








ORIGINAL ARTICLE



Cerebellar pilocytic astrocytoma in childhood: Investigating the long-term impact of surgery on cognitive performance and functional outcome

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ABSTRACT

Objective: Previous studies differ regarding the long-term effects of surgically removed pediatric cerebellar pilocytic astrocytomas (CPA). Thus, the aim of this study was to investigate the long-term impact on neurocognitive and functional outcome and to analyze age as an influencing factor. **Methods:** Fourteen CPA patients were compared to the age norm and to a group of 14 high-achieving peers regarding cognitive functioning, health-related quality of life (HRQoL), and stress regulation. Mean follow-up time after diagnosis was 13.29 years (range: 3–21 years). **Results:** Patients showed satisfactory academic achievement and did not differ from the norm except for the bodily dimension of HRQoL. However, there were marked differences in specific neurocognitive functions between patients and high achievers. Age at diagnosis did not influence neurocognitive outcome. **Conclusion:** CPA patients treated with surgery only seem to have a favorable long-term outcome, yet, in comparison with high achievers specific cognitive impairments become apparent.

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Introduction

Cerebellar pilocytic astrocytomas (CPA) account for approximately 30% of all pediatric central nervous system tumors and thus, constitute the second largest pediatric brain tumor group after medulloblastomas (MB).^{1–3} The treatment of choice is total surgical resection and in most cases no further irradiation or chemotherapy is required.⁴ Given current surgical methods, the overall prognosis for this low-grade tumor is favorable with long-term survival rates of up to 80–95%.^{4,5} However, at the same time these improved survival rates demand a careful consideration of possible long-term sequelae such as cognitive deficits and functional impairments. A phenomenon commonly referred to as “growing into deficit”⁶ highlights the importance of careful follow-ups even for survivors of low-grade CPAs: patients who initially show no deficits may still develop cognitive and functional impairments years after treatment. According to the vulnerability theory, a young age at the time of diagnosis is especially thought to have a detrimental effect on late outcome.^{1,7,8} As younger children have not developed all basic cognitive functions yet, they may especially be at risk of struggling more with the subsequent development of higher cognitive abilities.^{1,9}

Several studies have demonstrated both cognitive and behavioral problems in patients treated for pediatric CPA with surgery only.^{10–15} The corresponding results show a pattern of difficulties that fit the so-called cerebellar cognitive affective syndrome (CCAS¹⁶). The CCAS is closely related to lesions of the cerebellum and as such it highlights the role of the cerebellum not only in motor function but also as a

modulator of emotional and cognitive processes.¹⁰ Its central symptoms are deficits in executive functioning, language difficulties as well as problems with spatial cognition and affect regulation (cf. ref.¹⁵). In their study on the neuropsychological consequences of cerebellar tumor resection in childhood, Levisohn, Cronin-Golomb and Schmahmann¹³ found that all investigated patients showed impairments in the above-mentioned areas of cognitive functioning. Additionally however, deficits in attention,^{1,10,15,17} processing speed,^{1,15} and memory^{1,10,15,18} have also been observed in long-term CPA survivors, calling for timely intervention.¹⁰

These cognitive deficits in turn are thought to impair functional outcomes such as academic achievement and, as a consequence, quality of life (QoL).⁶ Even though CPA survivors tend to have a better prognosis than, for instance, MB survivors⁹, there is evidence that they still show an elevated risk for deficits in academia: studies evaluating academic performance report incidences of difficulties, ranging from 3%¹⁹ to approximately 45%.¹ At the same time, there is a strong notion in the corresponding literature that CPA patients fare very well and that their overall outcome regarding education, QoL, and cognitive functioning is favorable (see refs.^{2,19–22}). Zuzak and colleagues²² for instance found that CPA patients rated their health-related quality of life (HRQoL) similarly or even higher than a group of healthy controls. Correspondingly, Pompili and colleagues²¹ concluded in their study that most CPA patients show no late neurological deficits and report a QoL that is better than in other tumor patient groups.

