Incidence and prognostic factors of ataxia in children with posterior fossa tumors

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Abstract

Background. There is minimal literature specific to motor outcomes in children with posterior fossa tumors (PFTs) despite ataxia being a significant problem in this group. This study aims to report children's physical outcomes following management of PFT and determine which factors affect severity of ataxia and functional limitations.

Methods. Forty-two children aged between 5 and 17 and between 1 and 4 years following surgery for PFT were assessed using the Scale for the Assessment and Rating of Ataxia (SARA), the Brief Ataxia Rating Scale (BARS), and the mobility Pediatric Evaluation of Disability Inventory (PEDI) subscale to determine prevalence and severity of ataxia and a measure of physical function. Analysis was undertaken comparing impact of tumor location, tumor histology, adjuvant treatment, age at diagnosis, presence of preoperative ataxia, and presence of cerebellar mutism syndrome (CMS) on ataxia and physical function scores.

Results. Seventy-one percent of children demonstrated a SARA and BARS score greater than 2. A total of 48% of children had a PEDI-m score greater than 90. There was no correlation between age at diagnosis or preoperative ataxia and assessment scores. There was a significant difference in SARA/BARS and PEDI-mobility scores depending on tumor histology, tumor location, and presence of CMS.

Conclusions. A high proportion of children (>1 year) following surgery for PFT continue to present with ataxia. Higher ataxia and lower physical function scores were demonstrated in children with medulloblastoma and mid-line tumors and those diagnosed with CMS. The high prevalence of ataxia demonstrates the need for further research regarding rehabilitation management in this population.

Key words

ataxia | pediatrics | posterior fossa tumor

Brain tumors are the most common type of solid tumor diagnosed in children, and approximately 50% of all childhood brain tumors are located in the posterior fossa region.¹ Management of posterior fossa tumors (PFTs) typically involves surgical resection, solely or in combination with adjuvant treatments such as radiotherapy (RT) and chemotherapy. The potential for gross change perioperatively is documented,^{2–4} but detailed motor outcomes

and predictors of short- and long-term outcomes remain relatively ill defined.

Ataxia describes the predominant and most disabling collective of motor clinical signs in children with PFTs before and following intervention. Indeed, 58% to 90% of children with PFTs present with this sign,^{2,3} frequently describing either balance or gait impairment, tremor, speech disturbance, or incoordination.⁵ Balance and coordination

problems can affect activities of daily life, return to school, and participation with peers,^{6,7} and therefore it is important to gain further insight into these problems.

Ataxia often persists postoperatively, but current the literature focuses on neuropsychological and cognitive long-term outcomes.⁸⁻¹⁰ Ataxia is less well described despite its reported high prevalence. Recent research by Piscione et al (2014)⁷ reported 70% of children with PFTs have long-term postoperative balance problems, alluding to ataxia, but it remains unclear as to what prognostic factors, if any, exist perioperatively to determine this risk of outcome. An exploration of prognostic factors for impairment and functional limitations following management of PFT is further made challenging when set against normal childhood development. However, understanding the long-term impairment and functional limitations of children with PFTs by identifying and quantifying potential prognostic factors remains necessary to inform overall management and tailor rehabilitation packages.

To date there is minimal evidence to guide the type, intensity, and timing of physiotherapy intervention for children with ataxia. The literature on physiotherapy for people with ataxia has focused on the adult population with a suggestion of benefit from conventional physiotherapy, treadmill training, and video-gaming.⁵ It is not clear, however, whether these interventions will have the same impact in children with ataxia following management of PFTs. Gaining an understanding of prognostic factors may help design physiotherapy programs and guide future research.

This study provides a new insight pertinent to the management of PFT by quantifying motor outcomes for children (aged 5-17 years) between 1 and 4 years following surgical resection and any adjuvant oncological treatment. It presents novel data based on recently validated standardized measures of ataxia and motor-related function both for children and adults, namely incorporating the Scale for the Assessment and Rating of Ataxia (SARA),^{11,12} the Brief Ataxia Rating Scale (BARS),¹³ and the Pediatric Evaluation of Disability Inventory (PEDI).¹⁴ It explores potential prognostic factors for long-term outcomes such as age, overall management (adjuvant treatments; RT and chemotherapy), as well as tumor histology and location.

