

Advances in Diagnostic Strategies and Surgical Management of Pediatric Brain and Spinal Tumors: A Systematic Literature Review

Review began 09/13/2026

Review ended 10/15/2026

Published 10/21/2026

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DOI: 10.7759/cureus.118340

Saniya Yusufkhan Pathan ¹, Dixita R. Tailor ², Narendra Kumar Arya ³, Dilan Sathi Prakasan ⁴,
Haramohan Sahoo ⁵, Alka Singh ⁶, Biswabhinod Sanfui ⁷

1. Department of Kaumarbhritya-Balrog, Bharati Vidyapeeth Deemed to be University College of Ayurveda, Pune, IND
2. Department of Paediatrics and Neonatology, Anand Children Hospital, Surat, IND 3. Department of Pediatrics, Guru Gobind Singh Indraprastha University, Delhi, IND 4. Department of Stomatology, Tbilisi State Medical University, Tbilisi, GEO 5. Department of Neurology, Heritage Institute of Medical Sciences, Varanasi, IND 6. Department of Physiotherapy, Mangalayatan University, Aligarh, IND 7. Department of Community Medicine, K D Medical College Hospital and Research Centre, Mathura, IND

Corresponding author: Saniya Yusufkhan Pathan, saniyayusufkhanpathan@gmail.com

Abstract

Pediatric brain and spinal tumors require precise diagnostic evaluation and function-preserving surgical care because tumor biology, location, resectability, and long-term neurological consequences vary widely. Current evidence is distributed across imaging studies, molecular analyses, intraoperative adjunct evaluations, surgical cohorts, and neurocognitive outcome reports, limiting an integrated understanding of recent diagnostic and operative advances. This systematic review evaluated recent evidence on diagnostic strategies and surgical management of pediatric central nervous system tumors, with attention to magnetic resonance imaging, histopathology, molecular markers, intraoperative tools, extent of resection, postoperative morbidity, survival, recurrence, and functional outcomes. Searches were conducted in PubMed/MEDLINE, Scopus, Google Scholar, and Web of Science according to PRISMA 2020. After duplicate removal and screening, 10 studies were included. MRI and histopathological confirmation were the dominant diagnostic approaches. Molecular profiling, particularly BRAF V600E status, supported prognostic assessment in pediatric low-grade glioma. Sodium fluorescein and intraoperative ultrasound improved tumor localization and residual disease assessment. Surgical findings supported maximal safe resection, with gross total resection beneficial in selected tumors, although subtotal resection was not uniformly associated with poor outcome. Long-term neurological, cognitive, and behavioral monitoring remained essential. Integrated multidisciplinary, risk-adapted, and function-preserving care should guide pediatric neuro-oncology practice.

Categories: Oncology, Pediatrics, Neurosurgery

Keywords: cns tumours, diagnosis, intraoperative imaging, paediatric, spinal tumours, surgical management

Introduction And Background

Pediatric brain and spinal tumors (BSTs), encompassing primary central nervous system (CNS) tumors arising in the brain or spinal cord, are referred to as pediatric BSTs throughout this review. These tumors are clinically important because they affect developing structures of the brain and spinal cord and may have long-term neurological, cognitive, behavioral, endocrine, and functional consequences [1]. They arise at different anatomical sites and demonstrate considerable variation in histopathology, biological behavior, molecular characteristics, resectability, and prognosis. Pediatric BSTs frequently require multidisciplinary management involving neurosurgery, neuroradiology, neuropathology, oncology, rehabilitation, and neuropsychological care [2]. Children with pediatric BSTs may present with diverse neurological and systemic manifestations, including headache, vomiting, ataxia, visual disturbance, seizures, weakness, and endocrine dysfunction, making timely clinical recognition and structured evaluation important [1,2]. Diagnostic evaluation of pediatric CNS tumors increasingly extends beyond anatomical localization and incorporates imaging, pathological assessment, and molecular characterization [3]. MRI remains central to defining tumor location, morphology, extent, relationship to surrounding neural structures, and postoperative residual disease. Pediatric spinal tumor imaging literature demonstrates the importance of imaging and anatomical assessment in guiding clinical management and evaluating disease extent [4]. Preoperative MRI characteristics may contribute to assessment of tumor behavior and suspected grade, while definitive classification generally requires pathological evaluation. Advanced imaging findings are increasingly incorporated into diagnostic interpretation and treatment planning for pediatric spinal and brain tumors [4,5]. These complementary approaches support an integrated diagnostic framework in which radiological, pathological, molecular, and operative findings are considered together.

Surgery remains an important component of management for many pediatric BSTs [6]. It can provide tissue for diagnosis, support tumor removal, and contribute to clinical management, depending on tumor location and the feasibility of safe resection [7]. Advanced neuroimaging contributes to the assessment of tumor

How to cite this article

Pathan S, Tailor D R, Arya N, et al. (October 21, 2026) Advances in Diagnostic Strategies and Surgical Management of Pediatric Brain and Spinal Tumors: A Systematic Literature Review. Cureus 18(10): e118340. DOI 10.7759/cureus.118340

characteristics and anatomical relationships relevant to surgical planning [8]. Consequently, operative planning requires a balance between tumor control and preservation of neurological function. Evidence from pediatric intramedullary spinal tumor surgery emphasizes that postoperative neurological outcomes are associated with tumor pathology, tumor length, and preoperative neurological status [9]. Pediatric CNS imaging recommendations similarly emphasize the importance of anatomical assessment and surveillance in guiding management decisions [10]. Current surgical practice increasingly emphasizes maximal safe resection rather than pursuit of complete removal at the expense of neurological function. Surgical decision-making should therefore consider tumor biology, anatomical accessibility, expected morbidity, and the availability of postoperative surveillance or additional therapy. Imaging-based surveillance is particularly important when residual tumor remains after surgery, while clinical assessment and histopathological diagnosis provide additional information for the management of pediatric spinal meningiomas, with long-term MRI follow-up remaining important [10,11]. These considerations support individualized postoperative follow-up rather than reliance on residual tumor size alone.

Intraoperative adjuncts are increasingly used to support tumor localization and assessment of resection. Sodium fluorescein has been evaluated as an aid to intraoperative visualization and tissue localization in selected pediatric low-grade gliomas. Postoperative imaging remains important for evaluating residual disease, while advances in molecular pathology have further strengthened tumor classification and diagnostic interpretation [10,12]. Together, imaging, pathological assessment, and operative findings can assist surgical teams in balancing tumor removal with preservation of vulnerable neurological structures. Surgery for spinal cord tumors presents particular challenges because neurological outcome is closely related to tumor location, compartment, pathology, and the feasibility of safe resection. Evidence from pediatric intramedullary spinal tumor studies indicates that tumor characteristics and preoperative neurological status are important factors associated with surgical outcomes [9]. Preservation of function is especially important in spinal surgery because intervention may carry risks to motor, sensory, sphincter, and mobility functions.

Long-term outcome assessment in pediatric neuro-oncology extends beyond survival and radiological control. Advanced neuroimaging techniques provide information about pediatric brain tumor characteristics and functional anatomy, supporting individualized diagnostic assessment and treatment planning [8]. Management decisions for pediatric intradural spinal tumors should consider tumor characteristics, anatomical location, imaging findings, and molecular information [7]. Diagnosis, surgical planning, neurological preservation, surveillance, and functional follow-up are consequently interconnected components of pediatric neuro-oncology care. Available evidence remains distributed across different tumor types, diagnostic modalities, operative approaches, and outcome measures, making direct comparison difficult. A focused synthesis is therefore needed to examine these findings within their specific tumor and clinical contexts rather than assuming uniform applicability across all pediatric CNS tumors.

