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PREDICTORS OF SURGICAL OUTCOME IN PAEDIATRIC BRAIN TUMOURS: A SINGLE-SURGEON RETROSPECTIVE COHORT STUDY

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ABSTRACT

Background: Surgery is central to the management of paediatric brain tumours, yet the factors that determine early surgical outcome remain incompletely defined in resource-limited settings. We examined the clinical, radiological, surgical and pathological predictors of surgical outcome in children operated by a single neurosurgeon.

Materials and Methods: This retrospective cohort included 24 consecutive children (≤ 18 years) with histologically confirmed primary brain tumours operated by one neurosurgeon between December 2024 and May 2026, each followed for one month. A favourable outcome was defined as improvement or no deterioration in neurological status without major complication; unfavourable outcome comprised death, major deficit, severe complication, prolonged stay or reoperation. Associations were tested with the Student's and paired t-tests, chi-square/Fisher exact test, one-way ANOVA, Pearson correlation and Firth penalized logistic regression.

Results: Sixteen children (66.7%) had a favourable and eight (33.3%) an unfavourable outcome; 30-day mortality was 8.3%. Unfavourable outcome was associated with younger age, larger tumours, high WHO grade, sub-total resection or biopsy, malnutrition, poorer pre-operative performance status and greater blood loss (all $p < 0.05$). Among survivors, functional performance improved significantly after surgery (76.1 to 82.0; $p = 0.029$). Hospital stay differed markedly by extent of resection (ANOVA $p < 0.001$), and blood loss correlated strongly with operative duration ($r = 0.91$). On multivariable analysis, a pre-operative Lansky/Karnofsky score below 70 was the dominant independent predictor of unfavourable outcome (adjusted OR 22.6, 95% CI 5.9–194.9).

Conclusion: Extent of resection, tumour grade and — above all — pre-operative functional status were the principal determinants of early surgical outcome. These readily available variables can support pre-operative counselling and risk stratification in paediatric neuro-oncology.

Keywords: Paediatric brain tumour; surgical outcome; extent of resection; performance status; hydrocephalus; predictors.

INTRODUCTION

Central nervous system (CNS) tumours are the most common solid neoplasms of childhood and, collectively, the leading cause of cancer-related death in children.[1-5] Their biological and anatomical diversity was formally recognised in the 2021 World Health Organization (WHO) classification, which integrated molecular signatures with histology and dedicated an entire volume to paediatric-type tumours.[6] Although outcomes have improved in high-income settings, the burden falls disproportionately on low- and middle-income countries, where late presentation, limited imaging and constrained neurosurgical infrastructure translate into higher perioperative morbidity and

mortality.[1] Understanding what predicts a good or poor surgical result is therefore of direct clinical relevance in such environments.

Maximal safe resection remains the cornerstone of treatment for most paediatric brain tumours, and the extent of resection is repeatedly identified as one of the strongest prognostic factors for both survival and functional recovery.[2,4] Posterior fossa tumours predominate in children and are frequently accompanied by obstructive hydrocephalus, which may itself require cerebrospinal fluid (CSF) diversion and influence the postoperative course.[6-10] Beyond the tumour itself, host factors such as age, nutritional state and baseline functional performance, together with intra-operative variables such as operative duration and blood loss, plausibly shape the immediate outcome; yet these have seldom been examined together in a single, homogeneous surgical series.[3,9]

Despite this plausibility, the peri-operative predictors of early outcome are studied far less often than the determinants of long-term survival, and the few available reports come largely from heterogeneous, multi-surgeon databases in which case-mix and technique vary widely. [4,8] In children specifically, the interplay between nutritional state, baseline performance status and operative blood loss has received little dedicated attention, even though each is potentially modifiable and each is routinely recorded in everyday practice. In a tertiary Indian setting, where children commonly present late with large tumours and advanced hydrocephalus, quantifying the weight of these bedside variables is a practical first step towards local risk stratification.[12]

Multi-surgeon studies are confounded by heterogeneity in operative technique and peri-operative decision-making. A single-surgeon cohort minimises this variability and allows tumour- and patient-related predictors to be studied against a constant surgical background.[11] We therefore undertook a retrospective analysis of children with brain tumours operated by one neurosurgeon over an 18-month period. The primary objective was to identify the clinical, radiological, surgical and pathological factors that predict early surgical outcome. Secondary objectives were to relate demographic, tumour, resection and functional variables to postoperative recovery; to identify peri-operative determinants of 30-day morbidity, 30-day mortality, new neurological deficit, length of stay and reoperation; and to construct a multivariable model of independent predictors of favourable and unfavourable outcome.