Materials and Methods

Design

This prospective, cross-sectional study was approved by the Liverpool East Research Ethics Committee and local research and development office.

Participants

Children with a PFT who had surgical resection of a PFT undertaken between 1 to 4 years earlier, and who were aged between 4 and 18, were eligible for inclusion. Those who were within a year of resection or still undergoing chemotherapy or RT were excluded. Children were recruited from a single tertiary neurosurgical/oncology unit in the United Kingdom between 2012 and 2016.

Procedures

Potential participants were identified and screened for eligibility using a database of children with brain tumors treated at Alder Hey Children's NHS Foundation Trust, Liverpool, England. Informed and written consent was obtained from all children and/or their parents (with child assent) and data managed in accordance with the Declaration of Helsinki (2004).

Children who entered the study were assessed by a neuro-pediatric physiotherapist (from a team of 3 therapists) while attending the tertiary center for a clinic follow-up visit. The raters underwent a joint training session to optimize interrater reliability of outcome measure collection prior to commencement of the study.

Ataxia outcome measures

These measures were objectively assessed by 1 of 3 physiotherapists known to the child. These include the SARA (the SARA can be found in the appendix supplementary data of the original validation study by Schmitz-Hübsch et al),¹¹ the BARS (the BARS can be found in the original validation study by Schmahmann and colleagues),¹³ and a Clinical Global Impressions (CGI) Scale¹⁵ of ataxia severity (categorized as no, mild, moderate, or severe). The mobility domain of the PEDI was used as a functional mobility outcome measure (the PEDI can be found in the original PEDI manual by Hayley et al).¹⁴ Order of completion of rating scales was randomized to minimize fatigue and practice effects.

Baseline disease descriptors

These were collected from preexisting research database entries, including tumor histology, age at diagnosis and assessment, presence of preoperative ataxia (recorded as yes or no), adjuvant treatment (RT or chemotherapy), pediatric neurosurgeon who completed the surgical resection, and recording of cerebellar mutism syndrome (CMS), and were compared against physiotherapy outcome measures.

All preoperative imaging from children who were assessed was independently (blindly) reviewed (without reference to any assessment findings) by a consultant pediatric neurologist, and tumor location was classified as either midline or nonmidline.

Measures

The SARA¹¹ and the BARS¹³ are valid, reliable standardized measures of ataxia, commonly cited in research and used clinically.¹⁶ The SARA has 8 items and has a total score out of 40, with a higher score indicating more severe ataxia. The BARS has 5 items and is scored out of 30; again, a higher score indicates more severe ataxia. They demonstrate high interrater reliability both in adults and children and hold a significant correlation with the more traditionally used rating of ataxia, the International Cooperative Ataxia Rating Scale, while taking a much shorter time to complete.^{16,17} There are also emerging reports of good correlation (SARA

$r = -0.77$, BARS $r = -0.76$) between the scales and the PEDI mobility domain for children with PFTs.¹²

The PEDI is a valid and reliable functional measure in pediatric-acquired brain injury.^{14,18} It has self-care, mobility, and social function sections, which are used as whole or stand-alone domains. It is completed by parental questioning or examination by the therapist. Only the mobility domain of the scale was collected, termed PEDI-m, to minimise time-related burden on participants compared with the “complete PEDI” recommended 45- to 90-minute assessment.¹⁹

Data Analysis

Descriptive statistics were utilized to describe the prevalence of ataxia and functional motor deficits. Clinical outcome variables (SARA, BARS, and PEDI-m) were not normally distributed (Kolmogorov-Smirnov test $< .005$) and therefore data were analyzed and presented according to nonparametric methods in SPSS (IBM v.22, New York, USA). The PEDI is normative-referenced between 6 months and 7.5 years. In line with recommendations, raw scores were converted to scaled scores to enable the use of the PEDI-m in children over the age of 7.5 years. PEDI scores range from 0 to 100 with a higher score representing a better level of physical function.