Objective of the study

This systematic review aims to synthesize recent evidence on diagnostic strategies and surgical management of primary pediatric BSTs. Specifically, it evaluates imaging, histopathological and molecular assessment, intraoperative adjuncts, extent of resection, postoperative neurological outcomes, recurrence or progression, survival, and long-term functional outcomes. Because the included evidence spans different tumor entities and study designs, findings are interpreted according to tumor type and diagnostic or surgical context.

Review

Methodology

Study Design

This systematic literature review aimed to assess diagnostic strategies and surgical management approaches for pediatric BSTs. Original clinical studies reporting imaging, histopathological, molecular, intra-operative, surgical, neurologic, survival, recurrence, or functional outcomes were included in the review. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines were followed for the transparent reporting of study identification, screening, eligibility assessment, and inclusion [13]. The review protocol was not prospectively registered in PROSPERO or any other systematic review registry. A qualitative synthesis was used because the studies included had different types of tumors, diagnostic methods, surgical techniques, definitions of outcomes, and follow-up periods. The review question focused on how contemporary diagnostic strategies and surgical approaches are applied in pediatric BSTs and how these approaches relate to neurological, oncological, and functional outcomes.

Search Strategy

A structured literature search was conducted in PubMed/MEDLINE, Scopus, Google Scholar, and Web of Science on 21 June 2026. Search terms were selected to identify studies related to pediatric BSTs, CNS tumors, diagnostic imaging, histopathology, molecular markers, intraoperative adjuncts, surgical

management, extent of resection, postoperative outcomes, survival, recurrence, and neurocognitive outcomes. Relevant terms were combined using Boolean operators, with minor adaptations according to the search format of each database. Only English-language original clinical studies relevant to the diagnostic or surgical management of pediatric CNS tumors were considered. Records retrieved from the databases were compiled, and duplicate records were removed before title and abstract screening. The database-specific Boolean search strategies used for literature retrieval are presented in Table 1.

Database	Search concepts/terms	Boolean search strategy
PubMed/MEDLINE	Pediatric brain tumor, pediatric spinal tumor, CNS tumor, low-grade glioma, medulloblastoma, MRI, sodium fluorescein, intraoperative ultrasound, molecular markers, extent of resection, postoperative outcome, survival, recurrence, neurocognitive outcome	("pediatric brain tumor" OR "pediatric spinal tumor" OR "pediatric CNS tumor" OR "low-grade glioma" OR medulloblastoma) AND (MRI OR "magnetic resonance imaging" OR histopathology OR "molecular markers" OR "sodium fluorescein" OR "intraoperative ultrasound") AND ("extent of resection" OR surgery OR "postoperative outcome" OR survival OR recurrence OR "neurocognitive outcome")
Scopus	Pediatric CNS tumors and diagnostic/surgical management terms	("pediatric brain tumor" OR "pediatric spinal tumor" OR "CNS tumor" OR "low-grade glioma" OR medulloblastoma) AND (MRI OR histopathology OR molecular OR "sodium fluorescein" OR "intraoperative ultrasound") AND (surgery OR "extent of resection" OR outcome OR survival OR recurrence)
Web of Science	Pediatric CNS tumors, diagnostic modalities, surgery, and outcomes	("pediatric brain tumor" OR "pediatric spinal tumor" OR "CNS tumor") AND (MRI OR histopathology OR "molecular markers" OR "intraoperative ultrasound" OR fluorescence) AND (surgery OR resection OR survival OR recurrence OR outcome)
Google Scholar	Pediatric brain/spinal tumors with diagnostic and surgical outcome terms	"pediatric brain tumor" OR "pediatric spinal tumor" combined with MRI, histopathology, molecular markers, sodium fluorescein, intraoperative ultrasound, extent of resection, survival, recurrence, and neurocognitive outcome

TABLE 1: Database-Specific Literature Search Strategy

Study Selection

There were several stages in the process of study selection. Two reviewers independently screened the titles and abstracts of retrieved records and subsequently assessed potentially eligible full-text articles. Any disagreements regarding study inclusion were resolved through discussion and consensus. There were 252 records found in the database search. After removing 41 duplicates, 211 titles and abstracts were screened. Records that were clearly not related to any brain or spinal tumor, diagnostic assessment, surgical treatment, or relevant clinical outcomes were excluded. The 47 full-text articles were assessed for eligibility. Of these, 37 articles were excluded for predefined eligibility reasons, as shown in the Appendix. There were 10 studies included in the final systematic review. The relatively small final evidence base reflects the focused eligibility criteria, which prioritized original pediatric CNS tumor studies reporting directly relevant diagnostic, surgical, or clinical outcomes. The included studies were heterogeneous in tumor type, study design, and outcome assessment; therefore, direct comparison was limited and the findings were synthesized qualitatively rather than quantitatively. The selection process is summarized and documented in the PRISMA flow diagram, making the inclusion process transparent.

Eligibility Criteria

Studies were selected according to inclusion and exclusion criteria covering the population, study design, clinical focus, outcomes, language, and article type. Eligible studies included pediatric patients with primary brain, spinal cord, or other CNS tumors and reported relevant diagnostic, surgical, neurological, survival, recurrence, progression, or functional outcomes. Reviews, editorials, commentaries, non-English publications, adult-only studies, non-CNS tumor studies, and studies without relevant diagnostic or surgical outcome data were excluded. The inclusion and exclusion criteria applied during study selection are summarized in Table 2.

Criterion	Inclusion criteria	Exclusion criteria
Population	Pediatric patients with primary brain, spinal cord, or other central nervous system tumors	Adult-only populations
Tumor type	Primary pediatric brain, spinal cord, or other central nervous system tumors	Non-central nervous system tumors
Study design	Original clinical studies, including retrospective cohorts, case series, multicohort prognostic analyses, diagnostic imaging studies, intraoperative imaging/adjunct studies, and neurocognitive outcome studies	Reviews, editorials, and commentaries
Diagnostic focus	Studies reporting relevant imaging, histopathological, molecular, or intraoperative diagnostic findings	Studies without relevant diagnostic information
Surgical focus	Studies reporting surgical management, intraoperative adjuncts, extent of resection, or postoperative outcomes	Studies without relevant surgical information or outcomes
Outcomes	Studies reporting neurological outcomes, recurrence/progression, survival, morbidity, or functional/neurocognitive outcomes	Studies without relevant outcomes for the review objectives
Language	English-language publications	Non-English publications
Data availability	Original studies with extractable data relevant to the review objectives	Studies without sufficient relevant extractable data

TABLE 2: Eligibility Criteria for Study Selection

Data Extraction

Data were extracted using a structured study table containing predefined variables, including author, publication year, study design, clinical setting, sample size, tumor type, diagnostic or surgical approach, intraoperative adjuncts, extent of resection, molecular findings, postoperative neurological outcomes, recurrence or progression, survival, and neurocognitive or behavioral outcomes. Data extraction was independently performed by two reviewers using the predefined extraction variables, with discrepancies resolved through discussion and consensus. Extracted data were organized in a standardized format to facilitate comparison across studies. Numerical summaries were reported where available, and findings were grouped according to diagnostic advances and surgical management outcomes.

