



**University of  
Zurich** <sup>UZH</sup>

**Zurich Open Repository and  
Archive**

University of Zurich  
Main Library  
Strickhofstrasse 39  
CH-8057 Zurich  
[www.zora.uzh.ch](http://www.zora.uzh.ch)

---

Year: 2013

---

## **Brainstem Tumours in Children**

Benitez, B

Other titles: Consecutive Case Series of 42 Patients

Posted at the Zurich Open Repository and Archive, University of Zurich  
ZORA URL: <https://doi.org/10.5167/uzh-93570>  
Dissertation

Originally published at:

Benitez, B. Brainstem Tumours in Children. 2013, University of Zurich, Faculty of Medicine.

Universitäts-Kinderkliniken Zürich  
Medizinische Klinik  
Direktor: Prof. Dr. med. F. H. Sennhauser  
Abteilung Onkologie  
Leiter: Prof. Dr. med. F. K. Niggli

---

Arbeit unter Leitung von Prof. Dr. med. M. Grotzer und PD Dr. techn. J. Sarnthein

Brainstem Tumours in Children: Consecutive Case Series of 42 Patients

**INAUGURAL-DISSERTATION**

zur Erlangung der Doktorwürde der Medizinischen Fakultät  
der Universität Zürich

vorgelegt von  
Benito Benitez, Dr. med. dent.  
von St.Gallen SG

Genehmigt auf Antrag von Prof. Dr. med. M. Grotzer  
Zürich 2013

# Index

- SUMMARY ..... 1**
- 1. INTRODUCTION ..... 2**
  - 1.1 CLASSIFICATION OF BRAINSTEM TUMOURS ..... 2
  - 1.2 DIFFUSE INTRINSIC BRAINSTEM GLIOMAS ..... 2
  - 1.3 FOCAL BRAINSTEM TUMOURS ..... 3
  - 1.4 BRAINSTEM GLIOMAS ASSOCIATED WITH NEUROFIBROMATOSIS TYPE 1 ..... 4
  - 1.5 SIGNS AND SYMPTOMS ..... 5
- 2. PATIENTS AND METHODS ..... 6**
  - 2.1 PATIENT SELECTION AND CLINICAL DATA ..... 6
  - 2.2 PATHOLOGY DATA ..... 6
  - 2.3 IMAGING DATA ..... 6
  - 2.4 TREATMENT DATA ..... 6
  - 2.5 STATISTICAL ANALYSIS ..... 7
  - 2.6 ETHICAL APPROVAL ..... 7
- 3. RESULTS ..... 8**
  - 3.1 PATIENT AND TUMOUR CHARACTERISTICS ..... 8
  - 3.2 PATHOLOGY DATA ..... 8
  - 3.3 IMAGING DATA ..... 9
  - 3.4 PRE-DIAGNOSTIC SYMPTOMATIC INTERVAL ..... 11
  - 3.5 FREQUENCY OF SIGNS AND SYMPTOMS AT DIAGNOSIS ..... 11
  - 3.6 TREATMENT DATA ..... 13
  - 3.7 PROGRESSION-FREE AND OVERALL SURVIVAL ..... 13
- 4. DISCUSSION ..... 18**
- 5. REFERENCES ..... 20**
- 6. LIST OF FIGURES ..... 24**
- 7. LIST OF TABLES ..... 25**
- 8. CURRICULUM VITAE ..... 26**

## Summary

**Objective:** To study the pre-diagnostic symptomatic interval, the signs and symptoms at diagnosis and the long-term outcome of paediatric brainstem tumours.

**Methods:** We reviewed 42 consecutive patients under 16 years of age (median age at diagnosis 5.5 years) who were diagnosed between January 1980 and December 2010 at the University Children's Hospital of Zurich, Switzerland.

**Results:** The most frequent symptoms and signs at diagnosis were: cranial nerve palsies (61%), usually affecting eye movement, increased intracranial pressure (61%) and abnormal gait and coordination (59%). In children younger than 4 years (29%): most common initial signs were abnormal gait and coordination (58%) and head tilt (58%). 93% of the patients presented with three or more symptoms/signs at diagnosis. The median pre-diagnostic symptomatic interval was 48 days (range 0 to 395 days) with a median parents' delay of 19 days and a median doctor's delay of 7 days. Treatments included surgery (19/42 [45%]), radiotherapy (15/42 [36%]) and chemotherapy (12/42 [29%]). Median progression-free survival was 5.7 months and median overall survival was 16.6 months. Median overall survival was 7.9 months in patients with tumour localization in the pons compared to the others with a median survival of 36.3 months. Median progression-free survival of 4.8 months and a median overall survival of 9.6 months were seen in children with diffuse intrinsic brainstem gliomas. Treatment of these patients with surgery, radiotherapy, chemotherapy or a combination resulted in a significant better median progression-free ( $p=0.042$ ) and median overall survival ( $p=0.001$ ) than observational treatment.

**Conclusion:** Children with brainstem tumours present with various often unspecific signs and symptoms. The combination of multiple neurological signs and symptoms should alert the clinician and lead to CNS imaging without delay. The prognosis of diffuse intrinsic pontine tumours is dismal.

## **1. Introduction**

In children, tumours of the central nervous system (CNS) are the most common group of solid tumours and the second most common malignancy, after leukaemia. This is equally true for the U.S. [1], for Europe [2] as well as for Switzerland [3]. CNS tumours account for up to 30 % of all tumour types in children [4]. Among paediatric CNS tumours, tumours within the brainstem constitute 10-15 % [5, 6]. No gender predominance could be found [5, 7-13]. Brainstem tumours occur primarily in children and arise rather seldom in adults [6, 7, 14-16]. Prognosis and treatment of these tumours depend mainly upon location within the brainstem.

### ***1.1 Classification of brainstem tumours***

Brainstem tumours are a heterogeneous group of tumours that have markedly differences in biologic behaviours and prognoses. The majority of them are gliomas [17]. Standard method for diagnosis of brainstem tumours is magnetic resonance imaging because the eloquent location of these lesions makes biopsy difficult [18, 19]. Computed tomography is not the imaging modality of choice, because many of these tumours are isointense [20-22]. Neuroimaging characteristics divide these tumours into two groups: diffuse intrinsic tumours and focal tumours [23, 24]. Diffuse intrinsic brainstem glioma account for 80 % of paediatric cases. They have a dismal prognosis [25]. Most of them are high-grade, locally infiltrative tumours, either anaplastic astrocytomas (WHO-grade III) or glioblastomas (WHO-grade IV) [26]. Focal brainstem tumours constitute the other 20 % of the cases [26]. They include midbrain tumours, dorsal exophytic brainstem tumours, and cervicomedullary junction tumours [6, 23]. Histopathologically, most of these tumours are low-grade astrocytomas, usually pilocytic astrocytomas (WHO-grade I) [18]. Tumours without pontine involvement are described to be almost low-grade, showing a more favourable outcome [5].