MATERIALS AND METHODS

Study design and setting: This was a single-centre, single-surgeon retrospective cohort study conducted in the Department of Neurosurgery of a tertiary academic hospital. All operations were performed by the same consultant neurosurgeon between December 2024 and May 2026, giving a study period of 18 months.

Participants: We included all consecutive patients aged 18 years or younger who underwent surgery for a histologically confirmed primary intracranial tumour during the study period. Children with recurrent tumours operated elsewhere, purely diagnostic procedures without tumour-directed surgery, and those with incomplete records were excluded. Twenty-four children met the criteria. Because the study closed in May 2026, each patient was followed for one month after surgery.

Data collection: Data were extracted from operative notes, imaging, histopathology and inpatient records. Demographic variables were age, sex and nutritional status (categorised as normal or malnourished on weight-for-age). Radiological variables included tumour location (posterior fossa, supratentorial, sellar/intraventricular), maximum tumour diameter, presence of hydrocephalus and involvement of eloquent brain. Functional status was graded with the Lansky performance score for children under 16 years and the Karnofsky score for older children, recorded pre-operatively and at one month. Histopathological diagnosis and WHO grade were assigned per the 2021 classification and dichotomised into low (I–II) and high (III–IV) grade.[6] Extent of resection was determined from early postoperative imaging as gross-total (GTR), near-total (NTR), sub-total (STR) or biopsy. Peri-operative variables comprised operative duration, estimated blood loss, intra-operative complications, need for CSF diversion and duration of intensive-care stay.

Outcome definitions: A favourable outcome was defined as improvement or no deterioration in neurological status at discharge or one month, without major complication. An unfavourable outcome comprised death, a major new neurological deficit, a severe postoperative complication, prolonged intensive-care or hospital stay, or the need for reoperation. Secondary outcomes analysed individually were 30-day morbidity, 30-day mortality, new postoperative neurological deficit, length of hospital stay and reoperation.

Outcome adjudication and follow-up: Each child's outcome was classified independently of the analysis by reviewing the discharge summary and the one-month clinic note. A new deficit was counted only when it was absent pre-operatively and persisted at review; transient deficits that had resolved by one month were recorded as morbidity but did not, by themselves, define an unfavourable outcome. Prolonged stay was interpreted in the context of the surgical episode rather than by an arbitrary threshold, and reoperation included any unplanned return to theatre within 30 days. Because recruitment closed in May 2026, follow-up was uniform at one month for every patient, which standardises the observation window but confines the analysis to early surgical outcome.

Sample size.: The cohort comprised all eligible children operated by the index surgeon during the fixed 18-month window rather than a pre-specified sample; the study is therefore a complete consecutive series for that period. With 24 patients and eight unfavourable events, formal multivariable modelling is constrained by the number of events, and the regression analyses are presented as hypothesis-generating rather than confirmatory.

Statistical analysis: Continuous variables are summarised as mean ± standard deviation and categorical variables as counts and percentages. Continuous variables were compared between outcome groups with the Student's t-test and pre- versus post-operative performance scores with the paired t-test. Categorical associations were tested with the chi-square test, using the Fisher exact test where expected counts were small. Length of stay across the four resection categories was compared by one-way analysis of variance (ANOVA), and relationships between continuous variables by the Pearson correlation coefficient. Predictors of unfavourable outcome were examined by univariable and multivariable logistic regression. Because the small sample produced complete or quasi-complete separation for several binary predictors, Firth's penalized-likelihood method with profile-likelihood confidence intervals was used to obtain finite, bias-reduced odds ratios.[8] Given eight events, the multivariable model was restricted to two variables and is reported as exploratory. Two-sided $p < 0.05$ was considered significant. Analyses were performed in Python 3 (SciPy and statsmodels).

RESULTS

Cohort characteristics: The 24 children had a mean age of 7.5 ± 4.1 years (median 7, range 1–18) and a male predominance, with 16 boys and 8 girls (male-to-female ratio 2:1); nine (37.5%) were five years or younger and seven (29.2%) were malnourished. Posterior fossa tumours accounted for half the cohort, followed by supratentorial (37.5%) and sellar or intraventricular lesions (12.5%). Medulloblastoma and pilocytic astrocytoma were the commonest histologies (five each), followed by ependymoma, low-grade glioma, high-grade glioma, craniopharyngioma, ganglioglioma, choroid plexus papilloma and atypical teratoid/rhabdoid tumour. Ten tumours (41.7%) were high grade and 16 children (66.7%) had hydrocephalus. Gross-total or near-total resection was achieved in 17 children (70.8%), while seven (29.2%) underwent sub-total resection or biopsy. CSF diversion was required in 12 children, all of whom had pre-operative hydrocephalus. Baseline features are detailed in [Table 1].