Risk-of-Bias Assessment

Risk of bias was assessed using design-specific appraisal instruments selected according to the methodological characteristics and objectives of the included studies. Prognostic studies were evaluated using the Quality in Prognosis Studies (QUIPS) tool, which assesses six domains: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis and reporting [14]. Diagnostic accuracy studies were evaluated using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool, which examines patient selection, index testing, reference standards, and flow and timing, along with applicability concerns [15]. Observational cohort studies were assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Cohort Studies [16], while descriptive surgical case series were evaluated using the JBI Critical Appraisal Checklist for Case Series [17]. Analytical cross-sectional studies were assessed using the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies, which evaluates inclusion criteria, participant characteristics, exposure and outcome measurement, confounding, and statistical analysis [18]. The assessments were based on participant selection, exposure and outcome measurement, potential confounding factors, completeness of follow-up, and statistical reporting in the original publications. QUIPS domains were classified as low, moderate, or high risk of bias, while QUADAS-2 judgments were categorized as low, high, or unclear, with applicability evaluated separately. JBI checklist items were recorded as yes, no, unclear, or not applicable. Methodological concerns were reported at the domain or checklist-item level, without calculating composite scores or assigning generalized overall study-quality ratings.

Data Synthesis

A qualitative narrative synthesis was conducted because substantial clinical and methodological heterogeneity made quantitative pooling inappropriate. The included studies differed in tumor histology, anatomical location, diagnostic approach, surgical strategy, extent-of-resection definitions, follow-up

duration, and reported outcomes. Findings were organized into two thematic domains: diagnostic advances and surgical management with clinical outcomes. Diagnostic findings included MRI, histopathology, molecular markers, sodium fluorescein, intraoperative ultrasound, and neurocognitive assessment, while surgical findings included gross or subtotal resection, residual tumor behavior, recurrence, morbidity, survival, and functional outcomes. Numerical results from individual studies were reported where available, and study-level frequencies were used descriptively for graphical presentation in MS Excel (Microsoft Corp., Redmond, WA, USA) rather than as pooled treatment effects. No meta-analysis, meta-regression, or other pooled quantitative analysis was performed.

Result

Study Results

Database search yielded 252 articles from PubMed/MEDLINE, Scopus, Google Scholar, and Web of Science. Following the removal of 41 duplicate records, 211 records were screened by title and abstract. 164 records were excluded, and 47 full-text articles were assessed for eligibility. Of these, 37 were excluded because they did not meet the inclusion criteria, did not include outcome data, or were not published in English. After all, 10 studies were selected for the systematic review. Overall, these studies all focused on diagnostic imaging, intraoperative localization, extent-of-resection evaluation, surgical outcomes, survival, recurrence, and neurocognitive effects of pediatric BSTs. A total of 10 studies were identified, screened, and assessed for eligibility and included in the analysis (Figure 1).

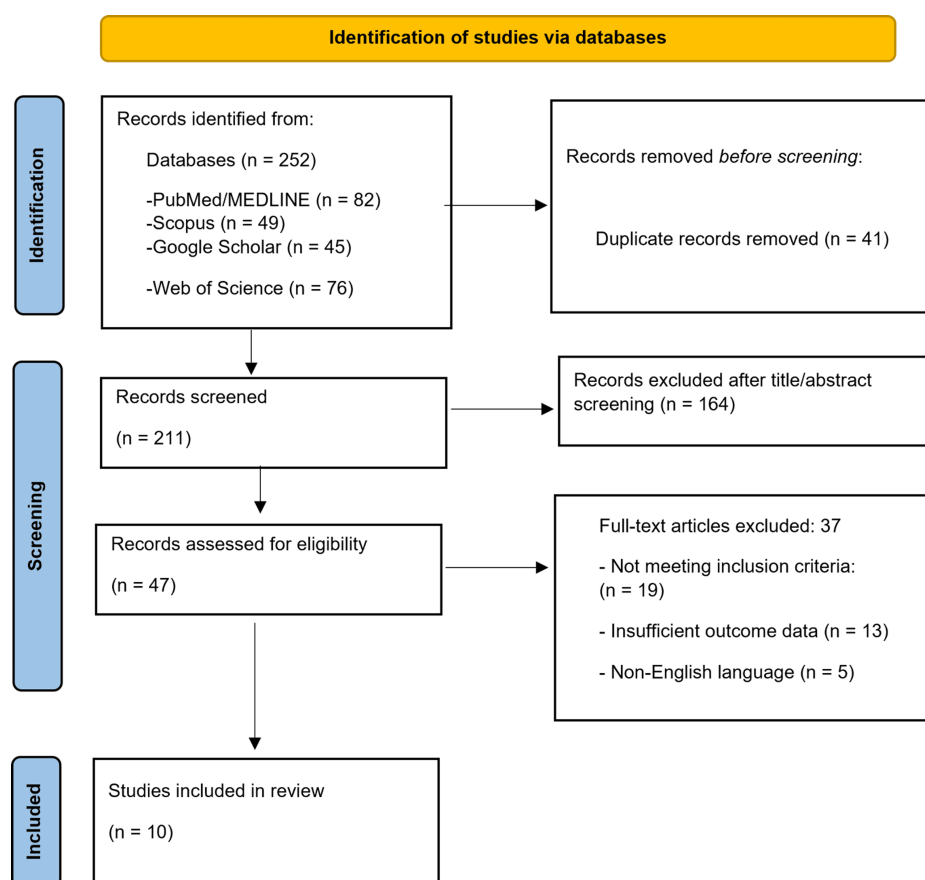


FIGURE 1: PRISMA Flow Diagram of Study Selection

PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Study Characteristics

The 10 included studies comprised retrospective single-center cohorts, multicohort prognostic analyses, intraoperative imaging studies, and neurocognitive outcome studies published between 2021 and 2026. Sample sizes ranged from 7 patients with incidentally detected pediatric brain tumors to 1110 patients with medulloblastoma. For synthesis, the studies were considered according to tumor type and clinical focus. Low-grade glioma studies evaluated MRI characteristics, BRAF V600E status, residual tumor behavior, sodium fluorescein-guided surgery, and neurocognitive outcomes. The medulloblastoma study focused on

the prognostic significance of subtotal resection, while the spinal tumor study evaluated clinicopathological features, extent of resection, and survival. Studies involving mixed or incidental pediatric CNS tumors primarily assessed multidisciplinary surgical management, extent of resection, postoperative neurological outcomes, and intraoperative ultrasound. Because these populations and interventions were clinically heterogeneous, findings were interpreted within their respective tumor and diagnostic or surgical contexts rather than combined as uniform effects. Table 3 summarizes the main findings and details of the 10 studies included.