### ***1.2 Diffuse intrinsic brainstem gliomas***

Due to their unresectable nature, devastating neurological lesions and poor response to adjuvant therapy, diffuse tumours infiltrating the brainstem have the worst prognosis of all brain tumours in children [25]. They usually present with a brief symptomatic period and evident neurological involvement. Magnetic resonance imaging alone is usually sufficient for diagnosis of diffuse intrinsic brainstem glioma, and it obviates the need for a surgical biopsy for diagnosis in most cases [27-29]. Characteristics on magnetic resonance imaging are a typically poorly margined, hypointense lesion on T1 and hyperintense lesion on T2 weighted images, with variable contrast enhancement. Because of the associated morbidity with surgery in this eloquent region of the brain, biopsies should be reserved for patients with atypical imaging findings, in order to identify patients with tumours not being high-grade lesions [29-31]. Due to the development of targeted therapies, the issues of stereotactic or open biopsies for diffuse

brainstem gliomas are currently being readdressed [28, 32]. Palliative corticosteroid therapy is common practice in children with symptomatic tumours [25]. Symptoms of peritumoural edema can rapidly improve after the administration of corticosteroids. Standard treatment consists of conventional fractionated local radiotherapy, which can lead to transient neurological improvement with a progression-free survival benefit, however, radiotherapy does not result in an increase of the probability for cure [6, 27, 28]. In order to reduce patients' treatment burden, hypofractionated radiotherapy has been used as an alternative with a shorter treatment time [28, 33-35]. No alternative radiation therapy technique has improved the survival outcome of children with diffuse intrinsic tumours [35-41]. So far, the application of chemotherapeutics either before, during or after radiation therapy has not resulted in a survival advantage in children with diffuse intrinsic brainstem gliomas [11, 42-49]. Most studies reveal a median overall survival time of shorter than one year, and nearly all children eventually die [6, 28, 50].

### **1.3 Focal brainstem tumours**

These tumours are subclassified according to their anatomic location: midbrain focal tumours, dorsal exophytic tumours and cervicomedullary junction tumours. Focal tumours are typically well circumscribed on magnetic resonance imaging, without local invasive growth or edema, but may be compressive or cystic. Characteristics on magnetic resonance imaging are a typically hypointense lesion on T1 weighted images and a hyperintense lesion on T2 weighted images with uniform contrast enhancement [19, 51]. Calcifications can be present in focal tumours of the midbrain with poor contrast enhancement [14]. Tectal gliomas typically exhibit a nonenhancing thickening of the tectal plate [19]. Hydrocephalus is often associated with tectal tumours and in dorsally exophytic brainstem tumours [6, 50, 52]. For cervicomedullary tumours, characteristic imaging findings are hypointense lesions on T1 weighted images and hyperintense lesions on T2 weighted images [20]. Differentiation of low-grade from high-grade brainstem gliomas is often possible by magnetic resonance imaging and biopsy is only indicated if diagnosis cannot be established due to atypical findings [51, 53, 54].

Focal brainstem tumours may be treated with surgery, radiation, chemotherapy or with conservative treatment. Hydrocephalus can be managed by cerebrospinal fluid diversion [55]. In contrast to diffuse tumours, surgical tumour debulking in dorsal exophytic tumours [56, 57] and cervicomedullary tumours [58, 59] is the preferred treatment. If surgical tumour resection is contraindicated, with stereotactic biopsy, important histological information can be obtained to guide further treatment [60]. In cases of tumour recurrence after resection, chemotherapy, radiotherapy or a second surgical tumour resection can be considered [61, 62]. Tectal tumours can cause aqueductal obstruction with increased intracranial pressure [18, 52, 63]. Initial therapy consists of cerebrospinal fluid diversion. Third ventriculostomy is described to be superior to a ventriculoperitoneal shunt, avoiding shunt malfunctions and the insertion of foreign

objects [52, 64, 65]. Conventional radiation therapy may be an option in patients with inoperable tumours, with residual disease after surgery or may be deferred until there is disease progression [54]. There is no additional survival benefit from hypofractionated (once per day) or hyperfractionated radiotherapy compared to conventional radiation therapy [66, 67]. Chemotherapy for children with unresectable or progressive low-grade tumours involving the brainstem is playing an increasing role. Chemotherapy has been described as a safe and effective treatment option for these children in order to delay and/or avoid radiotherapy [68, 69]. In summary, the subgroup of focal brainstem tumours, predominantly of low-grade histology, is associated with a favorable prognosis.

#### ***1.4 Brainstem gliomas associated with Neurofibromatosis type 1***

Neurofibromatosis type 1 (NF 1) is a common genetic disorder, with an incidence of approximately 1 in 2600 to 1 in 3500 [70-72]. NF 1 predisposes patients to the development of both benign and malignant tumors from peripheral or central nerve tissue [73-75]. Most of the CNS tumours are pilocytic astrocytomas (WHO grade I) [76]. Prevalent CNS tumours in NF 1 are optic pathway, hypothalamic and brainstem gliomas [77-79]. These tumours behave in a much more benign fashion than their counterparts in non-NF 1 children [80]. Brainstem lesions in children with NF 1 behave in a biologically indolent nature and most do not require therapeutic interventions [79, 81-85].

### ***1.5 Signs and symptoms***

The symptoms and signs of brain tumours in children are by no means pathognomonic and often mimic other more common and less serious illnesses, making the diagnosis in the early stage often difficult [9, 86]. This fact is reflected in rather long pre-diagnostic symptomatic intervals (PSI) [86-91]. The expanded access to neuroimaging has resulted in a shorter interval between the first medical consultation and diagnosis (doctor's delay) [86]. Nevertheless, for patients with low-grade brainstem gliomas, relatively long histories of minor signs and symptoms are described [6, 14, 18, 20, 22, 26, 53, 56, 92].

Signs and symptoms of brainstem tumours depend on the location of the lesion and the age of the child. Patients with diffuse intrinsic brainstem gliomas can present with a rapid appearance of: long tract signs, ataxia and cranial nerve palsies most commonly affecting the sixth and seventh nerve. However, involvement of cranial nerves III, IV, IX and X may also be discovered, or personality changes noted as the first signs. Hydrocephalus is described as rare, except in tumours located in the tectal area or in dorsal exophytic tumours. These tumours often combine hydrocephalus with increased intracranial pressure [6, 50, 52, 63]. In diffuse intrinsic brainstem gliomas, an intratumoural hemorrhage can rarely be present [93]. Histories of nonspecific symptoms such as headache and vomiting can provoke a delay in the diagnosis of brainstem tumours.

The present study was undertaken to investigate delays in the diagnosis, the signs and symptoms at diagnosis and the long-term outcome of paediatric brainstem tumours.



## **2. Patients and methods**

### ***2.1 Patient selection and clinical data***

42 patients, under the age of 16, with brainstem tumours were diagnosed at the University Children's Hospital of Zurich, Switzerland, between January 1980 and December 2010. Brainstem tumours were defined by the intra-axial location in the mesencephalon, pons or medulla oblongata. The following information was systematically derived from medical records of the 42 patients: date of birth, gender, age at diagnosis, pre-diagnostic symptomatic interval, the symptoms and signs at diagnosis, treatment modalities, progression-free survival, follow-up time and overall survival.

