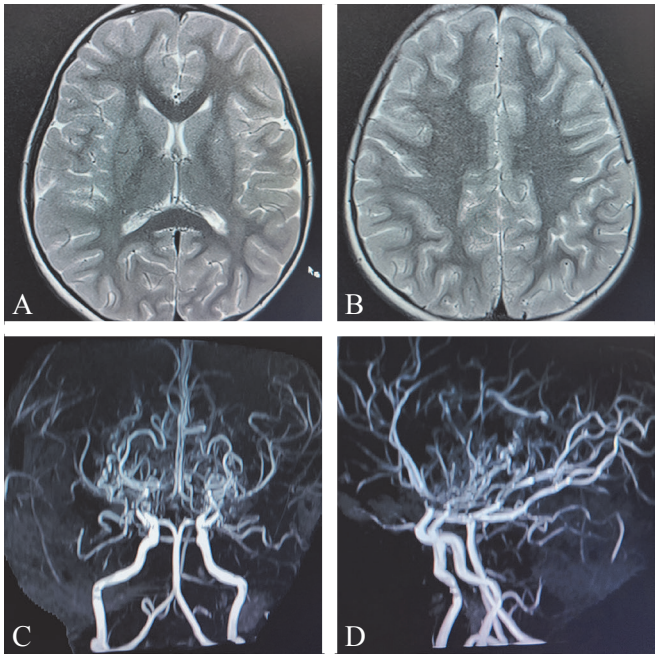

Figure 1.—A, B) Magnetic resonance imaging Brain T2-weighted sequence shows few linear hyperintense foci in bilateral cerebral hemisphere; and C, D) magnetic resonance angiography shows stenosis of distal ICA and MCA along with collateral formation suggestive of Moyamoya angiopathy.

The symptoms of MMA can occur in relation to transient cerebral hypoperfusion often in close temporal relation to various precipitating factors (Supplementary Digital Material 1: Supplementary Table I). Even the rarer precipitating factors like abrupt cold exposure must be kept by the treating physician due to its diagnostic and therapeutic implications.

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Conflicts of interest
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Operator perceived advantage of virtual surgical rehearsal in pediatric neurosurgical oncology: a preliminary experience

In the ever-evolving landscape of modern medical technology, virtual reality (VR) has emerged as powerful tool capable to transform various dimensions of neurosurgical patient care.[1] While the bulk of research findings have originated from adult patient experiences, an increasing acknowledgment of VR's potential utility in pediatric settings is gaining traction. This phenomenon is particularly significant in the pediatric neurosurgical oncology setting, where delicately balancing the imperative of extensive disease resection with the preservation of neurological functions is of vital importance.[2] In this complex dynamic, the integration of VR technology could

hold the key to unlocking innovative solutions, enhancing preoperative planning, guiding intraoperative procedures, and ultimately influencing postoperative outcomes. The versatility of VR has the capacity to be beneficial to areas such as refined surgical training, fostering comprehensive dialogues with parents, attaining a nuanced grasp of intricate neuroanatomy, and seamlessly incorporating advanced techniques such as minimally invasive and endoscopic procedures. The endeavor to formally assess the direct impact of VR technology on neurosurgical practices requires stringent standardization, a need accentuated in pediatric brain tumor resection. Nonetheless, in the absence of a one-size-fits-all quantitative approach, semiquantitative user-reported measures have been used for the evaluation of novel tools across diverse clinical scenarios. At the forefront of such evaluative efforts is the Likert scale, valued for its user-friendly nature and its adaptability as a satisfaction measure.[3] This tool is particularly valuable for assessing user perspectives in diverse contexts. The scale's simplicity coupled with its structured approach to measuring responses has propelled its popularity within the medical domain, serving as a reliable instrument for assessing not only satisfaction levels but also attitudes and opinions in a meticulous manner. Participant empowerment in being able to express agreement or disagreement for a set of statements is due to its inherent comprehensibility resulting in a gradual depiction of sentiments. The present study, which was conducted at Bambino Gesù Children's Hospital's Neurosurgery Unit from July to December 2022, focused on pediatric patients undergoing tumor-removing craniotomy with VR assistance (Surgical Theatre Inc, Cleveland OH). This endeavor was underpinned by an exhaustive collection of patient-specific data, including variables such as age, gender, lesion attributes, histology, tumor pattern, volume, and the extent of resection. These data points, assembled within an anonymized spreadsheet, constituted a foundational framework for the study's exploration. The technological centerpiece of the study was the VR system, connecting the insights collected from diagnostic MR images to generate three-dimensional models. These models, in turn, served as invaluable tools for surgical rehearsal, enriching the precision of lesion margin definitions on bi-dimensional images. The ability to review these models was not limited to only the surgical team, but extended to a specialized oncological neuroradiologist, fostering a multidisciplinary collaboration. The influence of VR technology extended beyond the preparatory phase. The integration with bi-dimensional navigation systems facilitated its pivotal role as an intraoperative reference point in the operating room. The surgical procedures themselves adhered unwaveringly to microsurgical techniques, augmented by supplementary aids such as ultrasound imaging and intraoperative monitoring. A total of 50 consecutive cases formed the foundation of this study, each case unveiling distinctive facets of pediatric neurosurgical oncology (Table I). The median patient age was 10 years, with a gender balance. Predominantly situated within the supratentorial compartment (30/50, 60%), the tumors exhibited diverse histological characteristics. Among these, gliomas (22/50, 44%) were most predominant, followed by the prevalence of embryonal tumors (10/50, 20%) and ependymomas (3/50, 6%). The planned extent of resection, a critical factor for oncological outcome, exhibited variability, with a majority of cases striving for gross total resection (43/50, 86%). The utilization of the Likert scale was noteworthy to gauge surgeons' perceptions concerning the utility of VR (Figure 1). The findings painted a generally positive picture, with principal surgeons expressing higher overall utility advantage scores (4/5)