Study	Study design/setting	Sample size	Tumor type/population	Diagnostic or surgical focus	Key findings
Spazzapan and Velnar [19]	Retrospective single-center prognostic analysis, Slovenia	110 pediatric patients; 130 procedures	Pediatric CNS tumors	Integrated diagnostic evaluation, surgical planning, extent of resection, neurological outcomes	Headache, vomiting, and ataxia were common presenting symptoms. Tumors were mainly supratentorial or infratentorial. Gross total resection was achieved in 60% of procedures. Infratentorial location and medulloblastoma histology were linked with cerebellar mutism and shunt dependency, supporting the prognostic value of anatomical and histological assessment.
Schaumann et al. [20]	Retrospective single-center multidisciplinary cohort, Germany	293 patients; 531 surgical interventions	Pediatric brain tumors	Multidisciplinary neuro-oncological surgical management and postoperative neurological outcomes	Planned extent of resection was achieved in 92.7% of cases. New postoperative neurological deficits occurred in 10.7%, with improvement or resolution in most cases within 30 days. The study supports specialized multidisciplinary infrastructure for pediatric brain tumor surgery.
Keeling et al. [21]	Multicohort molecular and clinical survival analysis	1110 medulloblastoma patients	Childhood medulloblastoma	Prognostic significance of subtotal resection	Subtotal resection was associated with poorer survival in univariable analysis but was not an independent prognostic factor after multivariable adjustment. Findings support maximal safe resection rather than aggressive resection when subtotal resection is the only risk factor.
De Laurentis et al. [22]	Retrospective single-center surgical imaging study	22 pediatric patients	Pediatric low-grade gliomas	Sodium fluorescein-guided surgery and intraoperative pathological sampling	Sodium fluorescein uptake was observed in 86% of lesions and was useful intraoperatively in 74% of fluorescent tumors. Fluorescence appeared to be associated with gadolinium enhancement and assisted intraoperative localization and pathological sampling.
Gorodezki et al. [23]	Retrospective single-center cohort with MRI volumetric analysis	172 surgical pLGG patients; 94 in postoperative cohort	Pediatric low-grade gliomas	Extent of resection, residual tumor growth velocity, BRAF V600E status	Incomplete resection was followed by significant postoperative tumor growth deceleration. Greater resection extent correlated with lower postoperative tumor growth velocity. BRAF V600E mutant tumors had higher postoperative growth velocity than wild-type tumors.
Grudzień et al. [24]	Retrospective MRI-based diagnostic study	32 pediatric patients	Low-grade and high-grade pediatric brain tumors	MRI features predicting WHO tumor grade	Infiltrative growth pattern and presence of cystic component were significantly associated with final WHO grade. Diffusion restriction approached statistical significance. The study supports the role of conventional MRI morphology in preoperative grading.
Antkowiak et al. [25]	Retrospective single-center case series	7 pediatric patients	Incidentally found pediatric brain tumors	Surgical treatment of incidental pediatric brain tumors	Most lesions were benign and surgically managed with favorable outcomes. Gross total resection was achieved in 71.4%, with no postoperative neurological deterioration, although one patient developed a postoperative wound complication.
					Cognitive and behavioral outcomes were

Taddei et al. [26]	Retrospective single-center neurocognitive outcome study	38 children	Pediatric low-grade CNS tumors treated only with surgery	Cognitive and behavioral outcomes after surgery	generally within the normal range, with weaknesses in verbal working memory and processing speed. Younger age at symptom onset, tumor type, cortical location, seizures, timing of surgery, and seizure control were associated with cognitive and behavioral outcomes.
Choi et al. [27]	Retrospective 32-year single-institution cohort, Korea	126 pediatric patients	Primary solitary spinal cord tumors	Clinicopathological features, extent of resection, survival outcomes	Extradural tumors were most common, and about half of the tumors were malignant. Ten-year overall survival was 81%, and progression-free survival was 66%. Pathology and extent of resection were associated with survival outcomes, although the prognostic importance of resection extent varied according to anatomical compartment.
Carai et al. [28]	Retrospective intraoperative imaging study	154 pediatric brain tumor resections	Pediatric neurosurgical oncology cases	Intraoperative ultrasound for extent-of-resection assessment	Intraoperative ultrasound showed high concordance with early postoperative MRI, with a positive predictive value of 98%, a negative predictive value of 92%, sensitivity of 86%, and specificity of 99%. The study supports ioUS as a practical intraoperative tool for pediatric tumor resection assessment.

TABLE 3: Characteristics of Included Studies

BRAF, B-Raf proto-oncogene; CNS, central nervous system; ioUS, intraoperative ultrasound; MRI, magnetic resonance imaging; pLGG, pediatric low-grade glioma; WHO, World Health Organization.

Risk-of-Bias Assessment

The methodological appraisal identified variation in participant selection, confounding control, outcome measurement, follow-up completeness, and statistical reporting across the included studies. Assessments were conducted according to the methodological characteristics of each study, and findings are presented at the individual domain or checklist-item level without calculating composite quality scores. The QUIPS assessment of prognostic studies is summarized in Table 4, covering six domains relevant to prognostic factor research.

Study	Study participation	Study attrition	Prognostic factor measurement	Outcome measurement	Study confounding	Statistical analysis and reporting
Spazzapan and Velnar [19]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Keeling et al. [21]	Moderate	Moderate	Moderate	Low	Moderate	Moderate
Gorodezki et al. [23]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Choi et al. [27]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

TABLE 4: Risk-of-Bias Assessment of Prognostic Studies Using QUIPS

QUIPS: Quality in Prognosis Studies.

Domain judgments are low-, moderate-, or high-risk of bias.

The appraisal indicated that confounding and statistical analysis were the principal methodological concerns, while outcome measurement was generally less problematic. These limitations should be considered when interpreting prognostic associations derived from retrospective datasets. Diagnostic accuracy was assessed by examining patient selection, index testing, reference standards, flow and timing, and applicability concerns. These findings are summarized in Table 5.

Assessment domain	Carai et al. [28]
Risk of bias	
Patient selection	Low
Index test	Unclear
Reference standard	Low
Flow and timing	Low
Applicability concerns	
Patient selection	Low
Index test	Low
Reference standard	Low

TABLE 5: QUADAS-2 Assessment of Diagnostic Accuracy

QUADAS-2: Quality Assessment of Diagnostic Accuracy Studies-2.

Judgments are low, high, or unclear.

The diagnostic appraisal indicated limited concerns regarding participant selection, reference standards, and flow and timing. However, uncertainty remained in the index-test domain, emphasizing the importance of complete reporting of diagnostic procedures and interpretation. The analytical cross-sectional study was evaluated using the JBI checklist, focusing on inclusion criteria, participant characteristics, measurement validity, confounding, and statistical analysis. The corresponding findings are presented in Table 6.

JBI appraisal item	Grudzień et al. [24]
1. Inclusion criteria clearly defined	Yes
2. Study participants and setting described in detail	Yes
3. Exposure measured validly and reliably	Unclear
4. Objective, standard criteria used to measure the condition	Yes
5. Confounding factors identified	No
6. Strategies to address confounding stated	No
7. Outcomes measured validly and reliably	Yes
8. Appropriate statistical analysis used	No

TABLE 6: JBI Critical Appraisal of the Analytical Cross-Sectional Study

JBI: Joanna Briggs Institute.

Responses are yes, no, unclear, or not applicable.

The analytical cross-sectional appraisal indicated adequate reporting of participant characteristics and outcome measurements. However, incomplete management of confounding and limitations in statistical analysis were identified, restricting the interpretation of observed imaging associations as independent diagnostic predictors. The observational cohort studies were assessed using the JBI Cohort Checklist, covering participant recruitment, exposure and outcome measurement, confounding, follow-up, and statistical analysis. The individual checklist findings are presented in Table 7.