The pre-diagnostic symptomatic interval (PSI) was defined as the interval between the onset of symptoms/signs and the time of diagnosis by neuroimaging (magnetic resonance imaging (MRI) or computed tomography). In 29 out of 42 patients (69%), medical records allowed a subdivision of the PSI into an interval between sign/symptom onset and first medical consultation (parents' delay) and between the first medical consultation and diagnosis by neuroimaging (doctor's delay).

Last follow-up information was obtained in December 2010, and the data was validated and compiled for statistical analysis. Given the retrospective nature of the study, some of the data points were not available from medical records.

### ***2.2 Pathology data***

In case of tumour surgery or autopsy the histopathological diagnosis was recorded either out of patient's charts or pathology reports.

### ***2.3 Imaging data***

Regarding patients without histological diagnosis, presumptive diagnosis was based on radiological findings. Sources of detailed MRI tumour data were medical or radiological reports and re-analysis done together with a neuro-radiologist (Dr. med. Ianina Scheer) in 34 out of 42 cases. The tumour entity, based on neuroimaging, as well as the anatomical location and radiographic appearance observed in the MRI (when available) were recorded.

### ***2.4 Treatment data***

Treatments included surgical debulking, cerebrospinal fluid diversion, radiotherapy, chemotherapy and palliation.

## **2.5 Statistical analysis**

Descriptive statistics were computed and survival curves with 95% confidence intervals (according to Peto) were calculated using the Kaplan Meier method with PASW Statistics 18 (Version 18.0.0) and R (Version 2.14.2). Survival time was measured from time of diagnosis to the date of last follow-up visit or death. Progression-free survival time was measured from diagnosis to obvious evidence of clinical and/or radiographic tumour progression.

Gender, age at diagnosis (age <4 and >4 years), radiologic appearance and tumour grade (high- versus low-grade), tumour localization and treatment modalities were evaluated by the Log Rank test (Mantel-Cox) and Breslow test (Generalized Wilcoxon) for their impact on survival. Median survival together with the corresponding 95% confidence interval (95% CI) was computed for each group. Results of the statistical analysis with p-value smaller than 0.05, were considered to be statistically significant. Whereas p-values larger than 0.05 and smaller than 0.1 were interpreted as tendency.

## **2.6 Ethical approval**

The retrospective data collection for this study was approved by the Institutional Review Board Zurich (KEK 2011-0069/3).

### **3. Results**

#### ***3.1 Patient and tumour characteristics***

42 children were diagnosed with intra-axial tumours located within the brainstem, between January 1980 and December 2010. The median age at diagnosis was 5.5 years (0.0 - 14.6 years). 20/42 (48%) children were female and 22/42 (52%) male. 2/42 (5%) children showed an underlying cancer predisposition (NF 1).

Diagnoses were established by typical imaging in 34/42 (83%) and confirmed by histology in 23/42 (55%). Table 1 describes tumour location, radiologic appearance, histology and treatment.

#### ***3.2 Pathology data***

Tumour samples were obtained from biopsy 5/25 (20%), resection 18/25 (72%) and autopsy 2/25 (8%). 2/25 (8%) biopsies were non-informative. Among the 23/42 cases with a histopathological diagnosis the majority of tumours (22/23) were found to be astrocytomas: 5 of these were pilocytic astrocytomas (WHO-grade I), 3 diffuse astrocytomas (WHO-grade II), 8 anaplastic astrocytomas (WHO-grade III) and 6 glioblastomas (WHO-grade IV). One tumour was diagnosed as atypical teratoid / rhabdoid tumour (WHO-grade IV). The WHO-grade of the tumour was high (grade III-IV) in 15/23 (65%) and low (grade I-II) in 8/23 (35%) patients (Table 1).

**Table 1 Demographic and brainstem tumour characteristics of all 42 children.**

<b><i>Tumour location</i></b>		
Mesencephalon	4	10%
Mesencephalon to pons	7	17%
Pons	10	24%
Pons to medulla oblongata	8	19%
Medulla oblongata	4	10%
Medulla oblongata to medulla spinalis	4	10%
whole brainstem	5	12%
<b><i>Radiological appearance (n=34)</i></b>		
Diffuse intrinsic	25	74%
Exophytic	4	12%
Focal intrinsic	3	9%
Cervicomedullary	2	6%
no imaging for review available	8	
<b><i>Histopathological diagnosis (n=23)</i></b>		
Pilocytic astrocytoma WHO I	5	22%
Diffuse astrocytoma WHO II	3	13%
Anaplastic astrocytoma WHO III	8	35%
Glioblastoma WHO IV	6	26%
Atypical teratoid / rhabdoid tumour WHO IV	1	4%
Non-informative	2	
<b><i>Treatment received</i></b>		
Partial or total resection	19	45%
Radiotherapy	15	36%
Chemotherapy	12	29%
Cerebrospinal fluid diversion	7	17%

### **3.3 Imaging data**

Detailed MRI data was available from medical or radiology reports. Additionally, re-analysis of neuroimaging together with a neuro-radiologist was performed in 34/42 cases. This information is described in Table 2.