Outcomes: Sixteen children (66.7%) achieved a favourable outcome and eight (33.3%) an unfavourable outcome. There were two deaths within 30 days (8.3%), both in malnourished children under five years with large, high-grade tumours and sub-total resection. A new neurological deficit occurred in eight children (33.3%), four required reoperation (16.7%) and overall 30-day morbidity was 41.7%. Mean intensive-care stay was 3.6 ± 2.7 days and mean hospital stay 12.9 ± 6.8 days.

Continuous predictors: Children with an unfavourable outcome were significantly younger (4.8 vs 8.9 years; $p = 0.013$), had larger tumours (5.4 vs 3.9 cm; $p < 0.001$), longer operations (288 vs 218 min; $p = 0.037$), greater blood loss (619 vs 283 mL; $p = 0.005$), longer intensive-care stay (6.9 vs 2.0 days; $p < 0.001$) and lower pre-operative performance scores (59.4 vs 81.6; $p < 0.001$). Hospital stay was more than twice as long in the unfavourable group (21.0 vs 8.8 days; $p < 0.001$). These comparisons are shown in [Table 2].

Categorical predictors: Malnutrition, high WHO grade, sub-total resection or biopsy, poor pre-operative function and age ≤ 5 years were each significantly associated with an unfavourable outcome [Table 3]. All seven children who underwent sub-total resection or biopsy had an unfavourable outcome, whereas none of the low-grade tumours did. In contrast, sex, hydrocephalus and eloquent-area involvement were not significantly associated with outcome, although eloquent involvement showed a non-significant trend. The distribution of outcomes across resection categories and grade groups is illustrated in [Figure 1].

Functional change, length of stay and correlations: Among the 22 survivors, the mean performance score improved significantly from 76.1 pre-operatively to 82.0 at one month (paired t-test, $p = 0.029$), confirming that surgery restored or preserved function in most children. Length of hospital stay differed significantly across resection categories (ANOVA, $F = 15.57$, $p < 0.001$), rising from a mean of 8.6 days after gross-total resection to 22.0 days after sub-total resection. Estimated blood loss correlated strongly with operative duration ($r = 0.91$, $p < 0.001$) and with tumour size ($r = 0.74$, $p < 0.001$), while pre- and post-operative performance scores were highly correlated ($r = 0.91$). Age correlated inversely with blood loss ($r = −0.51$, $p = 0.011$), reflecting the larger, more vascular tumours seen in the youngest children. These analyses are summarised in [Table 5], and the duration–blood-loss relationship and stay-by-resection distribution are shown in [Figure 2].

Secondary outcomes: Examined individually, the components of the composite outcome shared the same risk profile. Both 30-day deaths occurred in malnourished infants or pre-school children with tumours 5 cm or larger, high grade and sub-total resection, and both had pre-operative performance scores of 55 or below. New neurological deficits (eight children) clustered in high-grade and eloquent or midline tumours, including the two children who developed posterior fossa syndrome after resection

of midline medulloblastoma. The four reoperations were all in the sub-total-resection group and were driven by residual or recurrent mass effect and CSF-related complications. Length of stay was most strongly determined by the extent of resection and by the occurrence of any intra-operative complication, with intensive-care duration closely tracking blood loss. Thus the same small set of tumour- and host-related factors underlay morbidity, mortality, deficit, prolonged stay and reoperation alike, supporting their combination into a single composite endpoint.

Predictors of unfavourable outcome: On univariable Firth regression, age ≤ 5 years, malnutrition, tumour size ≥ 5 cm, high WHO grade, sub-total resection or biopsy, pre-operative performance below 70, blood loss ≥ 500 mL and prolonged intensive-care stay were all significant predictors of unfavourable outcome, whereas hydrocephalus was not [Table 4]. In the parsimonious multivariable model combining age and pre-operative performance, a Lansky/Karnofsky score below 70 remained the dominant independent predictor (adjusted OR 22.6, 95% CI 5.9–194.9; $p < 0.001$), while young age retained only a borderline association (adjusted OR 4.59, 95% CI 0.96–10.55; $p = 0.057$).