JBI appraisal item	Schaumann et al. [20]	Taddei et al. [26]
1. Groups similar and recruited from the same population	N/A	N/A
2. Exposures measured similarly across groups	N/A	N/A
3. Exposure measurement valid and reliable	Unclear	Yes
4. Confounding factors identified	Yes	Yes
5. Strategies to deal with confounding	No	Unclear
6. Participants free of outcome at baseline	N/A	N/A
7. Outcomes measured validly and reliably	Yes	Yes
8. Follow-up duration sufficient	Yes	Unclear
9. Follow-up complete	No	Unclear
10. Strategies to address incomplete follow-up	Unclear	Unclear
11. Appropriate statistical analysis	Yes	Yes

TABLE 7: JBI Critical Appraisal of Observational Cohort Studies

JBI: Joanna Briggs Institute; N/A: not applicable.

Responses are yes, no, unclear, or not applicable.

The cohort appraisal demonstrated generally adequate reporting of outcome measures and statistical procedures. Nevertheless, uncertainty regarding follow-up completeness and the management of potential confounding factors remained, which may influence the interpretation of clinical and neurocognitive outcomes. Finally, descriptive surgical case series were assessed using the JBI Case Series Checklist, examining participant inclusion, consistency of diagnostic measurements, clinical reporting, outcomes, and statistical analysis. The findings are presented in Table 8.

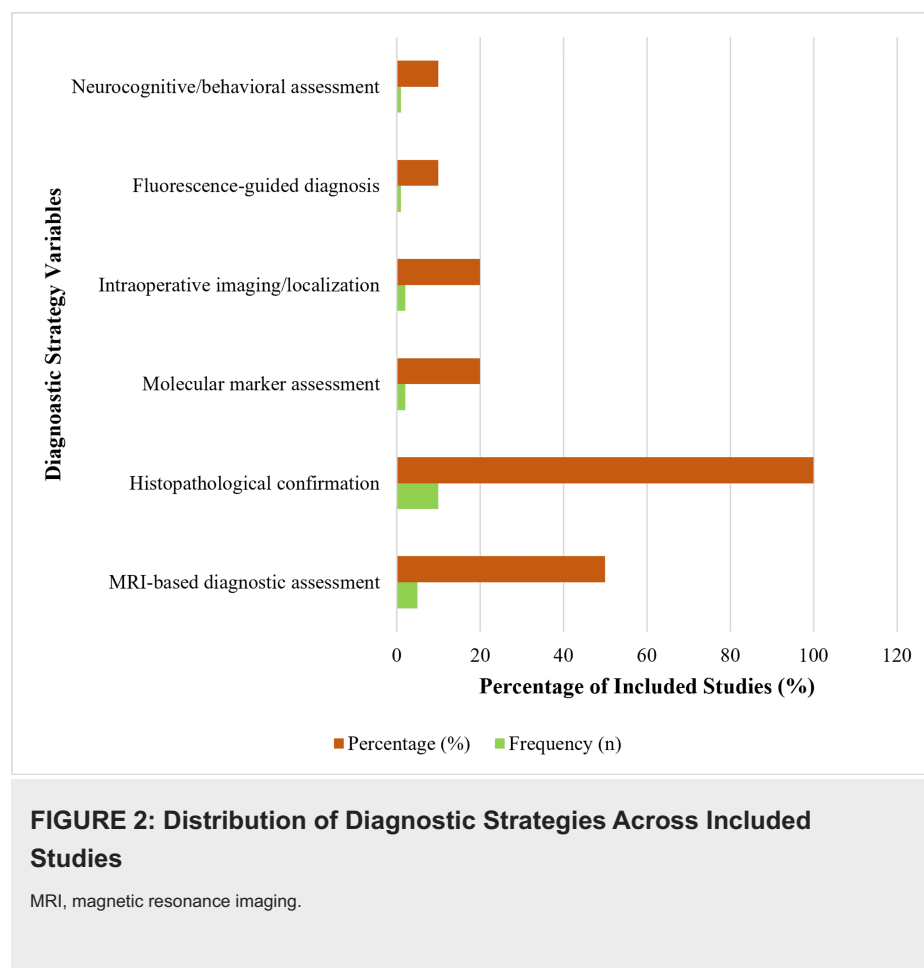
JBI appraisal item	De Laurentis et al. [22]	Antkowiak et al. [25]
1. Clear inclusion criteria	Yes	Yes
2. Condition measured consistently	Yes	Yes
3. Valid methods for identifying the condition	Yes	Yes
4. Consecutive inclusion of participants	Unclear	Unclear
5. Complete inclusion of eligible participants	Unclear	Unclear
6. Demographic characteristics reported	Yes	Yes
7. Clinical information reported	Yes	Yes
8. Outcomes or follow-up results reported	Yes	Yes
9. Demographic information for presenting sites reported	Unclear	Unclear
10. Appropriate statistical analysis	Yes	Yes

TABLE 8: JBI Critical Appraisal of Surgical Case Series

JBI: Joanna Briggs Institute.

Responses are yes, no, unclear, or not applicable.

The completed studies show that the development of a diagnosis of spinal and brain tumors in children relies on the integration of radiological, intra-operative, histopathological, and molecular information. MRI imaging continued to be the key modality for tumor localization, morphology, suspicion of malignancy, planning surgery, and follow-up after surgery. Infiltrative growth and cysts, enhancement pattern, and diffusion restriction were used to differentiate low-grade from high-grade lesions. Visual localization of low-grade gliomas was enhanced with sodium fluorescein, which was helpful in the process of the intraoperative sampling of tissue, particularly in conjunction with gadolinium enhancement. High agreement was observed between intraoperative ultrasound and the postoperative MRI for evaluating the tumor margins and residual disease. In addition, BRAF V600E status was found to be a prognostic factor for predicting the growth of residual low-grade glioma. Histopathology and MRI were the most frequently used diagnostic techniques in the various studies, as shown in Figure 2.



Surgical Management and Clinical Outcomes

The surgical evidence emphasized the need for the safest resection rather than aggressive resective surgery. Neurological preservation was most central, with gross total resection being associated with favorable control across mixed CNS tumors, incidentally detected, low-grade gliomas, and spinal cord tumors. In a multidisciplinary surgical setting, the planned extent of resection was achieved in a high proportion of cases. However, subtotal resection in medulloblastoma was associated with poorer survival in univariable analysis but was not an independent prognostic factor after adjustment for other clinical and molecular risk factors. In the absence of other high-risk factors, subtotal resection did not appear to be an independent prognosticator, suggesting that a risk-adapted approach to the treatment of medulloblastoma should be pursued. Growth slowdown following surgery was a frequent feature of the residual low-grade gliomas, but growth was faster with larger residual volumes and BRAF V600E mutation. Morbidity was generally satisfactory, and neurocognitive follow-up was still significant following surgery, especially in younger children. Gross/complete resection assessment and surgical outcome morbidity/neurological outcome are the most commonly reported surgical outcome variables, as illustrated in Figure 3.