RESULTS

**Table 2 Patient and tumour characteristics of 42 children with brainstem tumours.**

Case No.	Age at Diagnosis (yrs), Sex	PSI (days)	Location	Classification based on re-evaluation of neuroimaging	Histology (incl. WHO Tumor Grade)	Management	Clinical Course	FU Time Since Diagnosis (yrs)
39	6.8, M	7	Pons	Diffuse intrinsic pontine glioma			PD	0.2
19	4.6, F	30	Pons	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)		DOD	0.2
8	9.2, M	55	Pons	Diffuse intrinsic pontine glioma			PD	0.2
35	8.4, F		Pons	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)		DOD	0.7
6	10.4, F	14	Pons	Diffuse intrinsic pontine glioma		R	DOD	0.6
24	9.8, F	23	Pons	Diffuse intrinsic pontine glioma		R C	DOD	1.4
12	5.1, M	210	Pons	Diffuse intrinsic pontine glioma		R Sh	SD	0.3
25	3.5, F	24	Pons	Diffuse intrinsic pontine glioma	Glioblastoma multiforme (WHO IV)	S	SD	0.1
33	6.4, F	39	Pons	Diffuse intrinsic pontine glioma	Glioblastoma multiforme (WHO IV)	S	DOD	0.8
11	6.2, F	150	Pons	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)	S	PD	0.1
40	6.4, F	150	Pons and Medulla oblongata	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)		DOD	0.4
10	12.2, F	47	Pons and Medulla oblongata	Diffuse intrinsic pontine glioma		R C	PD	0.5
9	13.1, M	45	Pons and Medulla oblongata	Diffuse intrinsic pontine glioma	Glioblastoma multiforme (WHO IV)	R C S	DOD	0.1
20	8.2, M	21	Pons and Medulla oblongata	Diffuse intrinsic pontine glioma	Glioblastoma multiforme (WHO IV)	R C S Sh	PD	1.0
41	2.3, F	28	Pons and Mesencephalon	Diffuse intrinsic pontine glioma		C	DOD	0.7
23	2.8, F	182	Pons and Mesencephalon	Diffuse intrinsic pontine glioma		C	DOD	3.0
34	1.5, F	1	Pons and Mesencephalon	Diffuse intrinsic pontine glioma			DOD	0.1
2	6.0, M	59	Pons and Mesencephalon	Diffuse intrinsic pontine glioma		R	DOD	1.4
5	5.9, M	140	Pons to Brachium pontis and Medulla oblongata	Diffuse intrinsic pontine glioma	Glioblastoma multiforme (WHO IV)	R S	PD	0.8
37	7.1, M	49	Pons to Mesencephalon and Cerebellum	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)	R S Sh	PD	0.3
31	5.2, M	67	Pons to Mesencephalon and Medulla oblongata	Diffuse intrinsic pontine glioma			DOD	0.6
27	14.3, M	150	Pons to Mesencephalon and Medulla oblongata	Diffuse intrinsic pontine glioma		Sh	PD	0.1
36	8.9, M	10	Pons to Mesencephalon and Medulla oblongata	Diffuse intrinsic pontine glioma		R C	DOD	1.2
30	4.7, F	25	Pons to Mesencephalon and Medulla oblongata	Diffuse intrinsic pontine glioma		R C	DOD	1.2
32	9.2, M	16	Pons to Mesencephalon and Pedunculus cerebelli	Diffuse intrinsic pontine glioma	Astrocytoma, anaplastic (WHO III)	S	PD	0.5
16	1.7, F	189	Medulla oblongata and Medulla spinalis	cervicomedullary	Astrocytoma, anaplastic (WHO III)	C	PD	6.0
29	1.0, M	7	Medulla oblongata and Medulla spinalis	cervicomedullary	Non-informative biopsy	S	SD	3.0
42	4.4, M	365	Medulla oblongata	exophytic dorsally	Astrocytoma, pilocytic (WHO I)	C S	SD	1.7
7	1.3, M	270	Medulla oblongata	exophytic dorsally	Astrocytoma, diffuse (WHO II)	R C S Sh	PD	21.9
18	5.1, F	395	Medulla oblongata and Medulla spinalis	exophytic dorsally	Astrocytoma, pilocytic (WHO I)	S	SD	0.6
15	2.4, M	180	Tectum mesencephali	exophytic dorsally	Glioblastoma multiforme (WHO IV)	R C S Sh	PD	3.2
3	12.4, M		Mesencephalon	focal	Astrocytoma, anaplastic pilocytic (WHO III)	R S	PD	0.6
13	14.6, F		Tectum mesencephali	focal	Astrocytoma, fibrillary (WHO II)	R S Sh	PD	1.8
14	9.3, M	365	Tectum mesencephali	focal	Astrocytoma, fibrillary (WHO II)	S	SD	0.8
26	0.4, M	35	Medulla oblongata		Astrocytoma, pilocytic (WHO I)	S	DOD	0.3
22	3.8, F	180	Medulla oblongata			S	SD	0.1
28	1.7, M	6	Medulla oblongata and Medulla spinalis		Astrocytoma, pilocytic (WHO I)		DOD	0.3
4	5.6, F	180	Pons and Medulla oblongata		Astrocytoma, pilocytic (WHO I)	S	PD	14.8
38	3.8, F	42	Pons and Mesencephalon				PD	0.0
1	5.4, F		Pons to Medulla oblongata and Brachium pontis				SD	1.6
21	0.0, M	0	Pons to Mesencephalon, Medulla oblongata and Pedunculus cerebellaris		Atypical teratoid / rhabdoid tumour (WHO IV)		DOD	0.0
17	4.4, M	60	Pons, Medulla oblongata				SD	16.0

PSI = Pre-diagnostic Symptomatic Interval; R = Radiotherapy; C = Chemotherapy; S = Surgery; Sh = Shunt; DOD = Death of Disease; SD = Stable Disease; PD = Progressive Disease; FU = follow-up

The pons was involved in 30/42 (71%), followed by the medulla, which was involved in 21/42 (50%), and the mesencephalon was involved in 16/42 (38%) patients. Tumours involved more than one brainstem region in 20/42 (48%) cases. Further data regarding patients and tumour characteristics are detailed in Table 2.

Regarding the 34 patients where review of neuroimaging was possible, the radiological tumour appearance was diffuse intrinsic in 25/34 (74%), exophytic in 4/34 (12%), focal intrinsic in 3/34 (9%) and cervicomedullary in 2/34 (6%) (Table 2).

### ***3.4 Pre-diagnostic symptomatic interval***

In 38/42 patients, medical records allowed to define a PSI (Table 2). In 29/38 (76%) patients, medical records allowed a subdivision of the PSI into parents' delay and doctor's delay. The median PSI was 48 days (range 0 to 395 days) with a median parents' delay of 19 days (range 0 to 365 days) and a median doctor's delay of 7 days (range 0 to 270 days).

### ***3.5 Frequency of signs and symptoms at diagnosis***

The initial signs and symptoms at the time of diagnosis are presented in Table 3. 41 different symptoms and signs were identified. Regarding one patient, signs and symptoms could not be retrieved from the medical record, so this patient was excluded from statistics below. None of the patients were monosymptomatic. All 41 patients had two (2/41 [5%]), three (4/41 [10%]), four (4/41 [10%]), five (5/41 [12%]), six (4/41 [10%]), and seven (3/41 [7%]) or more (18/41 [44%]) signs/symptoms. One patient was asymptomatic at time of diagnosis, and diagnosis was an incidental finding.

Signs and symptoms of increased intracranial pressure were observed in 25/41 (61%) patients at diagnosis. 13/41 (32%) had hydrocephalus. Cranial nerve palsies were the most frequent sign overall (25/41 [61%]), and they usually affected eye movement. The abducens nerve was widespread (15/41 [37%]), followed by the facial nerve (13/41 [32%]) and oculomotorius nerve (3/41 [7%]). Other frequent symptoms/signs at diagnosis were: abnormal gait and coordination (24/41 [59%]), squint and diplopia (24/41 [59%]), ataxia (19/41 [46%]), headache (16/41 [39%]), head tilt (15/41 [37%]), nausea and vomiting (14/41 [34%]), pyramidal signs (13/41 [32%]), hydrocephalus (13/41 [32%]), nystagmus (12/41 [29%]), behavioural change (9/41 [22%]) and hemiparesis (8/41 [20%]). In children younger than 4 years (12/41 [29%]), the most common initial symptoms and signs were abnormal gait and coordination (7/12 [58%]) and head tilt (7/12 [58%]).