Table 1. Baseline demographic, clinical, radiological and tumour characteristics (n = 24)

Characteristic	Category	n (%) or mean ± SD
Total patients	—	24
Age (years)	Mean ± SD	7.5 ± 4.1
	Median (range)	7 (1–18)
	≤ 5 years	9 (37.5%)
Sex	Male : Female	16 (66.7%) : 8 (33.3%)
Nutritional status	Malnourished	7 (29.2%)
Tumour location	Posterior fossa	12 (50%)
	Supratentorial	9 (37.5%)
	Sellar / intraventricular	3 (12.5%)
Tumour size (cm)	Mean ± SD	4.5 ± 0.9
Hydrocephalus	Present	16 (66.7%)
Eloquent-area involvement	Present	6 (25%)
WHO grade	High (III–IV)	10 (41.7%)
	Low (I–II)	14 (58.3%)
Pre-operative Lansky/KPS	Mean ± SD	74.2 ± 12.8
Extent of resection	GTR / NTR	13 (54.2%) / 4 (16.7%)
	STR / Biopsy	6 (25%) / 1 (4.2%)
Surgery duration (min)	Mean ± SD	241.7 ± 63.2
Estimated blood loss (mL)	Mean ± SD	395.0 ± 223.9
CSF diversion	Required	12 (50%)
ICU stay (days)	Mean ± SD	3.6 ± 2.7
Hospital stay (days)	Mean ± SD	12.9 ± 6.8
30-day morbidity	Yes	10 (41.7%)
30-day mortality	Yes	2 (8.3%)
New neurological deficit	Yes	8 (33.3%)
Reoperation	Yes	4 (16.7%)
Outcome	Favourable	16 (66.7%)
	Unfavourable	8 (33.3%)

GTR, gross-total; NTR, near-total; STR, sub-total resection; KPS, Karnofsky performance status; ICU, intensive care unit; CSF, cerebrospinal fluid.

Table 2. Student's t-test: continuous variables by surgical outcome (mean ± SD)

Variable	Favourable (n=16)	Unfavourable (n=8)	t	p
Age (years)	8.9 ± 3.8	4.8 ± 3.3	2.78	0.013
Tumour size (cm)	3.9 ± 0.5	5.4 ± 0.6	−6.12	<0.001
Surgery duration (min)	218.4 ± 42.1	288.1 ± 75.0	−2.44	0.037
Blood loss (mL)	283.1 ± 99.1	618.8 ± 240.4	−3.79	0.005
ICU stay (days)	2.0 ± 1.0	6.9 ± 2.0	−6.43	<0.001
Pre-op Lansky/KPS	81.6 ± 7.7	59.4 ± 6.2	7.59	<0.001
Hospital stay (days)	8.8 ± 2.8	21.0 ± 4.7	−6.76	<0.001

Table 3: Chi-square / Fisher exact test: categorical predictors versus outcome

Predictor	χ^2	p (χ^2)	p (Fisher)	Significant
Male sex	0.00	1.000	1.000	No
Malnutrition	9.10	0.003	0.001	Yes
High WHO grade (III–IV)	13.39	<0.001	<0.001	Yes
STR / Biopsy (vs GTR/NTR)	15.76	<0.001	<0.001	Yes
Hydrocephalus	0.02	0.878	0.667	No
Eloquent-area involvement	2.25	0.134	0.129	No
Poor pre-op function (<70)	12.40	<0.001	<0.001	Yes
Age ≤ 5 years	6.77	0.009	0.005	Yes

Table 4: Firth penalized logistic regression: predictors of unfavourable outcome

Predictor	OR	95% CI	p	Multivariable
Age ≤ 5 years	15.08	3.86–82.05	<0.001	aOR 4.59 (0.96–10.55); p 0.057
Malnutrition	26.87	5.66–257.75	<0.001	—
Tumour size ≥ 5 cm	165.00	20.12–>999	<0.001	—
High WHO grade (III–IV)	98.60	27.25–520.81	<0.001	—
STR / Biopsy	165.00	20.12–>999	<0.001	—
Hydrocephalus	1.61	0.57–4.20	0.351	—
Eloquent involvement	5.80	1.29–33.26	0.023	—
Pre-op Lansky/KPS <70	51.67	11.31–489.78	<0.001	aOR 22.59 (5.92–194.92); p<0.001
Blood loss ≥ 500 mL	26.87	5.66–257.75	<0.001	—
ICU stay > 3 days	175.67	39.62–>999	<0.001	—

OR, odds ratio; aOR, adjusted odds ratio; CI, confidence interval. Multivariable model: age ≤ 5 y + pre-op Lansky/KPS < 70 (24 patients, 8 events). "> 999" denotes a very wide upper bound from small-sample separation.