In light of these inconclusive results and differing perspectives, more research is warranted. Especially, research focusing on a homogenous group of patients with the same diagnosis, tumor location and treatment is needed as it promises better insights into treatment-related long-term effects for this particular group. Also, a thorough assessment of all areas of functioning known to be possibly impacted by CPA resection (i.e., cognition, functional outcome, and academic achievement) will allow for more comprehensive conclusions. Thus, we opted to include a group of CPA patients who did not receive any treatment other than surgical resection during childhood and assess them at least 3 years after surgery. Additionally, we chose to compare CPA patients not only to the norm of healthy coevals (as done in previous studies^{1,10}), but also to a group of high-achieving peers to gain more differential insights into the relationship between neurocognitive functioning, academic achievement, and QoL.

Objectives

This study's main objective is to analyze the long-term cognitive and functional outcome in patients who had undergone CPA surgery during childhood. Furthermore, age at the time of diagnosis shall be considered as a possible influencing factor when evaluating late effects of cerebellar surgery on neurocognitive performance. Thus, the following two research questions (RQs) can be stated for the current study:

RQ1: Are there differences in cognitive functioning, HRQoL and stress regulation between CPA patients and the norm as well as between CPA patients and high-achieving peers?

RQ2: Is there an influence of age at the time of diagnosis on long-term cognitive outcome?

Methods

The presented study was part of a larger study protocol (cf. ref.²³) that was evaluated and approved by the local ethics committee of the Medical University of Vienna, Austria (<http://www.meduniwien.ac.at/ethik>) according to the Declaration of Helsinki.

Participants

Patients treated between 1992 and 2009 for a CPA with surgery only were included in this study. Exclusion criteria were an age above 15 years at the time of diagnosis, craniospinal irradiation or chemotherapy, a localization of the tumor other than the cerebellum, a diagnosis of neurofibromatosis (NF), and a VP-shunt. The final sample consisted of eight males (57.1%) and six females (42.9%) with a mean age of 21.42 (SD 5.40 years) at the time of assessment (range: 15–31 years). The average follow-up time was 13.29 years (SD 4.97), and the mean age at the time of diagnosis was 8.10 (SD 2.77) years (range: 3.7 – 13.7 years). All 14 patients had a gross total resection of the CPA; however, 4 of them had an initial subtotal resection and therefore underwent a second

surgical intervention (two of them because of a progression of the tumor). Moreover, one patient had to undergo gross total surgery twice because of a relapse. Only one patient presented with a hydrocephalus prior to diagnosis. None of the patients needed insertion of a VP-shunt, only two patients were temporarily treated with external ventricular drains (EVDs) in the immediate postoperative course. The average primary tumor size was 3.43 cm, ranging from 1 to 5 cm. Eight patients (57%) had a cystic tumor component. Regarding their educational status at the time of assessment, four patients (29%) had completed compulsory education, six (43%) had completed an apprenticeship, three (21%) high school, and one had finished university (7%). More than half (57%) of the patients were employed or self-employed, two attended university (14%), another 21% ($N = 3$) were going to school and one patient was an apprentice (7%). See Table 1 for a detailed overview over patient characteristics.

The control group consisted of 14 high achievers (gender distribution was comparable; seven males and seven females) that were recruited among highly successful medical university students. Success was defined by the grades achieved in exams. Students were matched to the patients regarding age. Hence, the mean age of the control group was 23.41 (SD 2.70) years, and there was no age difference between the two groups

Table 1. Patient characteristics.