**Table 3 Frequency of signs and symptoms at diagnosis in children with brainstem tumours depending on age.**

Signs and symptoms	All (n=41)	Age < 4 years (n=12)	Age > 4 years (n=29)
Cranial nerve palsies (NOS)	25 61%	4 33%	21 72%
Symptoms of raised ICP (NOS)	25 61%	4 33%	21 72%
Squint and diplopia	24 59%	4 33%	20 69%
Abnormal gait and coordination	24 59%	7 58%	17 59%
Ataxia	19 46%	4 33%	15 52%
Headache	16 39%	0 0%	16 55%
Abducens palsy	15 37%	2 17%	13 45%
Head tilt	15 37%	7 58%	8 28%
Nausea and vomiting	14 34%	1 8%	13 45%
Pyramidal signs (NOS)	13 32%	1 8%	12 41%
Facial palsy	13 32%	2 17%	11 38%
Hydrocephalus	13 32%	4 33%	9 31%
Nystagmus	12 29%	3 25%	9 31%
Behavioral change	9 22%	2 17%	7 24%
Hemiparesis	8 20%	4 33%	4 14%
Fatigue and sleepiness	7 17%	0 0%	7 24%
Enlargement of the head	6 15%	4 33%	2 7%
Hypoglossus palsy	5 12%	0 0%	5 17%
Dizziness	5 12%	0 0%	5 17%
Dysarthria	4 10%	0 0%	4 14%
Oculomotorius palsy	3 7%	0 0%	3 10%
Dysphagia	3 7%	0 0%	3 10%
Uvular deviation / glossopharyngeus palsy	3 7%	0 0%	3 10%
Tremor	3 7%	1 8%	2 7%
Trigemius palsy	2 5%	0 0%	2 7%
Dehydratation	2 5%	0 0%	2 7%
Apathy	2 5%	0 0%	2 7%
Weight gain	2 5%	0 0%	2 7%
Seizure	2 5%	1 8%	1 3%
Involuntary salivation	2 5%	1 8%	1 3%
Growth failure	2 5%	1 8%	1 3%
Development delay	2 5%	1 8%	1 3%
Sphincter disturbance	2 5%	1 8%	1 3%
Lethargy	1 2%	0 0%	1 3%
Weight loss	1 2%	0 0%	1 3%
Sucking weakness	1 2%	0 0%	1 3%
Nervus vagus palsy	1 2%	0 0%	1 3%
Accessory palsy	1 2%	0 0%	1 3%
Sleep disturbance	1 2%	1 8%	0 0%
Head banging	1 2%	1 8%	0 0%
Paraparesis	1 2%	1 8%	0 0%
ICP=intracranial pressure. NOS=not otherwise specified			
For one patient signs and symptoms could not be identified out of clinical records, and this patient was excluded.			

### **3.6 Treatment data**

Partial or total resection was performed in 19/42 (45%) patients. 15/42 patients (36%) underwent radiation therapy, and 12/42 patients (29%) received chemotherapy. 7/42 patients (17%) underwent cerebrospinal fluid diversion with ventriculoperitoneal shunt. In 13/42 (31%) patients, treatment was palliative only.

### **3.7 Progression-free and overall survival**

The median follow-up time of all 42 patients was 7.6 months (range 0 - 22.2 years). Tumour progression occurred in 33/42 patients (79%) and death due to tumour progression was documented in 17/42 (40%). The median progression-free survival was 5.7 months (95% CI, 2.8 to 8.7) (Figure 1) and the median overall survival was 16.6 months (95% CI, 11.5 to 21.6) as determined by the Kaplan-Meier method (Figure 2).



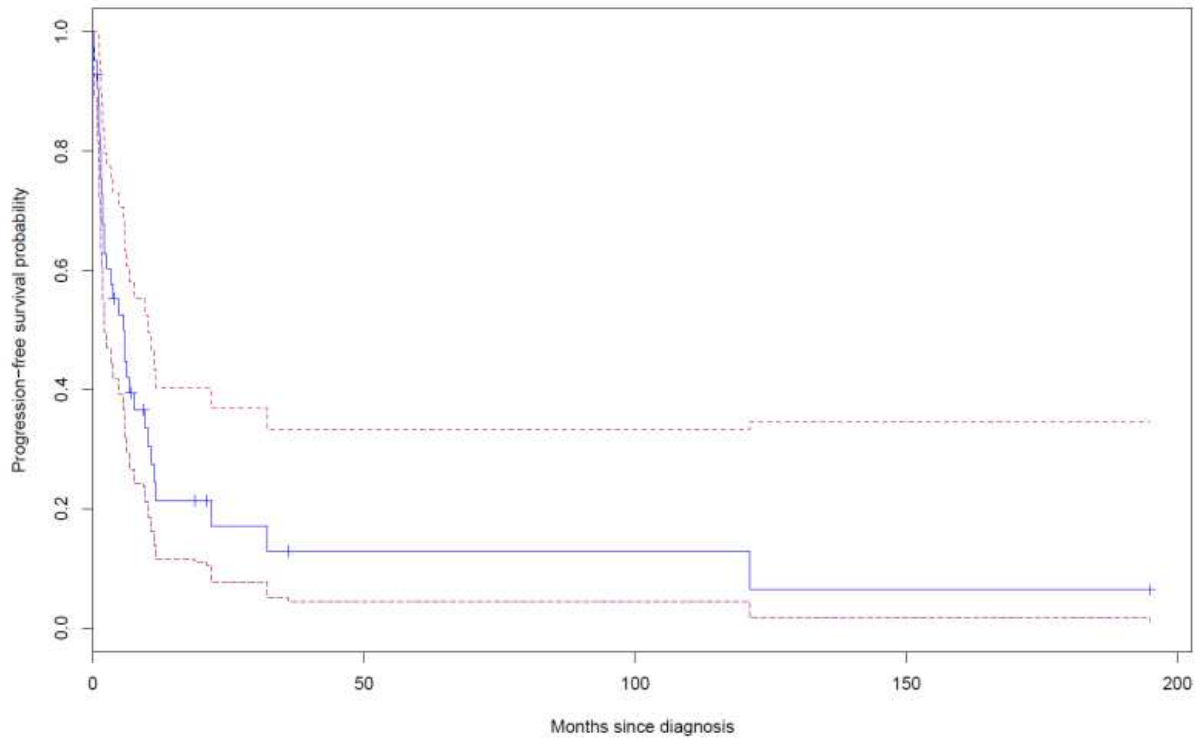


Figure 1. Progression-free survival with 95% confidence intervals for 42 children with brainstem tumours.