Spearman's rank correlation coefficients explored associations between the core motor outcome measures (SARA, BARS, and PEDI-m) and age at diagnosis. The Mann-Whitney U test explored hypotheses that tumor histology, adjuvant treatment, neurosurgeon experience, presence of preoperative ataxia, and tumor location could affect the core outcome measures. In all cases alpha was set at .05, with a corresponding significance level of 5%. Subgroup analysis was undertaken using the Mann-Whitney U test (significance level 5%) to explore the impact of variables such as tumor location, tumor histology, and intervention modalities after PFT resection.

Results

Study Sample

Eighty-six patients were screened for eligibility, 76 of whom were approached (10 excluded because of age), of whom 72 consented, as illustrated in Fig. 1. From this patient group 42 patients completed the standardized assessments between 1 and 4 years postsurgical resection and were thus eligible for analysis for this part of the study. Twenty (48%) were male, with the age range of children between 5 and 17 years. Fifty-seven percent were receiving physiotherapy at the time of assessment. Sample characteristics are detailed in Table 1.

Ataxia Outcome Measures

Scale for the Assessment and Rating of Ataxia

The median SARA score was 4.25 (range, 0-29). A higher score (maximum 40) represents more severe ataxia. (See supplementary Table 1 for raw scores).

Brief Ataxia Rating Scale

The BARS scores ranged from 0 to 24 with a median of 4.0; again, a higher score (maximum 30) refers to a higher degree of ataxia. (See supplementary Table 2 for raw scores).

From previous work (with children over the age of 7) it was suggested that a score of 2 on either the SARA or the BARS can be used as a threshold for distinguishing no ataxia from mild ataxia.¹² On this basis, 30 (71%) of the children assessed were classified as having ataxia.

Ataxia Clinical Global Impressions scale

CGI scale scores reported that 12 (29%) had no ataxia, 17 (40%) had mild ataxia, 7 (17%) had moderate ataxia, and 6 (14%) had severe ataxia.

Pediatric Evaluation of Disability Inventory: mobility score

The median PEDI-m score was 85.2 (range, 30.6-100; maximum score 100). Fourteen children demonstrated a scaled score of 100 (high functional capability), with a further 20 children (48%) scoring over 90. Three children demonstrated scores ranging between 54.8 and 85.2. Five demonstrated lower functional mobility capability with scores below 50.

Exploring baseline disease descriptors as predictors of postoperative clinical score change

Several variables were analyzed to identify their possible impacts on ataxia and motor outcomes (namely the SARA, BARS, or PEDI-m scores). Given the ordinal nature of the scales, all comparisons were explored using nonparametric methods.

Age at Diagnosis. There are no correlations between age at diagnosis and SARA, BARS, or PEDI-m score (SARA -0.24 , BARS -0.12 , PEDI-m 0.25 , respectively).

Tumor Histology. Owing to small numbers of ependymoma ($n = 5$) and cerebellopontine angle schwannoma ($n = 3$), only medulloblastoma ($n = 13$) and low-grade glioma ($n = 21$) remained suitable as comparators within hypothesis testing. A significant effect of tumor histology is reported in the SARA, BARS, and PEDI-m scores ($P < .001$, $P = .001$, $P = .004$, respectively). The medulloblastoma group median SARA and BARS ataxia scores were higher than those of the low-grade glioma group (9.5 and 9 compared with 2.5 and 2, respectively) and PEDI-m score lower (50 compared with 58), suggesting that children with medulloblastoma typically feature more severe ataxia and lower functional motor ability.

Tumor Location. Significant differences were also reported in median SARA, BARS, and PEDI-m scores according to grouping by tumor location ($P < .001$, $P = .007$, $P = .01$, respectively). The SARA and BARS scores were higher and PEDI-m scores lower in the midline group compared with the nonmidline group ([SARA: midline = 6.5, nonmidline = 1.5], [BARS: midline = 5, nonmidline = 1], [PEDI-m:

Fig. 1 Participants (Strengthening of the Reporting of Observational Studies in Epidemiology Flow Diagram). BARS indicates Brief Ataxia Rating Scale; PEDI, Pediatric Evaluation of Disability Index; SARA, Scale for Assessment and Rating of Ataxia.

midline = 54, nonmidline = 59)), suggesting that this midline zone was associated with severe ataxia and lower functional motor ability.