Characteristics	CPA patient group ($N = 14$)	
Sociodemographic data^a		
Age, M (SD) [range]	21.42 (5.40)	[15.0–31.0]
Age at diagnosis, M (SD) [range]	8.10 (2.77)	[3.7–13.7]
Follow-up time, M (SD) [range]	13.29 (4.97)	[3.0–21.0]
Gender (female), N (%)	6 (42.9)	
Medical data		
EVD, N (%)	2 (14)	
VP shunt, N (%)	0 (0)	
Relapse, N (%)	1 (7)	
Tumor progression, N (%) ^b	2 (14)	
Subtotal resection, N (%)	4 (29)	
Gross total resection, N (%)	14 (100)	
2 surgeries, N (%)	4 (29)	
Hydrocephalus (preoperative), N (%)	1 (7)	
Postoperative cerebellar Mutism syndrome	1 (7)	
Solid vs. solid+cystic tumor Components, N (%)	6 (43) vs. 8 (57)	
Average tumor size [range]	3.43 cm	[1–5 cm]
Tumor localization, N (%)	3 (21)	Left cerebellum
	1 (7)	Left cerebellum +vermis
	4 (29)	Vermis
	4 (29)	Right cerebellum +vermis
	2 (14)	Right cerebellum
Education (completed)^c		
Compulsory education, N (%)	4 (29)	
Apprenticeship, N (%)	6 (43)	
High school, N (%)	3 (21)	
University, N (%)	1 (7)	
Occupational/educational status		
Apprenticeship, N (%)	1 (7)	
Vocational school, N (%)	1 (7)	
High school, N (%)	2 (14)	
University, N (%)	2 (14)	
Employed, N (%)	6 (43)	
Self-employed, N (%)	2 (14)	

Note. CPA, cerebellar pilocytic astrocytoma; EVD, external ventricular drain (postoperative); VP shunt, ventriculo-peritoneal shunt.

^aAge and follow-up time data are given in years.

^bTumor progression after first sub-total resection.

^cEducation completed at time of assessment.

at the time of assessment ($t(26) = -1.175, p = 0.251$). All controls and all patients had German as their mother tongue (one patient migrated during early infancy and grew up bilingually).

Procedure

Medical records provided information about tumor type, type of treatment (surgery), time of diagnosis and the presence of a hydrocephalus, relapse, secondary surgery, shunting as well as the postoperative status. Based on these records, CPA patients were diligently chosen according to the inclusion and exclusion criteria (see above). The high achieving peers were chosen according to a pre-screening conducted to select the most successful students. Upon their verbal consent to participate, patients and controls were invited to the clinic on weekdays between 9:30 and noon to complete the neuropsychological assessment and related questionnaires (for a detailed overview over measures see below). The overall assessment was concluded in one sitting and lasted around 2–3 h including individual breaks. All participants signed an informed consent form, which was drafted according to the Declaration of Helsinki. The study was approved by the institutional review board, and both patients and controls received a small financial compensation to cover their travel expenses.

Measures

A battery of neuropsychological tests was used alongside a socio-demographic survey and questionnaires. The neuropsychological test battery covered neurocognitive functions such as memory, executive functioning, visuospatial skills, information processing speed, attention, language skills, motor functioning, as well as the overall full scale IQ as a measure of general intelligence. The questionnaires covered functional outcomes such as stress regulation strategies and HRQoL. Below, the used measures are described in more detail.

Overall cognitive functioning

Depending on the age of the participant either the German version of the Wechsler Intelligence Scale for Adults (WIE)²⁴ or the Hamburg Wechsler Intelligence Scale for children IV (HAWIK IV)²⁵ were used to assess different areas of cognitive functioning. The test battery consists of 15 subtests, which may be summarized to calculate full-scale IQ. The subtests will be reported separately in the results section to additionally inform about different areas of cognitive functioning (i.e., language skills).

Memory

Both the Verbal Learning and Memory Test (VLMT)²⁶ as well as the Rey Complex Figure Test and Recognition Trial (RCFT)²⁷ were applied to assess memory. The overall score as well as the recognition score of the VLMT served as indicators of verbal memory, whereas the RCFT scores for immediate recall and delayed recall represented figural (visuospatial) memory. Furthermore, the subtest working memory from the computer-based Test-battery for Attentional Performance (Testbatterie zur Aufmerksamkeitsprüfung, TAP²⁸) was used as an indicator for working memory performance.

Executive functioning

The letter-number switching task (Form 4) from the Trail Making Test (TMT)²⁹ as well as the error score (percentage of wrong assignments) from the computer-administered version of the Wisconsin Card Sorting Test (WCST)^{30,31} served as measures of executive functioning.

Information processing speed

Both the TMT letter sequencing and TMT number sequencing²⁹ reflected information processing speed.