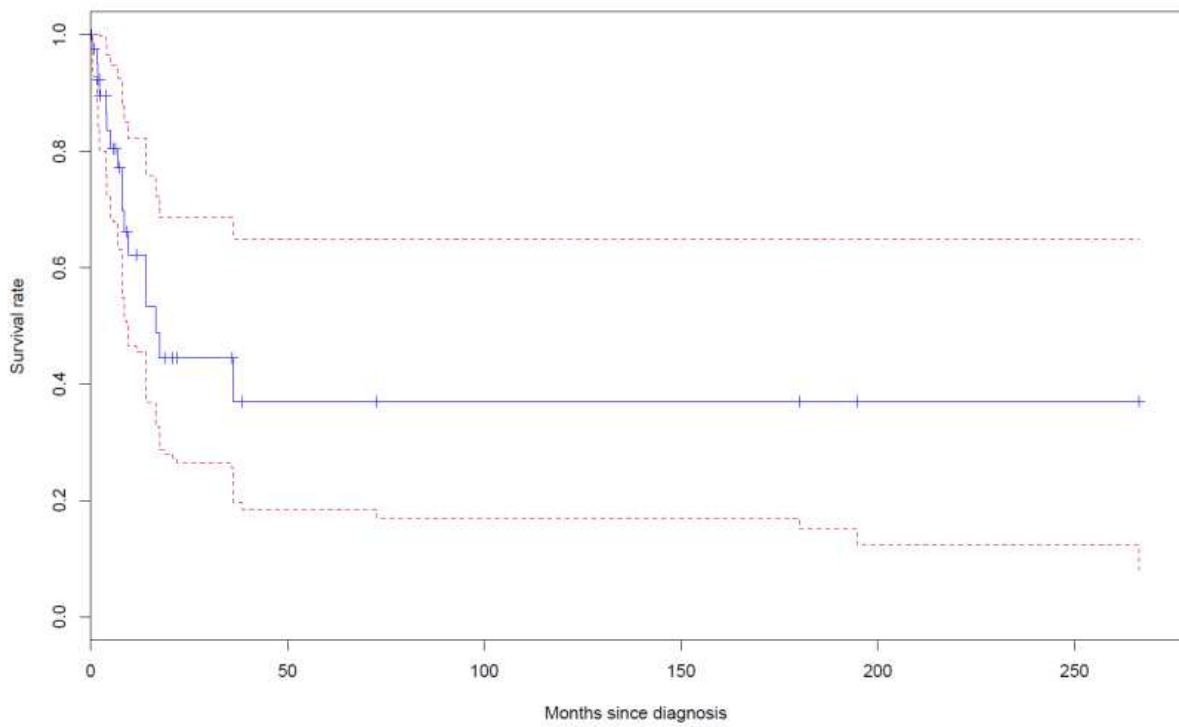
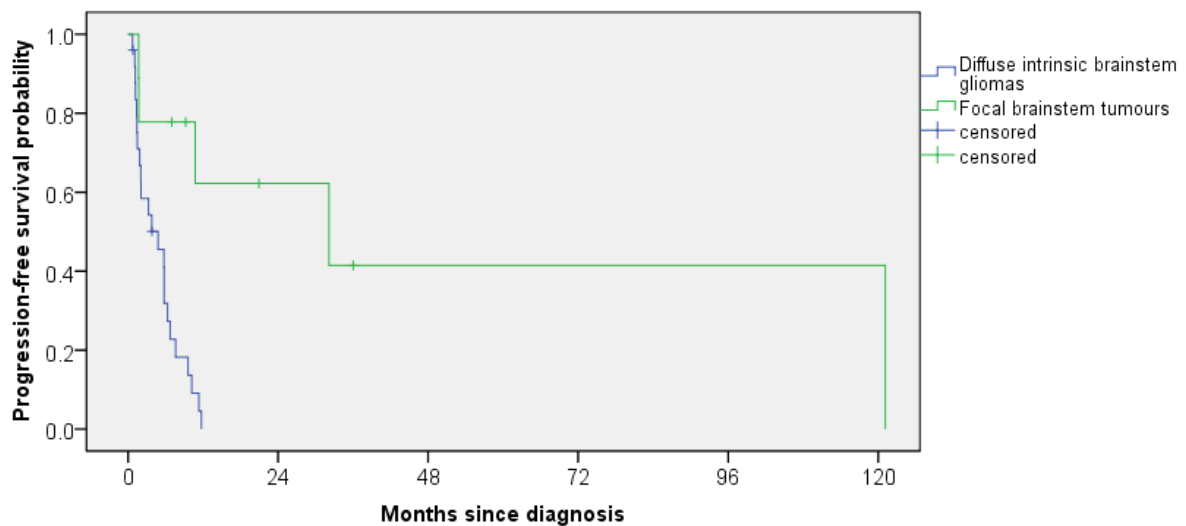


Figure 2. Overall survival with 95% confidence intervals for 42 children with brainstem tumours.

Patients with described tumour extension into pons, medulla and mesencephalon showed a tendency to worse overall survival ( $p=0.094$ ) compared to children with tumours not affecting the entire brainstem. Median survivals of 14.1 months (95% CI, 2.7 to 25.6) and 36.3 months (95% CI, 3.7 to 68.9) were estimated for patients with tumour extensions to the entire brainstem, respectively for patients with tumours not affecting the entire brainstem.

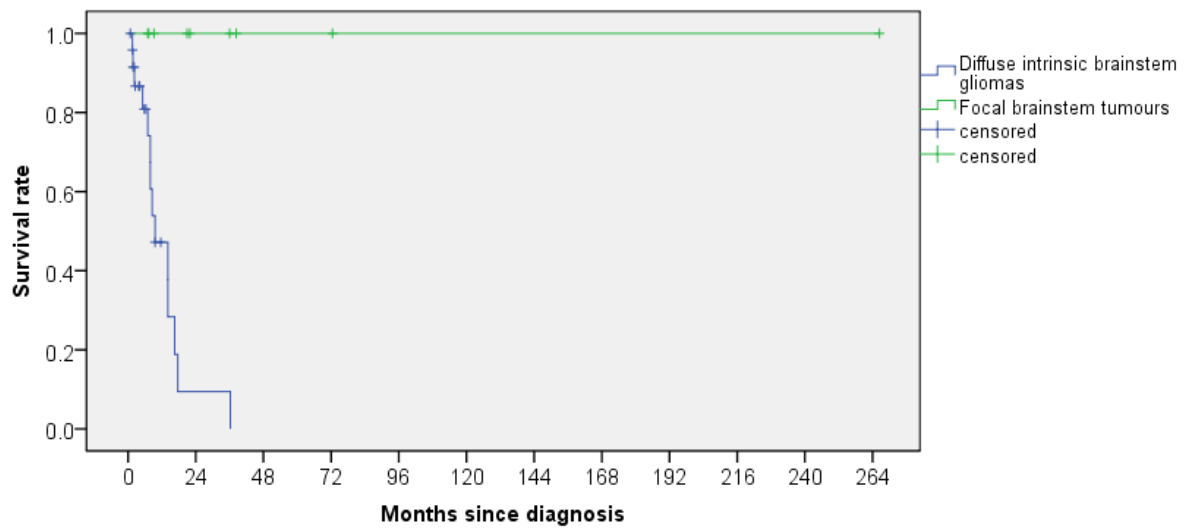
Patients with tumour localization in the pons only, showed a median survival of 7.9 months (95% CI, 7.8 to 8.1) compared to the others with a median survival of 36.3 months (95% CI, 0 to 95.5) but the median survival was not significantly different ( $p=0.325$ ). Patients with brainstem tumours not involving the pons did not show a significantly better overall survival rate than children with brainstem tumours with pontine involvement, but in general a better survival could be noticed ( $p=0.104$ ).

Children with diffuse intrinsic brainstem gliomas showed a significant worse median progression-free survival of 4.8 months (95% CI, 0.5 to 9.1) compared to children with focal brainstem tumours (exophytic, focal intrinsic and cervicomedullary) with a median progression-free survival of 32 months (95% CI, 0 to 74.1) ( $p=0.001$ )(Figure 3).



**Figure 3. Progression-free survival probability of children with diffuse intrinsic brainstem gliomas compared to children with focal brainstem tumours.**

Patients with diffuse intrinsic brainstem gliomas showed a median overall survival of 9.6 months (95% CI, 2.8 to 16.3). The median overall survival time of children with focal brainstem tumours (exophytic, focal intrinsic and cervicomedullary) could not be observed, and therefore the difference was statistically significant ( $p < 0.001$ ) (Figure 4).