TABLE I.—*Case population description by analyzed variables.*

Parameters	N.=50
Age in years; median (IQR)	10 (3.5-14.1)
Size (cm^3); median (IQR)	18.6 (6.7-40.6)
Gender	
Male	30 (60%)
Female	20 (40%)
Lesion site	
Supratentorial (ST)	30 (60%)
Infratentorial (IT)	20 (40%)
Site	
Frontal	6 (12%)
Temporal	6 (12%)
Parietal	6 (12%)
Occipital	4 (8%)
Fronto-temporal	1 (2%)
Fronto-parietal	3 (6%)
Intraventricular	3 (6%)
Pineal	1 (2%)
IV ventricle/Brainstem	14 (28%)
Cerebellar hemisphere	6 (12%)
Pattern	
Solid	35 (70%)
Cystic	15 (30%)
Histology	
Embryonal	10 (20%)
Glioma	22 (44%)
Ependymoma	3 (6%)
Meningioma	3 (6%)
Other	12 (24%)
Planned extent of resection	
Gross total resection	43 (86%)
Subtotal resection	5 (10%)
Biopsy	2 (4%)

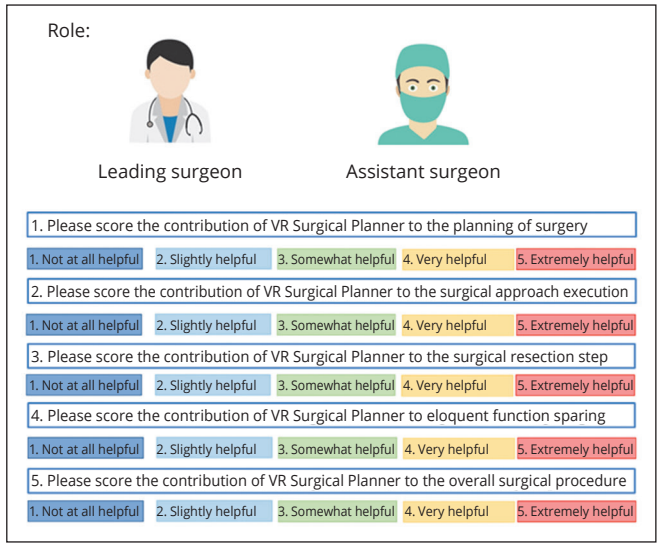

Figure 1.—The Likert-Scale-based questionnaire developed to evaluate surgeons' opinions on advantage of virtual reality in pediatric neurosurgical oncology.