Attention

The TAP²⁸ subtests Alertness (with and without warning signal), Divided Attention and Incompatibility (left vs. right) were used as measures of attentional performance.

Language skills

Different language-related subtests from the WIE and HAWIK-IV^{24,25} reflected verbal comprehension, active vocabulary, and abstract-verbal reasoning.

Motor function

Five different subtests of the Motor Achievement-Series test type S3 (MLS)³² were applied to test for motor function in the right and left hand.

Stress regulation

The German version of the Stress Regulation Questionnaire 120-item version (SVF-120)³³ contains 20 subscales, which may be summarized to the two secondary scales positive strategies and negative strategies.

HRQoL

The Short Form Health Survey (SF-36)³⁴ on physical and mental health constructs was applied as a measure of HRQoL. In this study, seven subscales were used (physical functioning, role – physical, bodily pain, mental health, social functioning, vitality and general health perceptions) to assess health-related well-being.

Results

All data from the neuropsychological test battery as well as from the questionnaires were compared to normative data (German samples) and corrected for age. Subsequently, data were analyzed using SPSS version 20 (SPSS, Inc. Chicago, IL). Independent sample *t*-tests were carried out to test for differences between patients and controls, and one-sample *t*-tests were computed to compare patients to the norm population. A Pearson correlation was conducted to investigate possible influences of age on neuropsychological functioning. A significance threshold of $p < 0.05$ was chosen for the interpretation of all results, and effect sizes are represented by Cohen's *d* (Cohen, 1988).

Cognitive performance and functional outcome

Data for cognitive performance and functional outcome were first compared to a norm population and corrected for age. The resulting *T*-values represent standardized values (M 50, SD 10). To compare CPA patients to norm references, a one-sample *t*-test

(reference value = 50) was conducted. Furthermore, independent sample *t*-tests were computed to test for differences between the CPA patient group and the group of high-achieving peers. All results are described below. For a detailed overview over means (M) and standard deviations (SD) as well as significance values for cognitive performance see Table 2.

Cognitive performance

Overall, CPA patients differed significantly from the norm only in two areas of cognitive functioning: attention (TAP Incompatibility) and motor function (MLS subtests *Tracing*

and *Pens*). The patient group made significantly less errors in the TAP incompatibility task (M 59.57, SD 13.107; $t(13) = 2.732, p < 0.05, d = 0.82$) than the norm population. Furthermore, CPA patients (M 59.51, SD 13.859) needed significantly less time to complete the MLS pen task with their left hand than the norm ($t(12) = 2.474, p < 0.05, d = 0.79$), and more time (M 43.36, SD 10.498) to complete the tracing task with the right hand as compared to their healthy coevals, $t(12) = -2.280, p < 0.05, d = -0.65$.

More pronounced differences (in memory, executive functioning, information processing speed, and language skills) were found

Table 2. Scores for cognitive functions in CPA patients ($N = 14$) compared to high-achieving controls ($N = 14$) and a norm reference value ($T = 50$).