Low-grade gliomas do feature mixed locations in terms of midline and unilateral histology. Subgroup analysis of those with low-grade glioma was therefore additionally examined for trends within core outcome measures depending on tumor location. These data (Table 2) reveal a trend for those with low-grade gliomas and midline tumors to have notably higher SARA/BARS scores and lower PEDI-m scores. Because of low numbers, however,

there was not enough power within this analysis to report a statistically significant difference in scores.

Preoperative Ataxia. There was no difference in SARA, BARS, and PEDI-m scores in children who were reported to have preoperative ataxia compared to those who were reported to have no ataxia preoperatively (SARA 0.16, BARS 0.16, PEDI-m 0.13, respectively).

Surgical experience: Data were available for 40 children. An individual consultant pediatric neurosurgeon operated on 25 of the children in this study; the remaining

Table 1 Baseline Characteristics of Participants (n = 42)

Characteristics		Number
Diagnosis:		
Medulloblastoma		13 (31%)
Low-grade glioma		21 (50%)
Ependymoma		5 (12%)
CP angle schwannoma		3 (7%)
Age at time of diagnosis	Mean (SD)	9.24 (3.56)
	Median (IQR) (range)	9 (6) (3-16)
Age at time of assessment	Mean (SD)	11.31 (3.42)
	Median (IQR) (range)	11 (5) (5-18)
Years postdiagnosis	Mean (SD) (range)	2.07 (0.87)
	Median (IQR) (range)	2 (0) (1-4)
Tumor location		n (%)
Midline		29 (69%)
Unilateral		11 (26%)
Missing		2
Treatment		n (%)
Sx		23 (55%)
Sx + R		5 (12%)
Sx + R + C		14 (33%)
Postoperative cerebellar mutism syndrome		9 (21%)
Physiotherapy intervention n (%)		
Received physiotherapy immediately postoperatively		35 (83%)
Receiving physiotherapy at the time of assessment		24 (57%)
SARA	Mean (SD)	6.80 (7.03)
	Median (IQR, range)	4.25 (9) (0-29)
BARS	Mean (SD)	5.95 (6.22)
	Median (IQR, range)	4.00 (9) (0-24)
PEDI-m, raw scores	Mean (SD)	49.95 (13.24)
	Median (IQR, range)	56.50 (13) (10-59)
PEDI-m, scaled scores	Mean (SD)	81.02 (20.45)
	Median (IQR, range)	85.2 (39.1) (30.6-100)

Abbreviations: BARS, Brief Ataxia Rating Scale; CP, cerebellopontine; IQR, interquartile range; PEDI-m, mobility domain of the Pediatric Evaluation of Disability Inventory; SARA, Scale for the Assessment and Rating of Ataxia; SD, standard deviation; Sx, surgery alone received by children; Sx + R, combination of surgery and radiotherapy received; Sx + R + C, combination of surgery, radiotherapy, and chemotherapy received.

15 children were operated on by a range of 8 consultant pediatric neurosurgeons. Owing to the variation in number of operations completed by the pediatric neurosurgeons and an unknown quantification of operations undertaken by all concerned (historically and outside the tertiary center in question), the only suitable comparator of experience was between 2 groups: an individual frequent PFT operator consultant pediatric neurosurgeon ("individual," n = 25) compared with the group of 8 less-frequent group PFT operators ("group," n = 15). There was no difference between the individual and group SARA, BARS, and PEDI-m scores (SARA median 3 and 4, respectively; BARS median 4 and 3, respectively; and PEDI-m 94.2 and 85.2, respectively). The study was not powered to detect a difference using statistical analysis.

Cerebellar Mutism Syndrome. There is a significant difference in SARA, BARS, and PEDI-m scores in children who were reported to have CMS postoperatively compared to those reported without CMS as illustrated in [Table 3](#). The SARA/BARS scores both were higher and PEDI-m score lower in the CMS group, suggesting that CMS postoperatively is associated with more-severe ataxia scores and lower functional motor ability.