TABLE II.—*Leading surgeon's (LS) and assistant surgeon's (AS) median advantage perceived scores by secondary variables' clustering.*

Parameter	Planning		Approach		Resection		Eloquence sparing		Overall	
	LS	AS	LS	AS	LS	AS	LS	AS	LS	AS
Lesion site		*		*	*			*	*	*
ST	4	4	3	4	3	3	4	3	4	4
IT	3	3.5	3	3	3	3.5	3	3	3	3
Site	*			*	*	*	*	*	*	*
Hemispheric	4	4	3.5	4	3	3	4	3.5	4	3.5
Temporal	2	4	2	3	2	1	3	3	3	3
Deep-ST	4.5	5	3	4.5	4	4	4.5	4.5	4.5	5
IV ventricle/Brainstem	3	3.5	3	3	3	3.5	3	3	3	3
Cerebellar hemisphere	3.5	3.5	3.5	3	2.5	3.5	3	3	4	3.5
Volume (cm^3)										
>18 mL	4	4	3	3	3	3	3	3	4	3
≤18 mL	4	4	3	3	3	4	3	3	4	4
Pattern										
Solid	4	4	3	3	3	3	3	3	4	3.5
Mixed	4	4	3	3	3	4	3	3	4	3
Histology	*	*		*						*
Glioma	3.5	4	3	3	3	3.5	3	3	4	3.5
LEAT	4	4	3	3	2.5	2	3.5	3	3.5	3
Embryonal	3	3	3	3	3	3	3	3	3	3
Other	4	4	4	4	3	4	4	4	4	4
Age (years)	*		*		*				*	
<10	4	4	4	3	3	3	4	3	4	3
≥10	3	4	3	3	3	4	3	3	3	4
Planned resection	*		*				*		*	
Gross total resection	3.5	4	3.5	3	3	3	3	3	3.5	3.5
Subtotal resection	5	5	5	5	3	4	4	4	4	5
Biopsy	3.5	4	3.5	4	4	3.5	4.5	4	4.5	4

*Statistical significance within group corresponding to a P value <0.05.

compared to their assistant counterparts (3/5). The statistical significance of VR's benefits excelled through various scenarios, particularly in the context of deep supratentorial tumors (4.5/5), cases necessitating restrained resections (4.5/5) and patients younger than 10 years (4/5), all conditions in which availability of anatomical landmarks is scarce (Table II). This observation supports the notion that VR's advantages are most pronounced when confronted with surgical decision-making complexities. In these contexts, enhanced visualization facilitated by VR emerges as a critical advantage. We acknowledge that direct contribution of VR to the resection phase is limited; however, we experienced that familiarization with the three-dimensional conformation of the desired resection margins during preoperative virtual surgical rehearsal improves confidence while performing the real procedure. The nuanced differences in responses between leading surgeons and assistant surgeons underscored the distinctive impact of their respective roles within the surgical team. In conclusion, this study not only offers a preliminary glimpse into VR's promising potential within pediatric neurosurgical oncology, but also highlights the need for further exploration. The findings underscore VR's capacity to substantially enrich surgical planning, procedural execution, and potentially, patient outcomes, particularly within difficult cases. As the technological evolution continues, the role of VR in pediatric neurosurgery is set to continue to expand, potentially reshaping the landscape and elevating the caliber of patient care. While this study serves as an initial foundation, the necessity for future research endeavors featuring larger patient cohorts becomes evident, in order to validate these initial findings and discover VR applications' full potential in the pediatric neurosurgical oncology field. VR is characterized by limitless possibilities, especially as technological breakthroughs continue to unfold.[4, 5] The seamless integration of VR into the pediatric neurosurgical setting emerges as a forerunner of transformation with each advancement made. Driven by effectively combining innovative technology and medical expertise, it provides great promise to approaching intricate cases and amplifying positive outcomes for young patients affected by the many challenges of brain tumors.

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Conflicts of interest

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Authors' contributions

Roberto Premuselli, Carmen D'Amore, and Andrea Carai conceptualized the work. Andrea Carai, Alessandra Marasi, Roberto Premuselli, Giada Del Baldo, Carmen D'Amore, Eleonora Piccirilli wrote the manuscript. Matteo Barba, Alessandra Marasi, Alessandro De Benedictis, Carlo E. Marras, Andrea Carai, Roberto Premuselli, Giovanna S. Colafati, Eleonora Piccirilli contributed to data collection. Carmen D'Amore performed statistical analysis. Andrea Carai, Giada Del Baldo supervised the works. Giada Del Baldo, Andrea Carai, Roberto Premuselli contributed to the finishing of the work and revised it critically for important intellectual content. All authors read and approved the final version of the manuscript.

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