Cognitive functions	Patients M (SD)	Controls M (SD)	t-Test	
			Controls p-Value	Norm p-Value
Overall cognitive functioning				
Full-scale IQ (WIE/HAWIK)	50.80 (10.171)	62.71 (7.458)	0.002**	0.773
Memory				
Verbal memory (VLMT)	49.51 (11.261)	62.07 (6.382)	0.002**	0.874
Verbal recognition (VLMT)	50.38 (8.191)	54.71 (2.655)	0.079	0.865
Figural memory – immediate (RCFT)	50.45 (10.583)	54.29 (10.492)	0.344	0.876
Figural memory – delayed (RCFT)	48.54 (13.583)	53.89 (9.871)	0.243	0.693
Working memory (TAP)				
reaction time	48.36 (10.616)	50.50 (10.435)	0.595	0.572
omissions	46.64 (8.670)	51.93 (4.649)	0.058	0.171
Digit span (WIE/HAWIK)	53.63 (11.778)	60.00 (9.382)	0.125	0.270
Letter-number sequencing (WIE/HAWIK)	45.62 (11.372)	55.69 (8.867)	0.016	0.190
Executive functioning and reasoning				
Letter number switching (TMT)	49.88 (10.009)	57.19 (6.194)	0.028*	0.964 ^a
Errors (%) (WCST)	24.78 (14.080)	7.53 (9.901)	0.002**	
Picture completion (WIE/HAWIK)	49.01 (9.489)	52.87 (6.131)	0.238	0.749
Matrix reasoning (WIE/HAWIK)	52.60 (7.073)	56.14 (4.841)	0.139	0.210
Information processing speed				
Number sequencing (TMT)	49.40 (12.144)	57.58 (4.196)	0.030*	0.856
Letter sequencing (TMT)	49.23 (10.130)	57.62 (5.432)	0.013*	0.780
Symbol search (WIE/HAWIK)	48.54 (12.830)	60.74 (10.336)	0.011*	0.689
Attention				
Alertness (TAP)				
without signal (reaction time)	49.64 (15.270)	50.93 (10.745)	0.799	0.932
with signal (reaction time)	45.07 (15.122)	49.79 (8.478)	0.318	0.244
Divided Attention (overall score) (TAP)	44.93 (10.759)	46.71 (6.787)	0.604	0.101
Incompatibility (TAP)				
reaction time	50.14 (13.300)	54.43 (7.449)	0.303	0.969
errors	59.57 (13.107)	56.93 (5.136)	0.492	0.017*
Language skills				
Word reasoning (WIE/HAWIK)	46.16 (8.488)	59.51 (7.191)	0.000**	0.129
Vocabulary (WIE/HAWIK)	48.45 (9.428)	58.30 (8.626)	0.008**	0.549
Similarities (WIE/HAWIK)	46.91 (6.653)	55.24 (9.048)	0.010*	0.106
Information (WIE/HAWIK)	45.69 (10.709)	60.24 (6.361)	0.000**	0.156
Comprehension (WIE/HAWIK)	53.22 (11.220)	65.80 (8.156)	0.003**	0.342
Motor function				
Aiming (MLS)				
Right errors	46.88 (12.487)	48.14 (9.195)	0.776	0.386
Left errors	44.38 (9.457)	42.93 (10.261)	0.716	0.053
Steadiness (MLS)				
Right errors	48.37 (11.112)	53.97 (10.555)	0.200	0.606
Left errors	53.69 (9.831)	53.95 (9.601)	0.947	0.201
Tracing (MLS)				
Right errors	45.36 (10.239)	49.27 (9.463)	0.322	0.128
Right time to complete	43.36 (10.498)	42.18 (9.181)	0.762	0.042*
Left errors	49.03 (8.605)	48.02 (11.478)	0.801	0.692
Left time to complete	49.50 (8.892)	46.18 (8.634)	0.344	0.843
Pens (MLS)				
Right time to complete	56.75 (16.012)	61.11 (13.765)	0.464	0.155
Left time to complete	59.51 (13.859)	63.42 (10.885)	0.432	0.029*
Tapping (MLS)				
right	49.58 (11.948)	51.93 (11.429)	0.614	0.902
left	50.25 (10.250)	50.72 (10.254)	0.908	0.930

Note. All means (M) and standard deviations (SD) are provided in *T*-values (M 50, SD 10) except for the WCST error rate (presented in %).

WIE, Wechsler Intelligence Scale for Adults; HAWIK IV, Wechsler Intelligence Scale for Children IV; VLMT, Verbal Learning and Memory Test; RCFT, Rey Complex Figure Test; TAP, Test-battery for Attentional Performance; TMT, Trail Making Test; WCST, Wisconsin Card Sorting Test; MLS, Motor Achievement Series;

^aNo age-corrected values available, instead raw scores (error %) were used.