Adjuvant Treatment. [Table 4](#) reports SARA, BARS, and PEDI-m scores for children assessed with respect to the oncological treatment they received. Children who underwent surgery, RT, and chemotherapy notably demonstrated higher ataxia scores and lower PEDI-m scores than children who underwent surgery and RT and those who

Table 2 Subgroup Analysis in Children With Low-Grade Gliomas

	Midline	Unilateral	Significance
N ^a	12	8	Mann-Whitney <i>U</i> test
SARA mean (SD)	6.33 (7.07)	1.81 (1.98)	<i>P</i> = .08
Median (IQR)	3 (12)	1.25 (2)	
BARS mean (SD)	5.75 (6.82)	2 (2.20)	<i>P</i> = .24
Median (IQR)	3 (9)	1.5 (4)	
PEDI-m (raw) mean (SD)	50.67 (13.03)	56.25 (4.10)	<i>P</i> = .38
Median (IQR)	58 (19)	59 (5)	

Abbreviations: BARS, Brief Ataxia Rating Scale; IQR, interquartile range; PEDI-m, mobility domain of the Pediatric Evaluation of Disability Inventory; SARA, Scale for the Assessment and Rating of Ataxia; SD, standard deviation.

^aOne missing observation.

Table 3 Analysis of Scores in Relation to Cerebellar Mutism Syndrome

	No	Yes	Significance
N	33	9	Mann-Whitney <i>U</i> test
SARA mean (SD)	4.37 (4.69)	15.72 (7.15)	<i>P</i> < .001
Median (IQR)	2.5 (5)	16 (8)	
BARS mean (SD)	3.76 (6.82)	14 (5.96)	<i>P</i> < .001
Median (IQR)	3 (5)	14 (9)	
PEDI-m (raw) mean (SD)	53.61 (13.03)	36.56 (15.08)	<i>P</i> = .002
Median (IQR)	58 (6)	36 (21)	

Abbreviations: BARS, Brief Ataxia Rating Scale; IQR, interquartile range; PEDI-m, mobility domain of the Pediatric Evaluation of Disability Inventory; SARA, Scale for the Assessment and Rating of Ataxia; SD, standard deviation.

Table 4 Analysis of Scores in Relation to Adjuvant Treatment Type

	Sx + R + C	Sx + R	Sx	Significance
				Sx vs Sx + R + C ^b
N	14	5	23	Mann-Whitney <i>U</i> (significance):
SARA				
Mean (SD)	13.14 (7.42)	4.22 (3.00)	3.50 (4.81)	<i>P</i> < .001
Median (IQR)	13 (11)	5.50 (6)	2 (4)	
BARS				
Mean (SD)	11.14 (6.38)	3.60 (2.89)	3.30 (4.55)	<i>P</i> < .001
Median (IQR)	11 (11)	5 (6)	2 (3)	
PEDI-m (raw)				
Mean (SD)	38.86 (16.35)	55.40 (3.36)	55.42 (7.01)	<i>P</i> < .001
Median (IQR)	40 (31)	54 (7)	59 (4)	

Abbreviations: BARS, Brief Ataxia Rating Scale; IQR, interquartile range; PEDI-m, mobility domain of the Pediatric Evaluation of Disability Inventory; SARA, Scale for the Assessment and Rating of Ataxia; SD, standard deviation.

^bOnly comparison-tested Sx vs Sx + RT + C because of low numbers in the Sx + RT group.

had surgical treatment alone. Because of the small number of children in the surgery and RT group, these findings are best reported as trends and statistical hypothesis

testing among the 3 groups was not undertaken. Children undergoing RT and chemotherapy will have received differing dose/frequency of RT and differing chemotherapy

regimens depending on individual protocols, representing significant variation in adjuvant treatment.

Discussion

This is the largest study to date quantifying ataxia and physical functioning in children following management of a PFT. The results highlight that a considerable proportion of children will continue to present with long-term ataxia and functional mobility problems (between 1 and 4 years postsurgical resection). The results in this study indicate that 71% of children present with ataxia after 1 year, which is comparable to 70% of children with balance problems reported by Piscione et al.⁷ Sønderkaer et al.³ further report that 68% of children have ataxia at the point of presentation, which could imply that ataxia is a direct consequence of PFT histology rather than a consequence of subsequent management.