**Figure 4. Overall survival of children with diffuse intrinsic brainstem gliomas compared to children with focal brainstem tumours.**

Patients with diffuse intrinsic brainstem gliomas receiving surgery, radiotherapy, chemotherapy, or a combination of them, showed a median progression-free survival of 5.7 months (95% CI, 3.9 to 7.5) and a median overall survival of 14.2 months (95% CI, 8.4 to 20). Regarding patients with observational treatment, median progression-free survival was 1.5 months (95% CI, 0.5 to 2.5) and median overall survival was 5.2 months (95% CI, 0.7 to 9.7). The difference between progression-free survival ( $p=0.042$ ) and overall survival ( $p=0.001$ ) was significant (Figure 5 and Figure 6).

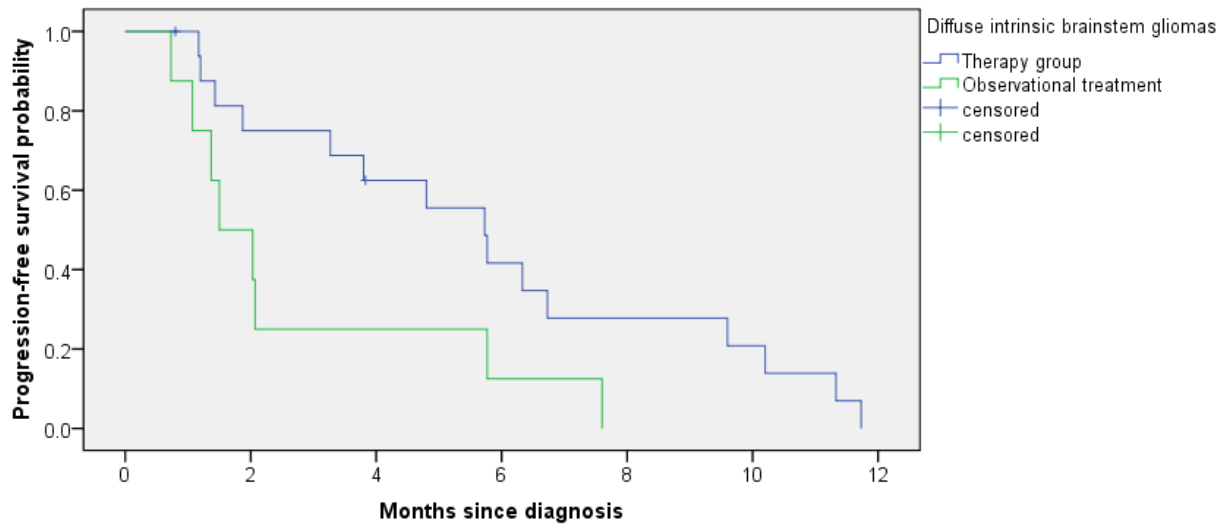


Figure 5. Progression-free survival of children with diffuse intrinsic brainstem gliomas receiving therapy compared to children with observational treatment.

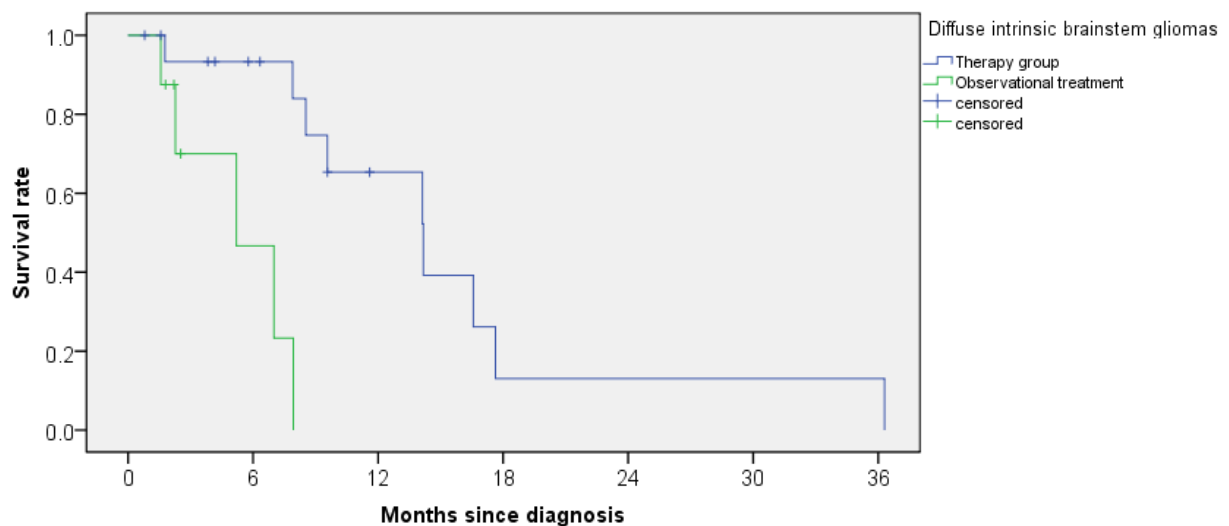


Figure 6. Overall survival of children with diffuse intrinsic brainstem gliomas receiving therapy compared to children with observational treatment.

## 4. Discussion

Paediatric brainstem tumours constitute a challenging group in terms of treatment. Although once considered to be a single entity, these tumours comprise several groups with heterogeneous biological behaviours [17]. Neuroimaging characteristics divide these tumours into two large groups: intrinsic tumours and focal tumours [6, 14]. The majority are intrinsic tumours diffusely infiltrating the pontine area and medulla oblongata [53]. Despite the attempts with radio- and chemotherapy, most cases have a fatal prognosis [26].

In our study population, there was no gender predominance, concurring with other studies [5, 7-13]. The median age at diagnosis of 5.5 years was found to be marginally lower compared with other studies [5, 8, 9, 12, 13]. There was one atypical teratoid / rhabdoid tumour in the brainstem diagnosed antenatal. Diffuse intrinsic brainstem tumours have also been reported in the neonate, with prognosis as poor as in older children [94]. But there are described spontaneous remissions of diffuse brainstem lesions in a neonate [95]. An increased frequency of brainstem tumours among children showing an underlying cancer predisposition (neurofibromatosis type 1) is already known and described [5, 79, 82, 83] and our found prevalence of about 5% has been as reported in the literature [5]. Both patients with NF 1 were alive at last follow-up, thus, as described in the literature, brainstem tumours in patients with NF 1 appear to have a much more favourable prognosis [79, 81-84].

As for tumour location within the brainstem, tumours most often involved the pons (71%) as also seen in other studies [5, 96]. The medulla was involved in 50% and the mesencephalon in 48%. Tumours involved more than one brainstem region in 20 cases (48%) which was clearly more than described in studies conducted in other areas [5]. The radiological tumour appearance of our analyzed patients was: 74% diffuse intrinsic, 12% exophytic, 9% focal intrinsic and 6% cervicomedullary. These radiological findings corresponded approximately with the relative frequency of different tumour types in the literature [6].

Children showed various signs and symptoms at diagnosis, usually already three or more symptoms. 41 different symptoms and signs were identified. More than half of the patients were already polysymptomatic at time of diagnosis. Signs and symptoms of increased intracranial pressure were noticed in 25/41 (61%). 25/41 (61%) presented with cranial nerve palsies also found as one of the most common deficits in other studies [96]. Abnormal gait and coordination was seen in 24/41 (59%), whereas others found abnormal gait and coordination to be by far the most common sign [97].