** $p < 0.01$ (two-tailed).

when comparing the CPA patients group to the group of high-achieving controls. CPA patients (M 49.51, SD 11.261) achieved a significantly lower verbal memory score (VLMT) than medical students (M 62.07, SD 6.382), $t(20,570) = -3,630$, $p < 0.01$, $d = -1.37$. Furthermore, patients' performance on measures of executive functioning and reasoning, such as the TMT *letter-number switching* task (M 49.88, SD 10.009) was worse than that of high achievers (M 57.19, SD 6.194), $t(26) = -2.323$, $p < 0.05$, $d = -0.88$. Similarly, their WCST error score (M 24.78, SD 14.080) lay above the control group's score (M 7.53, SD 9.901), indicating a higher number of card assignment errors (numbers are given in %) in the patients' group, $t(23) = 3,599$, $p < 0.01$, $d = 1.42$.

Also, the two groups differed significantly in information processing speed tasks such as the TMT subtest *number sequencing* (patients: M 49.40, SD 12.144; controls: M 57.58, SD 4.196), $t(16,060) = -2.382$, $p < 0.05$, $d = -0.90$, the TMT *letter sequencing* (patients: M 49.23, SD 10.130; controls: M 57.62, SD 5.432), $t(26) = -2.732$, $p < 0.05$, $d = -1.03$, and the WIE/HAWIK IV *Symbol search* (patients: M 48.54, SD 12.830; controls: M 60.74, SD 10.336), $t(25) = -2.732$, $p < 0.05$, $d = -1.05$.

Finally, there were pronounced differences in favor of the high achievers regarding overall language skills. Here, CPA patients achieved lower scores in the WIE/HAWIK IV subtests *word reasoning* (patients: M 46.16, SD 8.488; controls: M 59.51, SD 7.191), $t(25) = -4,419$, $p < 0.01$, $d = -1.70$, *vocabulary* (patients: M 48.45, SD 9.428; controls: M 58.30, SD 8.626), $t(26) = -2.884$, $p < 0.01$, $d = -1.09$, *similarities* (patients: M 46.91, SD 6.653; controls: M 55.24, SD 9.048), $t(26) = -2.775$, $p < 0.05$, $d = -1.05$, *information* (patients: M 45.69, SD 10.709; controls: M 60.24, SD 6.361), $t(26) = -4.371$, $p < 0.01$, $d = -1.65$, and *comprehension* (patients: M 53.22, SD 11.220; controls: M 65.80, SD 8.156), $t(24) = -3.304$, $p < 0.01$, $d = -1.28$.

Functional outcome

Again, age-corrected norm T -values (M 50, SD 10) were used to analyze data regarding dimensions of functional outcome. Table 3 presents means (M) and standard deviations (SD) as well as significance values for differences between CPA patients and a norm value of $T = 50$ as well as CPA patients and high-achieving controls.

No differences in stress regulation (SVF-120) were found between the CPA patient group and the high-achieving control

group ($p = 0.347-0.400$) as well as between patients and a norm population ($p = 0.395-0.682$). Similarly, patients and high-achieving controls did not differ on any HRQoL scale ($p = 0.188-0.958$), yet when comparing patients to the norm the following SF-36 subscales showed significantly higher scores in CPA patients than the norm value (M 50, SD 10): *physical functioning* (M 53.97, SD 4.680), $t(13) = 3.175$, $p < 0.01$, $d = 0.51$, *bodily pain* (M 59.56, SD 2.568), $t(13) = 13.926$, $p < 0.01$, $d = 1.31$, and *general health perceptions* (M 56.07, SD 7.349), $t(13) = 3.091$, $p < 0.01$, $d = 0.69$.

Influence of age at diagnosis

To evaluate the possible influence of age at diagnosis (range: 3.7-13.7 years) on the CPA patients' cognitive functioning years after treatment, age was correlated with all assessed cognitive functions (overall cognitive functioning, memory, executive functioning and reasoning, information processing speed, attention, language skills as well as motor function). No significant correlations between age at diagnosis and cognitive functioning could be detected (Pearson r ranging from $-0.490 - 0.520$). Similarly, age had no significant influence on stress regulation (SVF-120, $r = -0.331 - 0.398$) or HRQoL (SF-36, $r = -0.146 - 0.366$).