The results of this study also support prior reports of children continuing to present with neurological sequelae (although not specifically physical function) years following treatment in almost 50% of samples studied.^{3,20} Encouragingly, most of the children feature ataxia at the milder end of the spectrum and still retain a high mobility capability. However, despite mild classification of ataxia and mild mobility restrictions, the presence of any ataxia signs could still precipitate disability and participation restrictions for children, worthy of future research in this area. This is supported by 24 (57%) of the children continuing to receive physiotherapy input at the time of their assessment.

There was no association between ataxia and mobility scores and age of children at diagnosis. This is in agreement with other studies that reported no influence of age at diagnosis.^{7,20,21} There are, however, a small number of studies that report being diagnosed at a younger age results in greater disability.^{22–24} This is potentially caused by an underdeveloped sensory motor system being affected compared with that of an optimized system in adult age. Additional research in this field appears to be indicated in view of the conflicting findings and varying methods within studies (predominantly employing retrospective questioning of adult survivors many years after PFT management).

There was no significant difference found in scores for both ataxia rating scales and the PEDI-m depending on presence of preoperative ataxia. However, it should be noted that presence of preoperative ataxia was recorded only as present or not, from preexisting data available. Ataxia was noted as a presenting sign in 22 children (55%, data not known for 2 participants), which is in line with other reports.^{2,25} Formal preoperative assessments were not completed as part of this study, though the use of ataxia scale assessments preoperatively would add value to longitudinal studies to allow direct comparison preoperatively and postoperatively, and this should be considered for future research.

There was no difference in scores for both ataxia rating scales and the PEDI-m depending on the pediatric neurosurgeon who completed the surgical resection, although

there was not an even split in neurosurgeons for analysis (1 consultant pediatric neurosurgeon frequently operating on PFT compared with a group of 8 less-frequently PFT operating consultant pediatric neurosurgeons.) However, all surgeons were consultants specializing in pediatric neurosurgery. Previous literature has reported that extent of tumor resection (and mortality)^{26,27} can be influenced by surgical experience although the impact on any subsequent neurological deficit is less clear and could be examined further in larger studies. Before this can be investigated further, a method of quantifying surgeon experience needs to be established and sample size estimations undertaken to inform adequate powering of future research.

There was a significant difference found in scores for both ataxia rating scales and the PEDI-m depending on tumor location (midline vs unilateral) and tumor histology. This effect of tumor histology is consistent with past reports that children with medulloblastoma present with more balance and fine motor problems and poorer health-related quality of life.^{2,7,20,28,29} Subgroup analysis in this study, examining influence of location in children with low-grade gliomas, indicated that midline location may be a risk factor for more severe ataxia within this histological group. This in turn could suggest that tumor location rather than specific histological tumor type may be more of a predictive factor. The increasing depth of literature on CMS suggests specific tumor infiltration of the brainstem and fourth ventricle location are the only consistently reported risk factors of CMS, again highlighting the importance of specific location.^{4,27,30,31} Despite best attempts, it remains difficult to isolate the impact of single variables (histology, location, resection procedure, RT, or chemotherapy) on the ataxia and mobility in children with PFTs, given the potential for these variables to interact. Children with medulloblastoma, because of the nature of the tumor type, typically feature midline tumors and receive multimodality therapy, eg, RT and chemotherapy. This study also had scope to consider only a limited classification of location of PFT (midline or unilateral) and would benefit further if pathological changes to more precisely reported structures could be explored. The literature reporting ataxia both in the genetic population and in children with PFTs considers involvement of the deep cerebellar nuclei a key factor in persistent ataxia, reiterating the importance of tumor location.^{2,32,33} Exploration of long-term ataxia and mobility restrictions alongside knowledge of primary or secondary histological changes to the nuclei, cerebellar peduncles, vermis, or hemispheres, for example, could potentially improve future prognostic abilities.