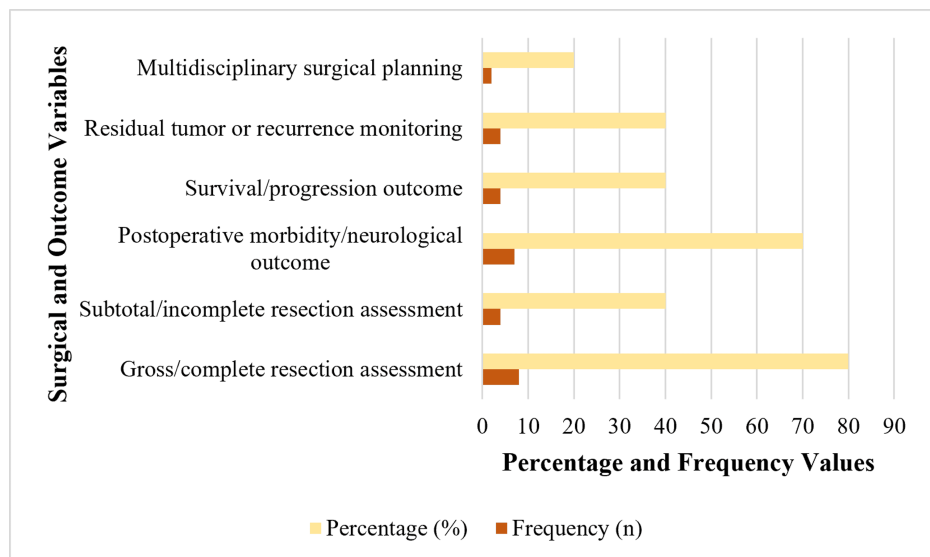


FIGURE 3: Distribution of Surgical Management and Clinical Outcome Variables

Discussion

This systematic review indicates that the contemporary management of pediatric BSTs increasingly relies on integrated diagnostic evaluation, intraoperative guidance, molecular characterization, and risk-adapted surgical decision-making. The findings should be interpreted according to tumor type and clinical context because the included studies differed substantially in population, study design, diagnostic modality, surgical intervention, and outcome assessment. Across the included studies, surgical planning was informed not only by tumor location but also by radiological features, histopathological subtype, molecular profile, expected resectability, neurological risk, and anticipated long-term functional outcomes. The review therefore identifies recurring clinical themes rather than uniform comparative effects across all pediatric BSTs. This is clinically relevant because these tumors are biologically heterogeneous, anatomically diverse, and associated with variable prognoses. Advances in tumor-specific diagnostic and therapeutic approaches, including emerging nanoparticle-based strategies, further reflect the need for individualized management in pediatric neuro-oncology [29].

Following the study selection process, 10 studies were identified from a total of 252 records, which is a small evidence base regarding the advances in diagnosis and surgery for pediatric BSTs. It is no surprise that the majority of studies that were included were retrospective cohort studies or institutional case series, given the rarity of many tumor entities in pediatric neurosurgical oncology, and the fact that randomized surgical studies are impractical. The included studies provided clinical insights into MRI-based diagnosis, intraoperative fluorescence, intraoperative ultrasound, extent-of-resection evaluation, residual tumor behavior, spinal tumor survival, postoperative neurological outcomes, and neurocognitive consequences. These findings are relevant to broader developments in pediatric neuro-oncology, including emerging diagnostic and therapeutic technologies and the importance of perioperative management in surgical care [29,30].

There were some recurring themes in the studies within the focus, with diagnostic assessment being one of them. MRI was always used as the key imaging and planning modality in the diagnosis and surgery, and for localization, tumor characterization, and follow-up procedures. MRI gave clinically relevant information regarding the preoperative suspicion of tumor grade and surgical risk, such as infiltrative growth, cystic architecture, enhancement pattern, diffusion restriction, and anatomical compartment. Histopathological diagnosis remained the most frequently used diagnostic reference and was used as the last diagnostic criterion for tumor classification and treatment planning. Molecular testing, including BRAF V600E assessment in pediatric low-grade gliomas, provided additional information regarding postoperative residual tumor behavior. Alongside these diagnostic considerations, surgical evaluation of intramedullary spinal cord tumors requires careful assessment of tumor pathology, anatomical characteristics, resectability, and neurological preservation [31].

Intraoperative diagnostic adjuncts were an important advancement in the precision of surgery. Sodium fluorescein-assisted surgery was beneficial for the localization of the tumor and for the intraoperative pathological evaluation of the low-grade gliomas, especially those with gadolinium enhancement, in pediatric patients. The intra-operative sonography was also well correlated with the post-operative MRI in determining residual tumor, making ultrasound possibly a useful, readily available, and cost-effective tool

for the real-time assessment of residual tumor during tumor resection in children. These intraoperative approaches complement broader advances in neuro-oncological diagnostics, including cerebrospinal fluid-based molecular sequencing and advanced imaging techniques such as PET-MRI, which provide additional information for tumor characterization and diagnostic assessment [32,33].

The results of surgical operations confirm the principle of maximal safe resection as the central one. Gross total resection was generally associated with good disease control in many examples: for low-grade gliomas, incidental tumors, and some types of spinal tumors. It is also clear that there is no point in attempting to achieve total removal in all cases when aggressive surgical intervention carries a substantial risk of neurological morbidity. In multivariable analysis, the clinical and molecular risk factors were added, and subtotal resection was no longer identified as an independent risk factor in medulloblastoma. Univariable analysis revealed poorer survival for subtotal resection, but this was not the case in multivariable analysis when the clinical and molecular risk factors were included. These findings support individualized surgical decision-making rather than uniformly aggressive resection. Similarly, contemporary approaches to pediatric glioma management increasingly consider molecular characteristics, tumor biology, and available treatment strategies when determining individualized care [34].

The residual tumor behavior was determined as a prominent outcome domain. However, pediatric low-grade gliomas are not always associated with rapid progression after suboptimal resection and may demonstrate postoperative growth arrest. Residual volume and BRAF V600E mutation status may be able to identify patients at greater risk for recurrence, and thus molecular and volumetric surveillance is relevant to surveillance planning. In spinal cord tumors, surgical decision-making similarly requires consideration of tumor pathology, anatomical characteristics, and neurological function [31]. Evidence from pediatric intramedullary spinal tumor populations also demonstrates variation in treatment patterns and survival according to tumor histology, supporting individualized treatment planning [35].

Other important findings were postoperative morbidity and functional outcome at follow-up. A few reports have described acceptable neurological morbidity, particularly at multidisciplinary centers and centers specializing in these issues. In many instances, the deficits were temporary and ameliorated at follow-up, and therefore the long-term complications were minimized by proper perioperative management and skilled pediatric neurosurgical teams. Neurocognitive and behavioral outcomes are equally important as endpoints in pediatric neuro-oncology, as survival does not constitute an endpoint. Children who receive surgery alone may be within normal ranges of cognitive functioning but may have processing speed deficits and verbal working memory and behavioral deficits, particularly in younger children and those with cortical tumors and seizures. Advances in glioma surgery also emphasize emerging surgical techniques that aim to improve tumor management while considering neurological preservation [36].

The methodological appraisal indicated generally moderate risk of bias across the included studies, with some domains showing low risk. Retrospective design, single-center recruitment, and the fact that the included tumor types were heterogeneous and the number of samples was small and incomplete control of confounding. Improved reliability of measurement was provided by all MRI, histopathology, molecular testing, postoperative imaging, and standardized neurocognitive instruments. The results lend credence to the idea of an integrated diagnostic-surgical pathway, multidisciplinary planning, utilization of intraoperative adjuncts if available, and follow-up individualized based on tumor biology, residual disease, neurological status, and functional risk. New prospective multicenter trials, including uniform reporting of imaging, molecular markers, extent of resection, morbidity, survival, and neurocognitive outcomes, are needed to further enhance the quality of evidence and to inform pediatric neuro-oncology care.