Discussion

Given the contradictory results currently available on late effects of CPA surgery in childhood, the present study set out to examine a homogenous group of CPA survivors at least 3 years after surgery. The CPA patient group was compared to a healthy norm population as well as to high-achieving peers on measures of neurocognitive performance, HRQoL, and stress regulation strategies. Additionally, the influence of age on neurocognitive functioning was evaluated as prior research has suggested a possible detrimental impact of younger age at diagnosis on cognitive performance.^{1,9}

Cognitive performance and academic achievement

When comparing the CPA group to a norm population on measures of cognitive functioning, only few significant

Table 3. Scores for functional outcome in CPA patients ($N = 14$) compared to high-achieving controls ($N = 14$) and a norm reference value ($T = 50$).

Functional outcome	Patients M (SD)	Controls M (SD)	t-Test	
			Controls p -Value	Norm p -Value
Stress regulation (SVF-120)				
Positive strategies	48.87 (9.331)	52.44 (9.537)	0.400	0.682
Negative strategies	47.44 (10.019)	51.67 (9.812)	0.347	0.395
Health-related quality of life (SF-36)				
Physical functioning	53.97 (4.680)	53.88 (3.690)	0.958	0.007**
Role (physical)	51.56 (7.529)	51.35 (5.209)	0.937	0.453
Bodily pain	59.56 (2.568)	56.13 (8.197)	0.188	0.000**
Mental health	53.19 (7.540)	55.91 (7.490)	0.368	0.137
Social functioning	51.29 (6.948)	52.37 (6.181)	0.681	0.501
Vitality	49.29 (8.511)	52.45 (9.983)	0.392	0.761
General health perceptions	56.07 (7.349)	58.07 (6.137)	0.464	0.009**

Note. All means (M) and standard deviations (SD) are provided in T -values (M 50, SD 10).

SVF-120, Stress Regulation Questionnaire 120 items; SF 36, Short-Form Health Survey.

** $p < 0.01$ (two-tailed).

differences could be detected, which were mostly related to aspects of attention and fine motor skills. For instance, patients needed more time to trace a line with their right hand (MLS, tracing), but they made significantly fewer errors when reacting to incompatible stimuli (TAP, incompatibility task, measuring focused attention) and finished a task requiring them to put pens into small holes with their left hand much quicker than the norm (MLS, pens). Apart from this, however, their performance was predominantly within the age-appropriate average. This result is in line with prior research showing an altogether favorable long-term prognosis of cognitive functioning in CPA patients.^{12,15,21,22} Similarly, long-term CPA survivors included in this study were all well integrated into school or professional life. Of those who had finished their education, all were either employed or self-employed. This corresponds with findings showing normal education and independent functioning in CPA survivors.^{19,20} Overall, these study's results seem in favor of the notion that the majority of CPA patients treated only with surgery do not have as many academic difficulties as other patient groups with tumors of the posterior fossa treated with additional irradiation and chemotherapy. This observation may especially be helpful when trying to single out the role of irradiation in causing long-term cognitive impairments (for more details see ref.⁹).

In sum, our CPA patient group did not differ much from a healthy norm; however, when comparing the patient group to coeval medical students, the patient's disadvantages in neurocognitive performance become apparent. We found robust significant differences between the two groups in executive functioning, information processing speed and language-related abilities such as vocabulary and verbal memory. The most consistent disadvantages were noticeable in language skills: here, CPA patients achieved lower scores on subtests measuring general word knowledge and vocabulary, verbal reasoning and concept formation, as well as the ability to recognize conceptual relationships between common objects, concepts, or words. Similarly, CPA patients had more difficulties in verbal memory and in understanding the principles that govern behavior in social situations than high-achieving peers. Furthermore, the survivors' performance on measures of executive functioning that required them to flexibly adjust to new information (i.e., TMT letter number switching) was below the medical students' performance. Both executive functioning and language difficulties perfectly fit the cluster of disturbances related to the CCAS¹⁶ and as such they once again highlight the role of the cerebellum in higher cognitive functioning. Also, we observed significant differences between patients and students on measures of information processing speed. Again, patients had lower scores in tasks requiring visual scanning and fine motor speed (TMT and symbol search – WIE/HAWIK IV) than their high-achieving coevals. Not surprisingly, the overall measure of cognitive performance, the full-scale WIE/HAWIK IQ, which is a composite score of all subtests, also revealed an advantage of medical students over CPA patients.