Table 5: Paired t-test, one-way ANOVA and Pearson correlation

Analysis	Groups / pair	Statistic	p	Direction
Paired t-test (survivors, n=22)	Pre 76.1 → Post 82.0	t = −2.35	0.029	Improved (+5.9)
One-way ANOVA — LOS by EOR	GTR 8.6 / NTR 12.2 / STR 22.0 / Biopsy 16.0 d	F = 15.57	<0.001	STR longest
Correlation	Surgery duration vs blood loss	r = 0.91	<0.001	Positive
Correlation	Tumour size vs blood loss	r = 0.74	<0.001	Positive
Correlation	Pre- vs post-op performance	r = 0.91	<0.001	Positive
Correlation	Age vs blood loss	r = −0.51	0.011	Negative

EOR, extent of resection; LOS, length of stay. Paired analysis restricted to 22 survivors.

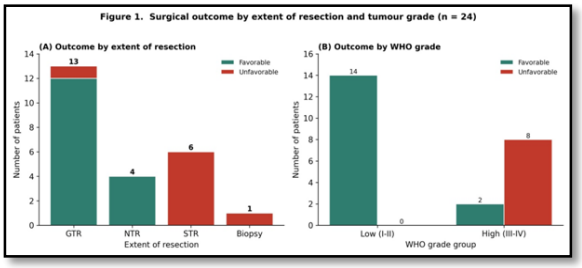

Figure 1: Surgical outcome by extent of resection (A) and WHO grade (B). All sub-total resections and biopsies, and all high-grade (III–IV) tumours, accounted for the unfavourable outcomes.

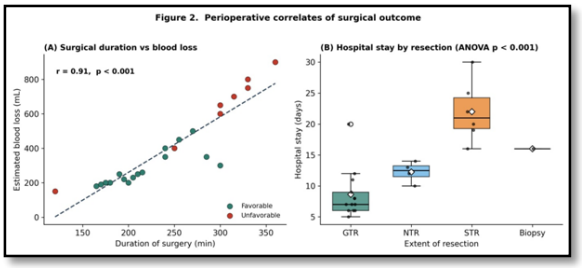

Figure 2: Perioperative correlates: operative duration versus estimated blood loss with fitted regression line (A) and hospital stay by extent of resection (B).

DISCUSSION

In this single-surgeon cohort of 24 children, two-thirds achieved a favourable early surgical outcome and 30-day mortality was 8.3%, figures consistent with contemporary series from comparable settings.[1,4] The strongest determinants of a poor outcome were the extent of resection, tumour grade and, most consistently, the child's pre-operative functional status. Because a single surgeon operated on every child, these associations are unlikely to be explained by variation in operative technique, lending internal coherence to the findings.

The relationship between extent of resection and outcome mirrors a large body of evidence. Sub-total resection and biopsy accounted for every unfavourable outcome in our series, and sub-total resection has been linked both to poorer functional recovery and to a substantially higher risk of persistent hydrocephalus after posterior fossa surgery.[2] These lesions tended to be larger, higher-grade and more often located in or near eloquent or midline structures, so that incomplete resection is as much a marker of tumour complexity as an independent cause of harm. High WHO grade was likewise strongly associated with unfavourable outcome, in keeping with the prognostic weight the 2021 classification places on grade and molecular aggressiveness.[4,6]

The most robust independent predictor on multivariable analysis was a pre-operative Lansky or Karnofsky score below 70. Performance status is a well-established prognostic marker across neuro-oncology and has recently been shown to predict postoperative functional trajectory even when modelled with advanced imaging.[9] Its dominance here suggests that the neurological reserve a child brings to surgery is at least as important as the tumour or the operation in shaping the immediate result, and that performance status deserves a central place in pre-operative counselling and risk stratification.

