).
- Disease categories representing <1% of annual treatment volume were combined into an “**Other**” group.

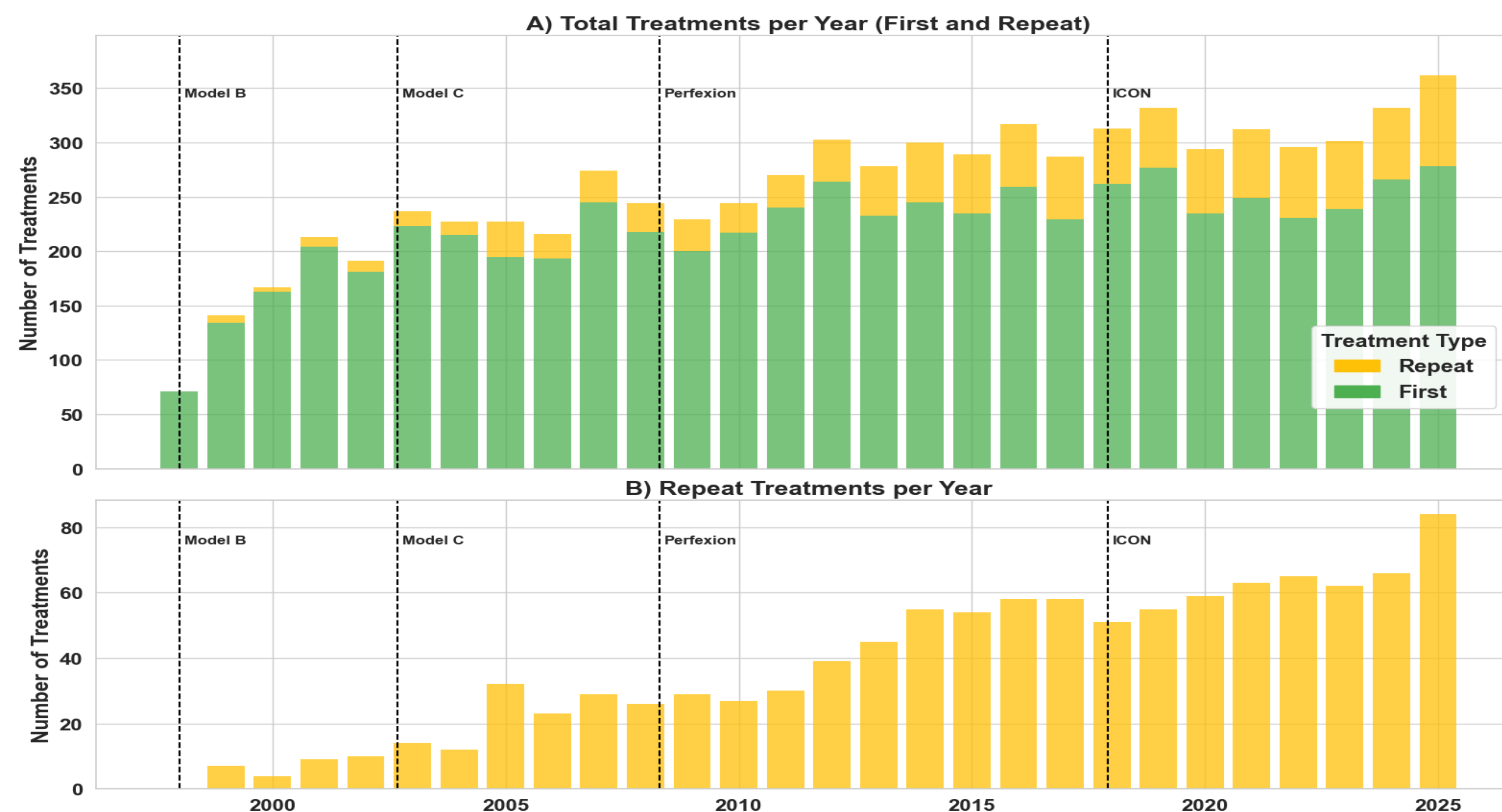


Figure 1. Annual first-time and repeat GKRS treatments, 1998–2025. Overall treatment volume increased over time in unadjusted analyses. **Repeat treatments demonstrated the strongest adjusted temporal growth**, whereas adjusted trends for total and first-time treatments were not statistically significant.