Limitations and Future Directions

There are some limitations to this review. Most of the studies were retrospective and performed at a single center; this may affect generalizability and introduce selection bias. The evidence was heterogeneous regarding tumor type, location, diagnostic approach, surgical method, outcome definitions, and follow-up duration. Sample sizes also varied considerably across studies. There was limited standardization of potential confounding factors, including tumor biology, molecular profile, adjuvant therapy, baseline neurological status, and surgeon experience. The restriction to English-language publications may have introduced language bias and resulted in the exclusion of potentially relevant non-English studies. Although design-specific risk-of-bias assessment tools were applied, methodological differences, incomplete control of confounding, and variability in follow-up reporting limited the interpretation and comparability of findings. A meta-analysis was not performed because substantial clinical and methodological heterogeneity precluded meaningful quantitative pooling.

Future prospective, multicenter studies should use standardized diagnostic, surgical, radiological, molecular, and functional outcome assessments in pediatric neuro-oncology populations. Long-term neurocognitive, behavioral, and quality-of-life outcomes should receive greater attention. Future studies should also evaluate the clinical utility of intraoperative ultrasound, fluorescence guidance, molecular markers, and residual tumor volumetry for risk-adapted surgical planning and postoperative monitoring.

Conclusions

The systematic review suggests that the assessment and treatment planning of pediatric BSTs have improved with advances in diagnostic procedures and surgery. In all the studies included, MRI was the most significant modality for tumor localization, grade of suspicion, operative planning, and postoperative surveillance, with histopathology as the ultimate diagnosis. In the case of pediatric low-grade glioma, molecular markers, particularly BRAF V600E, also proved to be useful for prognosis and helped to identify more aggressive tumors. Intraoperative adjuncts, such as sodium fluorescein and intraoperative ultrasound, aided in improved tumor localization and evaluation of the extent of resection. The surgical data were in favor of maximal safe resection, and not radical removal with the risk of compromising neurologic function. Gross total resection proved to be advantageous in some tumors; however, subtotal resection was not always associated with poor outcomes, especially when biological characteristics and risk factors of the tumor were taken into account. Endpoints of long-term neurological, cognitive, behavioral, and survival outcomes remain important. The use of multidisciplinary, individualized, function-preserving cancer treatment with standardized diagnostic, surgical, molecular, and follow-up workflow should be a priority in future pediatric neuro-oncology.

Appendices

Full-text exclusions and reasons

During the eligibility assessment, 47 full-text articles were reviewed, of which 37 were excluded. Reported reasons for exclusion were failure to meet the predefined inclusion criteria (n=19), insufficient outcome data relevant to the review objectives (n=13), and non-English publications (n=5). The article-level references and corresponding reasons for exclusion are presented in Table 9.

No.	Study	Reason for exclusion
1	Cohen AR. Brain tumors in children. N Engl J Med. 2022;386(20):1922-1931. doi:10.1056/NEJMra2116344.	Review article; ineligible study design.
2	Boop S, Shimony N, Boop F. How modern treatments have modified the role of surgery in pediatric low-grade glioma. Childs Nerv Syst. 2024;40(10):3357-3365. 10.1007/s00381-024-06412-w.	Review article; ineligible study design.
3	Pacchiano F, Tortora M, Doneda C, et al. Radiomics and artificial intelligence applications in pediatric brain tumors. World J Pediatr. 2024;20(8):747-763. 10.1007/s12519-024-00823-0.	Review article; ineligible study design.
4	Ronsley R, Cole B, Ketterl T, et al. Pediatric central nervous system embryonal tumors: presentation, diagnosis, therapeutic strategies, and survivorship—a review. Pediatr Neurol. 2024;161:237-246. 10.1016/j.pediatrneurol.2024.09.031.	Review article; ineligible study design.
5	Kehoe K, Sivaguru H, Coulter I, Cowie C. Delay in the diagnosis of paediatric brain tumours: a systematic review. Childs Nerv Syst. 2023;39(8):2053-2063. 10.1007/s00381-023-06022-y.	Systematic review; ineligible study design.
6	Vacek A, Kaliaperumal C. Radiation-induced cavernoma in pediatric CNS tumors: a systematic review and treatment paradigm. Childs Nerv Syst. 2024;40(11):3527-3536. 10.1007/s00381-024-06543-0.	Systematic review; ineligible study design.
7	Lutz K, Jünger ST, Messing-Jünger M. Essential management of pediatric brain tumors. Children (Basel). 2022;9(4):498. 10.3390/children9040498.	Review article; ineligible study design.
8	Jaju A, Li Y, Dahmouch H, et al. Imaging of pediatric brain tumors: a COG Diagnostic Imaging Committee/SPR Oncology Committee/ASPNR white paper. Pediatr Blood Cancer. 2023;70(suppl 4):e30147. 10.1002/pbc.30147.	Consensus publication; ineligible study design.
9	Lassaletta Á, Morales JS, Valenzuela PL, et al. Neurocognitive outcomes in pediatric brain tumors after treatment with proton versus photon radiation: a systematic review and meta-analysis. World J Pediatr. 2023;19(8):727-740. 10.1007/s12519-023-00726-6.	Systematic review and meta-analysis.
10	Nabavizadeh A, Barkovich MJ, Mian A, et al. Current state of pediatric neuro-oncology imaging, challenges and future directions. Neoplasia. 2023;37:100886. 10.1016/j.neo.2023.100886.	Review article; ineligible study design.