Host factors were also influential. The cohort showed a male predominance of roughly 2:1, in

keeping with the recognised epidemiology of paediatric CNS tumours, although sex itself was not associated with outcome in our series. Younger children and those who were malnourished fared worse, and age retained a borderline independent effect after adjustment. The youngest children harboured the largest and most vascular tumours, as reflected in the inverse correlation between age and blood loss, and they are least able to tolerate major haemorrhage. Blood loss and operative duration were tightly correlated and both were greater in the unfavourable group; the adverse effect of substantial peri-operative transfusion on outcome after paediatric tumour surgery has been documented elsewhere and reinforces the value of meticulous haemostasis and staged strategies for giant tumours.[3]

Hydrocephalus was present in two-thirds of children and prompted CSF diversion in half, yet it was not itself associated with outcome. This accords with the view that hydrocephalus is common and usually manageable, and that its prognostic importance lies more in the need for and durability of diversion than in its mere presence.[7,10] Length of stay rose steeply with decreasing extent of resection, and the significant ANOVA across resection categories underlines how tumour complexity propagates through the entire hospital course, from operating time and blood loss to intensive-care and ward stay. Reassuringly, functional performance improved significantly among survivors, confirming that, for most children, surgery achieves its central aim of preserving or restoring neurological function.[11]

Eloquent-area involvement did not reach statistical significance in this small series, but it carried a clear trend towards worse outcome and was over-represented among children who developed a new deficit, including those with midline tumours who experienced posterior fossa syndrome. The absence of significance most likely reflects limited power rather than a true absence of effect, since involvement of eloquent or midline structures is a recognised driver of postoperative morbidity and frequently forces the surgeon to accept a less-than-total resection to preserve function. This tension between oncological completeness and functional preservation lies at the heart of paediatric tumour surgery and argues for the selective use of adjuncts such as neuronavigation, intra-operative neurophysiological monitoring and, where available, intra-operative imaging, all of which aim to maximise safe resection in anatomically hazardous locations.[2,11] In our cohort the strong, graded relationship between extent of resection and both length of stay and outcome suggests that even incremental gains in safe resection may translate into measurable clinical benefit, provided they are not achieved at the cost of new neurological injury.

Our 30-day mortality of 8.3% sits within the broad range reported from resource-limited settings, where operative mortality for paediatric brain tumours varies considerably with case-mix and infrastructure, and it compares favourably with series dominated by very young infants or congenital tumours.[1] That both deaths shared the same constellation of malnutrition, very young age, large high-grade tumour and incomplete resection suggests that mortality in this population is concentrated in an identifiable high-risk subgroup rather than distributed randomly, which has implications for pre-operative consent and for the intensity of peri-operative support offered to such children.

Clinical implications: Taken together, these findings point towards a simple, pragmatic approach to pre-operative risk assessment. The variables that mattered most — performance status, age, nutritional state, tumour size and grade, and the anticipated extent of resection — are all known or estimable before the child reaches theatre. A child with a low performance score, malnutrition and a large high-grade tumour expected to permit only sub-total resection carries a materially higher risk of an unfavourable early outcome and may benefit from nutritional optimisation, careful counselling, planning for staged or adjunctive therapy, and proactive intensive-care provision. Conversely, older, well-nourished children with low-grade, resectable tumours can be counselled to expect an excellent early result, as reflected in the uniformly favourable outcomes seen after gross-total resection of low-grade lesions in this series.

Strengths and limitations: The principal strength of this study is its single-surgeon design, which removes inter-operator variability and yields granular, internally consistent peri-operative data. Its limitations are equally clear. The sample of 24 children is small and drawn from one centre, so the findings may not generalise; with only eight unfavourable events the multivariable model was necessarily limited to two variables and the confidence intervals are wide, despite the use of Firth penalization to contain small-sample bias. Several strong predictors were collinear and produced statistical separation, so their individual effects could not be disentangled. Follow-up was restricted to one month by the closing date of the study, which captures early surgical outcome but not tumour recurrence, adjuvant-therapy effects or long-term neurocognitive function. Larger, multi-centre and prospective studies with extended follow-up are needed to validate these predictors and to refine risk-stratification tools for paediatric neuro-oncological surgery.

CONCLUSION

In children undergoing surgery for brain tumours, early outcome was governed chiefly by the extent of resection, tumour grade and pre-operative functional status, with younger age, malnutrition, larger tumour size and greater blood loss adding further risk. A pre-operative Lansky or Karnofsky score below 70

was the single most powerful independent predictor of an unfavourable result. These variables are readily available at the bedside and can inform pre-operative counselling, surgical planning and peri-operative resource allocation. Confirmation in larger prospective cohorts with longer follow-up is warranted.

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