In this study, 9 children were reported to have CMS in the initial postoperative period. The tumor histology was mixed (3 low-grade glioma, 5 medulloblastoma, 1 ependymoma) and 8 out of 9 were classified as midline. Despite the small sample size, there is a trend in this group toward increased long-term ataxia and functional mobility problems, similar to other literature that report increased long-term neurocognitive and speech problems in children diagnosed with CMS postoperatively.³⁴ There is emerging literature regarding the potential to predict the risk of CMS,³⁵ and this strategy should be explored alongside specific reference to ataxia to minimize the risk of neurological deficit as a result of cerebellar pathology.

Consistent with prior research reports, a trend in this study's data points toward higher ataxia scores in children who have received RT and chemotherapy as adjuvant treatment. Although inherently linked with tumor histology and location as discussed above, Piscione et al⁷ suggest receipt of chemotherapy can contribute to predicting motor function, via mechanisms such as chemotherapy toxicity affecting physical functioning. It is reported that children who undergo chemotherapy can present with long-term motor and sensory problems secondary to chemotherapy toxicity that can affect physical function.³⁶ In particular the neurotoxicity of chemotherapy agents such as vincristine are acknowledged,³⁷ although all but 1 participant who received chemotherapy had vincristine as part of their treatment protocol, therefore it was not possible to review potential effects of this in isolation. Chemotherapy-induced neuropathy was not explored in this study, and some children (notably those assessed at 1 year postsurgery) who may still be in recovery from adjuvant treatment could have featured this at the time of assessment.

This study is one of few to use standardized ataxia and validated pediatric functional outcome measures to enable clear and objective reporting of clinical assessment findings. There is increased variability in scoring reported when using the ataxia scales in children under the age of 8.³⁸ Only 4 children in this participant group, however, were under this age threshold and there remains no alternative coordination assessment tools in this younger group, thereby justifying their use in this study. The PEDI-m was chosen as it is validated in the acquired brain injury population and can be used in children over the age of 7, but is only normative-referenced up to this age.¹⁴ Scores were converted to scaled scores to account for this, but using a tool with wider normative referencing would have added benefit to this study. One of the few studies to also look at physical functioning in children with brain tumors by Piscione and colleagues⁷ used the Bruininks-Oseretsky Test of Motor Performance second edition (BOT-2), which had the advantage of being normative-referenced from 4 to 21 years. However, although it has been evaluated in children with developmental coordination disorder, it is not validated in children with acquired neurological problems and therefore not selected for use in this study. It would be of interest to evaluate the psychometric properties of the BOT-2 in children with brain tumors, and potentially compare its use with the scales used in this study as it could examine coordination, balance, running speed, and strength to provide a broader construct of motor performance compared with that of the PEDI-m.

Although this study has a fairly large sample in relation to the literature in this area, with assessments completed within a defined time frame of 1-4 years postsurgery, a still larger sample would be required to allow the results to be generalized to the larger pediatric PFT population. This would further enable a fully powered subgroup analysis, as at present there are small numbers in some groups, eg, children with ependymoma. Future larger studies with validated motor outcome measures, possibly attached to national and international treatment trials, are advocated to confirm these findings and further the understanding of complex interactions among histology, tumor location, and multimodal therapies. This study demonstrated that tumor

histology and tumor location are predictive of severity of ataxia and physical function. A larger study could allow comparison among standardized groups that include different adjuvant treatment regimens to allow further analysis of which factors have the most impact on motor problems.

Conclusion

This study provides a new contribution to knowledge of ataxia and physical function following PFT resection in children. Overall, ataxia was reported in a significant proportion of the children with an associated impact on functional mobility. These issues were more prevalent in children with medulloblastoma and midline tumors. This new knowledge may be valuable to therapists and families when planning postoperative rehabilitation programs as well as helping to inform the design of clinical trials. This study demonstrates that the chosen ataxia measures, if reliably applied, could be used in future trials/audits of service outcomes as a measure of quality of survival.

Future research would be of value to prospectively longitudinally assess children following PFT resection at specific time points. A natural history of ataxia and functional change in this population may provide information as to when to maximize therapy. While observational research continues, there is also a need to pragmatically explore the impact of therapy in this patient group to determine whether contemporary rehabilitation programs can produce improved outcomes.

Supplementary Material

Supplementary material is available at *Neuro-Oncology* online.

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