Furthermore, there was no influence of age at diagnosis on any cognitive function in our patient sample. Hence, the assumption that a younger age at the time of tumor diagnosis

may be a detrimental factor in cognitive development was not supported by our results. We thus join a number of studies equally failing to find such an effect.^{2,15,17} However, the mean age of our patient sample at the time of diagnosis was 8 years and the youngest patient was 3.7 years old at the time of surgery. This circumstance does not allow for far-fetched conclusions. Future studies should consider samples representing all age groups (even those below 3 years of age).

Our observations lead to the conclusion that comparisons with norm standards may not suffice to paint an exhaustive picture of cognitive functioning in survivors of CPA surgery in childhood. The cognitive and academic outcome of survivors seems to be encouraging; yet, patients may still need timely interventions to be able to reach this level of functioning. In this study, we did not assess whether our patients were enrolled in special education services such as remedial teaching or whether they repeated classes; future studies shall focus on these aspects to be able to draw more firm conclusion about survivors' long-term academic welfare. Also, the average follow-up time in this study was 13.29 years (range: 3–21 years); taking a broader follow-up period into account and considering longitudinal instead of cross-sectional data may yield more insight into a phenomenon known as “growing into deficit.”⁶

Stress regulation and HRQoL

When comparing CPA patients with a norm population as well as with successful peers on measures of functional outcome, only HRQoL revealed significant differences. Here, long-term survivors reported a significantly better physical functioning, less bodily pain, and better general health perception than the norm. In contrast, there were no differences between patients and high achievers on other measures of HRQoL. Similarly, stress regulation strategies showed no significant group differences. This result corresponds with a study by Zuzak and colleagues,²² who found that CPA patients rated their QoL similarly or even higher than healthy controls. Additionally, another study²¹ showed that survivors of surgically removed low-grade CPA tend to have a better QoL than other brain tumor patients. As QoL is generally thought to be related to academic achievement and professional status, it may not be surprising to find such good ratings in a patient group that is quite well integrated in educational and professional life. Nevertheless, more studies are needed that differentially assess health perceptions, social integration, as well as participation in everyday life as defined by the International Classification of Functioning.^{35,36}

Limitations and conclusion

The current study succeeded in showing that while CPA patients do not significantly differ from the norm in most areas of cognitive functioning, there are marked differences between CPA survivors and high-achieving peers. However, this study has some limitations, which we would like to address here: first, sample sizes were quite small. The trade-off for recruiting a highly homogenous group of patients was a smaller sample and, thus, less statistical

power. However, large effect sizes (Cohen's *d*) ranging from 0.88 and 1.70 are in clear favor of the robustness of our results. Second, only age was considered in this study as a factor possibly influencing cognitive outcome. As only one of our patients was reported to have had a preoperative hydrocephalus and only one other a cerebellar mutism syndrome, the influence of these circumstances could not be taken into account in this study. Similarly, there was only one relapse, and no patient had had a shunt. Given the inconclusive results regarding tumor-related data, we also did not analyze the impact of tumor size, tumor location in the cerebellum, and the impact of the solid versus cystic character of the tumor.

All in all, disease control was very successful in our sample, and the tumor could be totally removed in all patients. Future studies, however, should include information about the existence of a preoperative hydrocephalus, tumor recurrence, as well as residual tumor size, as all these factors have been suggested to influence long-term neuropsychological outcome.^{1,8}

In sum, the current results show that, in general, CPA survivors fare well but when compared to high-achieving peers, several clear disadvantages come to the fore. Thus, patients with low-grade CPA may not altogether be dismissed from neuropsychological interventions on the basis of a favorable prognosis, but need to be closely monitored on long-term follow-ups in order to be able to detect possible deficits that may surface only years after surgery. However, they seem able to reach quite a satisfactory academic achievement and QoL provided they are accompanied properly in their recovery.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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