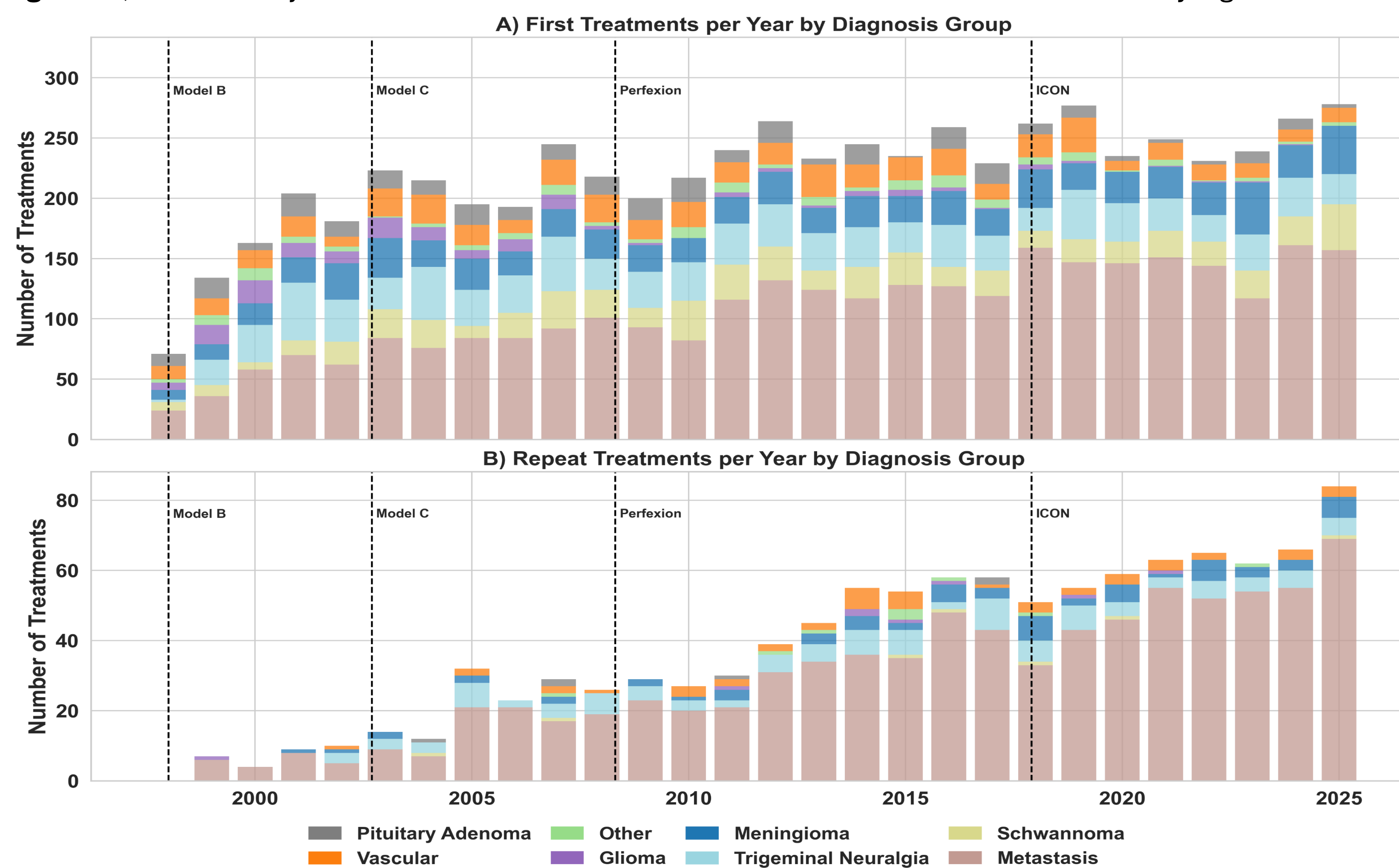


Figure 2. Diagnosis composition of first-time (A) and repeat (B) treatments annually over the study period. Among disease indications, **metastatic disease showed the strongest platform-adjusted growth**.