11	Gajjar A, Mahajan A, Abdelbaki M, et al. Pediatric central nervous system cancers, version 2.2023, NCCN clinical practice guidelines in oncology. <i>J Natl Compr Canc Netw</i> . 2022;20(12):1339-1362. 10.6004/jnccn.2022.0062.	Clinical practice guideline; ineligible study design.
12	Viaene AN. Pediatric brain tumors: a neuropathologist's approach to the integrated diagnosis. <i>Front Pediatr</i> . 2023;11:1143363. 10.3389/fped.2023.1143363.	Review article; ineligible study design.
13	Vella S, Lauri J, Grech R. Comparison of arterial spin-labeling and DSC perfusion MR imaging in pediatric brain tumors: a systematic review and meta-analysis. <i>AJNR Am J Neuroradiol</i> . 2025;46(1):178-185. 10.3174/ajnr.A8442.	Systematic review and meta-analysis.
14	Morales H. Common pediatric brain tumors: core statistics and imaging features. <i>Semin Ultrasound CT MR</i> . 2025;46(2):139-143. 10.1053/j.sult.2025.03.001.	Pictorial review; ineligible study design.
15	Bogdanović B, Montemagno C. From seeing to healing: the clinical potential of radiotracers in pediatric neuro-oncology. <i>Cancers (Basel)</i> . 2025;17(12):1905. 10.3390/cancers17121905.	Review article; ineligible study design.
16	Halfpenny AM, Wood MD. Review of the recent changes in the WHO classification for pediatric brain and spinal cord tumors. <i>Pediatr Neurosurg</i> . 2023;58(5):337-355. 10.1159/000528957.	Review article; ineligible study design.
17	Troudi A, Tensaouti F, Baudou E, Péran P, Laprie A. Arterial spin labeling perfusion in pediatric brain tumors: a review of techniques, quality control, and quantification. <i>Cancers (Basel)</i> . 2022;14(19):4734. 10.3390/cancers14194734.	Review article; ineligible study design.
18	Jung AY. Basics for pediatric brain tumor imaging: techniques and protocol recommendations. <i>Brain Tumor Res Treat</i> . 2024;12(1):1-13. 10.14791/btrt.2023.0037.	Review article; ineligible study design.
19	Limaye W, Ahmad T. Advanced MRI imaging techniques in pediatric brain tumors. <i>Pediatr Radiol</i> . 2024;54(8):1235-1246. 10.1007/s00247-024-05966-w.	Review article; ineligible study design.
20	Offenbacher R, Kobets A, Dalvi N, et al. A nine-month-old boy with regression of milestones and severe constipation: an unusual case of a spinal pilocytic astrocytoma. <i>Neuro Oncol</i> . 2022;24(suppl 1):i87-i88. 10.1093/neuonc/noac079.321.	Insufficient longitudinal outcome data.
21	Koptyra MP, Diarra N, Rokita JL, et al. METB-12. Gift from a child postmortem specimen dataset extension of the Pediatric Brain Tumor Atlas empowers pediatric brain tumor research. <i>Neuro Oncol</i> . 2024;26(suppl 4):0. 10.1093/neuonc/noae064.253.	Insufficient relevant clinical outcome data.
22	Jugas R, Pokorna P, Adamcova S, et al. Dataset of DNA methylation profiles of 189 pediatric central nervous system, soft tissue, and bone tumors. <i>Data Brief</i> . 2024;55:110590. 10.1016/j.dib.2024.110590.	Insufficient extractable clinical outcome data.
23	Familiar AM, Fathi Kazerooni A, Anderson H, et al. A multi-institutional pediatric dataset of clinical radiology MRIs by the Children's Brain Tumor Network. <i>arXiv</i> . Published online October 2, 2023. https://pmc.ncbi.nlm.nih.gov/articles/PMC10723526/	Insufficient relevant clinical outcome data.
24	Esteso-Orduña B, Vázquez-Gómez F, Moreno-Carrasco JL, et al. Feasibility of preoperative neuropsychological evaluation in pediatric brain tumor patients: is it possible to assess before surgery? <i>Neuro Oncol</i> . 2024;26(suppl 4). 10.1093/neuonc/noae064.629.	Inadequate reporting of relevant outcomes.
25	Kotch C, Solomon DA, Wallace K, et al. Clinical and molecular features of high-grade glioma in children and adults with neurofibromatosis type 1: a preliminary analysis. <i>Neuro Oncol</i> . 2024;26(suppl 4). 10.1093/neuonc/noae064.566.	Insufficient separately extractable pediatric outcomes.
26	Catanzaro G, Conte F, Besharat ZM, et al. Network analysis integrating microRNAs and clinical data to determine prognostic outcome in pediatric low-grade glioma patients. <i>Neuro Oncol</i> . 2024;26(suppl 4). 10.1093/neuonc/noae064.425.	Inadequate quantitative outcome reporting.
27	Simon N, Maass KK, et al. Towards clinical implementation of liquid biopsy analysis for paediatric brain tumour patients—a pan-European effort for standardization. <i>Neuro Oncol</i> . 2024;26(suppl 4). 10.1093/neuonc/noae064.028.	Insufficient diagnostic outcome data.
28	van Baarsen K, Slot M, Woerdeman P, Han S, Hoving E. Pediatric oncology neurosurgery, four years after centralization in the Princess Máxima Center. <i>Neuro Oncol</i> . 2022;24(suppl 1):i145. 10.1093/neuonc/noac079.534.	Incomplete surgical outcome reporting.

29	Carai A, Premuselli R, Barba M, et al. Virtual reality assistance in the management of pediatric brain tumors. Neuro Oncol. 2024;26(suppl 4). 10.1093/neuonc/noae064.644.	Insufficient patient-level clinical outcome data.
30	Lehman TE, Deal JL, Lee J, et al. The blood-based telomeric DNA C-circle assay can detect alternative lengthening of telomeres (ALT) in pediatric high-grade gliomas. Neuro Oncol. 2024;26(suppl 4). 10.1093/neuonc/noae064.332.	Limited diagnostic outcome reporting.
31	Nagabushan S, Dhall G, Abdelbaki M. Multi-institutional analysis of pediatric relapsed/refractory central nervous system germ cell tumors. Neuro Oncol. 2022;24(suppl 1):i58. 10.1093/neuonc/noac079.214.	Incomplete reporting of relevant outcomes.
32	Walsh K, Stoodley C, Nielsen J, et al. Impact of lesion location on motor and cognitive outcomes in pediatric cerebellar tumors. Neuro Oncol. 2024;26(suppl 4). 10.1093/neuonc/noae064.604.	Insufficient quantitative outcome reporting.
33	Kim AV, Khachatryan VA. Intraoperative fluorescence diagnosis using 5-aminolevulinic acid in surgical treatment of children with recurrent neuroepithelial tumors. Zh Vopr Neurokhir Im N N Burdenko. 2017;81(1):51-57. 10.17116/neiro201780751-57.	Non-English publication (Russian).
34	Golounina OO, Pavlova MG, Belaya ZE, et al. Endocrine late-effects and bone mineral density after combined treatment of malignant brain tumors in childhood and adolescence. Probl Endokrinol (Mosk). 2021;67(1):31-40. 10.14341/probl12680.	Non-English publication (Russian).
35	Niu FN, Wang Y, Du ZG, Xiong J. Ependymoma-like tumor with mesenchymal differentiation harboring ZFTA-NCOA1/2 fusion: clinical, histological and immunophenotypical characteristics. Zhonghua Bing Li Xue Za Zhi. 2023;52(4):396-398. 10.3760/cma.j.cn112151-20220729-00662.	Non-English publication (Chinese).
36	Yin CY, Wang YC, Du WC, Liu YF. Analysis of 18 cases of malignant rhabdoid tumor in children. Zhonghua Er Ke Za Zhi. 2022;60(9):908-914. 10.3760/cma.j.cn112140-20220323-00241.	Non-English publication (Chinese).
37	Wang SJ, Zhang W, He JP, et al. Classification of the types of pediatric posterior fossa brain tumors based on routine MRI using wavelet transformation analysis of whole tumor. Zhonghua Yi Xue Za Zhi. 2020;100(3):178-181. 10.3760/cma.j.issn.0376-2491.2020.03.004.	Non-English publication (Chinese).

TABLE 9: Full-text exclusions and reasons (n=37)

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Saniya Yusufkhan Pathan, Narendra Kumar Arya , Dilan Sathi Prakasan, Haramohan Sahoo, Alka Singh , Biswabinode Sanfui, Dixita R. Tailor

Acquisition, analysis, or interpretation of data: Saniya Yusufkhan Pathan, Narendra Kumar Arya , Dilan Sathi Prakasan, Haramohan Sahoo, Alka Singh , Biswabinode Sanfui, Dixita R. Tailor

Drafting of the manuscript: Saniya Yusufkhan Pathan, Narendra Kumar Arya , Dilan Sathi Prakasan, Haramohan Sahoo, Alka Singh , Biswabinode Sanfui, Dixita R. Tailor

Critical review of the manuscript for important intellectual content: Saniya Yusufkhan Pathan, Narendra Kumar Arya , Dilan Sathi Prakasan, Haramohan Sahoo, Alka Singh , Biswabinode Sanfui, Dixita R. Tailor

Supervision: Saniya Yusufkhan Pathan

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. Financial relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. Other relationships: All authors have declared that there are no

other relationships or activities that could appear to have influenced the submitted work.

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