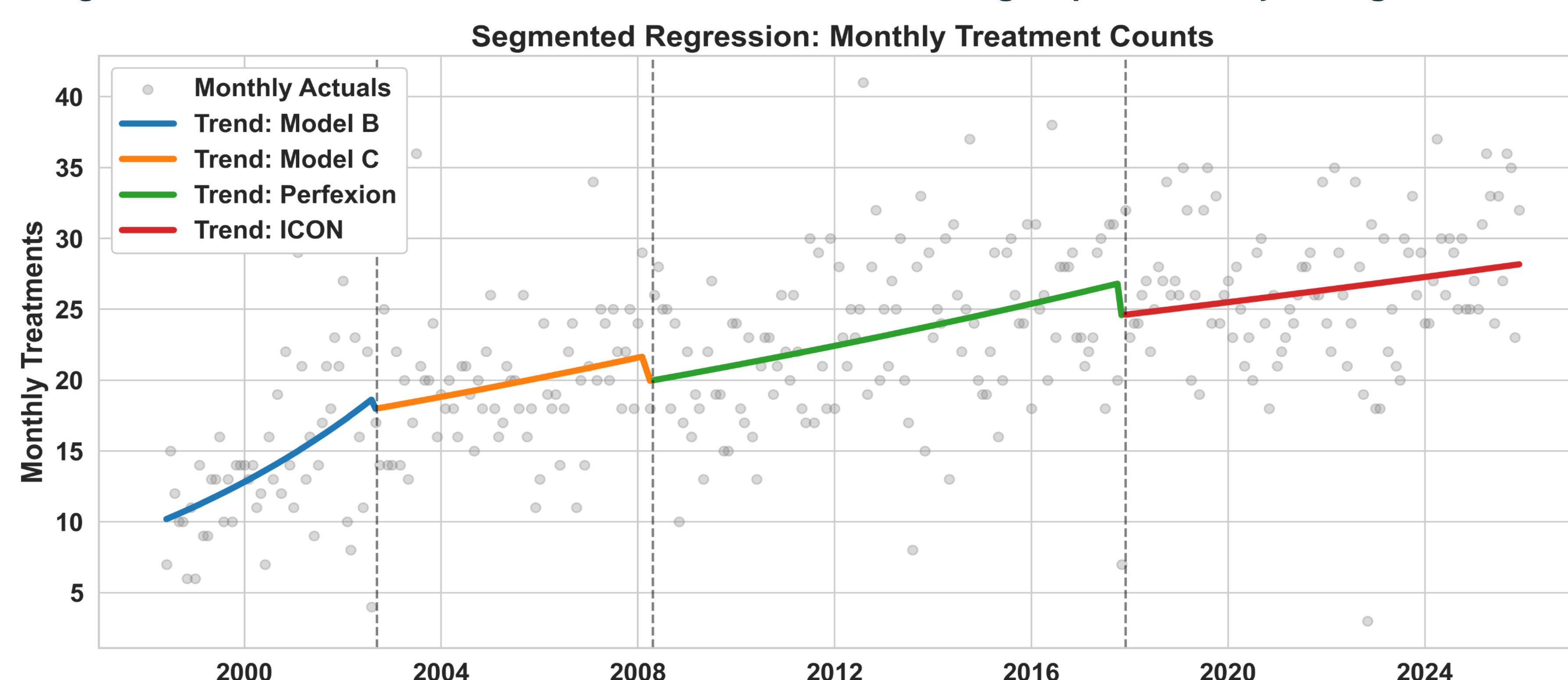


Figure 3. Piecewise segmented regression analysis of monthly GKRS treatments. Steepest increase during the **Model B era** (annualized CR 1.16), with significant attenuation following transition to **Model C** (annualized CR 0.90, $p=0.01$). No additional significant slope changes were observed at the Perfexion or Icon transitions.

Models		Unadjusted			Adjusted		
		CR	95% CI	p-value	CR	95% CI	p-value
Treatment Categories	Total	1.03	1.02, 1.04	<0.001	1.06	0.999, 1.12	0.053
	First-Time	1.02	1.01, 1.03	0.001	1.04	0.99, 1.10	0.148
	Repeat	1.09	1.06, 1.12	<0.001	1.14	1.07, 1.21	<0.001
	Total (Mets Only)	1.05	1.04, 1.07	<0.001	1.08	1.02, 1.14	0.01
	First-Time (Mets Only)	1.04	1.03, 1.06	<0.001	1.06	1.00, 1.12	0.094
	Repeat (Mets Only)	1.09	1.07, 1.12	<0.001	1.15	1.07, 1.22	<0.001
Disease Categories	Glioma	0.91	0.89, 0.93	<0.001	0.96	0.87, 1.06	0.374
	Meningioma	1.03	1.01, 1.04	<0.001	1.05	0.99, 1.12	0.093
	Metastasis	1.05	1.04, 1.07	<0.001	1.08	1.02, 1.14	0.012
	Other	0.99	0.96, 1.02	0.527	1.05	0.96, 1.16	0.276
	Pituitary Adenoma	0.97	0.95, 0.99	0.007	0.98	0.92, 1.03	0.419
	Schwannoma	1.02	1.00, 1.05	0.029	1.06	1.00, 1.12	0.003
	Trigeminal Neuralgia	1.01	0.99, 1.03	0.624	1.05	0.99, 1.11	0.126
	Vascular	1.00	0.99, 1.02	0.786	1.00	0.93, 1.05	0.802

Table 1. Negative binomial regression analysis of annual treatment counts stratified by treatment type and disease category. Count ratios (CR) are reported for unadjusted and machine era-adjusted models.

DISCUSSION

- Long-term GKRS utilization demonstrated sustained growth over four Gamma Knife platform generations.
- Strongest growth was observed in repeat treatments, with metastatic disease representing the dominant disease-specific contributor** to increasing utilization.
- Platform-transition analyses suggest that utilization patterns were driven more strongly by evolving clinical demand than by individual technology upgrades alone.

SUMMARY / CONCLUSION

- A total of 7,267 GKRS treatments were delivered between 1998-2025** with long-term growth concentrated primarily in repeat radiosurgery and metastatic disease management.
- Following rapid growth during the early Model B era, **subsequent platform generations maintained a stable utilization trajectory** without additional significant changes in long-term growth rates.
- These findings characterize longitudinal practice patterns within a single Gamma Knife program and should not be interpreted as evidence of comparative platform effectiveness or superiority.