Children younger than 4 years were analyzed separately because they are known to present themselves differently than older children, not yet being able to clearly describe their symptoms. The most common initial sign was found to be abnormal gait and coordination (7/12 [58%]) and head tilt (7/12 [58%]).

The parents' delay with a median of 19 days was found to be longer than the doctor's delay with a median of 7 days. The median pre-diagnostic symptomatic interval was 48 days, and this duration of symptoms/signs was also found in other studies [8, 96]. The highly variable duration of symptoms prior to diagnosis seen in our patients is also described in the literature [96].

We found a tendency to better overall survival rate depending on anatomical tumour location within the brainstem. On the one hand, tumour extension into the whole brainstem showed a tendency to worse overall survival. In addition, median overall survival was 7.9 months in patients with tumour localization in the pons only compared to others with a median survival of 36.3 months, but due to the small patient sample this was not significant. In patients with brainstem tumours not involving the pons a direction towards better survival was observed. Brainstem tumours without pontine involvement have recently been described as being almost invariably low-grade tumours with excellent outcome, even with careful initial observation [5].

Median progression-free survival of 4.8 months and median overall survival of 9.6 months was noticed in children with diffuse intrinsic brainstem gliomas. Treatment of these patients with surgery, radiotherapy, chemotherapy or a combination thereof, resulted in a significantly better median progression-free ( $p=0.042$ ) and median overall survival ( $p=0.001$ ) than observational treatment.

Our study is based on a retrospective analysis of patients' records, which has clear limitations. Moreover, the number of patients is rather limited. On the other hand, the study has carefully taken into account data from children with brainstem tumours during a 30-year period at a single institution. Nevertheless, data may be confounded due to changes in diagnostic and treatment techniques that have taken place during the last three decades.

In summary, we demonstrated that survival for children with brainstem tumours remains poor to dismal. Children with brainstem tumours present with various often unspecific signs and symptoms. The combination of multiple neurological signs and symptoms should alert the clinician and lead to CNS imaging without delay.

New approaches to paediatric brainstem tumours are clearly needed.

## 5. References

1. Linabery, A.M. and J.A. Ross, *Trends in childhood cancer incidence in the U.S. (1992-2004)*. *Cancer*, 2008. **112**(2): p. 416-32.
2. Kaatsch, P., et al., *Time trends of cancer incidence in European children (1978-1997): report from the Automated Childhood Cancer Information System project*. *Eur J Cancer*, 2006. **42**(13): p. 1961-71.
3. Michel, G., et al., *Incidence of childhood cancer in Switzerland: the Swiss Childhood Cancer Registry*. *Pediatr Blood Cancer*, 2008. **50**(1): p. 46-51.
4. Steliarova-Foucher, E., et al., *Geographical patterns and time trends of cancer incidence and survival among children and adolescents in Europe since the 1970s (the ACCISproject): an epidemiological study*. *Lancet*, 2004. **364**(9451): p. 2097-105.
5. Fried, I., et al., *Favorable outcome with conservative treatment for children with low grade brainstem tumors*. *Pediatr Blood Cancer*, 2012. **58**(4): p. 556-60.
6. Freeman, C.R. and J.P. Farmer, *Pediatric brain stem gliomas: a review*. *Int J Radiat Oncol Biol Phys*, 1998. **40**(2): p. 265-71.
7. Ueoka, D.I., et al., *Brainstem gliomas--retrospective analysis of 86 patients*. *Journal of the Neurological Sciences*, 2009. **281**(1-2): p. 20-3.
8. Schumacher, M., et al., *Magnetic resonance imaging compared with biopsy in the diagnosis of brainstem diseases of childhood: a multicenter review*. *J Neurosurg*, 2007. **106**(2 Suppl): p. 111-9.
9. Reulecke, B.C., et al., *Brain tumors in children: initial symptoms and their influence on the time span between symptom onset and diagnosis*. *J Child Neurol*, 2008. **23**(2): p. 178-83.
10. Chitnavis, B., et al., *Intrinsic brainstem tumours in childhood: a report of 35 children followed for a minimum of 5 years*. *Br J Neurosurg*, 1997. **11**(3): p. 206-9.
11. Jenkin, R.D., et al., *Brain-stem tumors in childhood: a prospective randomized trial of irradiation with and without adjuvant CCNU, VCR, and prednisone. A report of the Childrens Cancer Study Group*. *J Neurosurg*, 1987. **66**(2): p. 227-33.
12. Berger, M.S., et al., *Pediatric brain stem tumors: radiographic, pathological, and clinical correlations*. *Neurosurgery*, 1983. **12**(3): p. 298-302.
13. Littman, P., et al., *Pediatric brain stem gliomas*. *Cancer*, 1980. **45**(11): p. 2787-92.
14. Rubin, G., et al., *Pediatric brain stem gliomas: an update*. *Childs Nerv Syst*, 1998. **14**(4-5): p. 167-73.
15. Packer, R.J., *Brain tumors in children*. *Arch Neurol*, 1999. **56**(4): p. 421-5.
16. Guillamo, J.S., et al., *Brainstem gliomas in adults: prognostic factors and classification*. *Brain*, 2001. **124**(Pt 12): p. 2528-39.
17. Guillamo, J.S., F. Doz, and J.Y. Delattre, *Brain stem gliomas*. *Curr Opin Neurol*, 2001. **14**(6): p. 711-5.
18. Epstein, F. and S. Constantini, *Practical decisions in the treatment of pediatric brain stem tumors*. *Pediatr Neurosurg*, 1996. **24**(1): p. 24-34.
19. Sun, B., C.C. Wang, and J. Wang, *MRI characteristics of midbrain tumours*. *Neuroradiology*, 1999. **41**(3): p. 158-62.
20. Young Poussaint, T., et al., *Cervicomedullary astrocytomas of childhood: clinical and imaging follow-up*. *Pediatr Radiol*, 1999. **29**(9): p. 662-8.
21. Boydston, W.R., et al., *Gliomas of the tectum and periaqueductal region of the mesencephalon*. *Pediatr Neurosurg*, 1991. **17**(5): p. 234-8.
22. Epstein, F. and J. Wisoff, *Intra-axial tumors of the cervicomedullary junction*. *J Neurosurg*, 1987. **67**(4): p. 483-7.
23. Donaldson, S.S., F. Laningham, and P.G. Fisher, *Advances toward an understanding of brainstem gliomas*. *J Clin Oncol*, 2006. **24**(8): p. 1266-72.
24. Fischbein, N.J., et al., *Radiologic classification of brain stem tumors: correlation of magnetic resonance imaging appearance with clinical outcome*. *Pediatr Neurosurg*, 1996. **24**(1): p. 9-23.

25. Walker, D.A., J.A. Punt, and M. Sokal, *Clinical management of brain stem glioma*. Arch Dis Child, 1999. **80**(6): p. 558-64.
26. Fisher, P.G., et al., *A clinicopathologic reappraisal of brain stem tumor classification. Identification of pilocystic astrocytoma and fibrillary astrocytoma as distinct entities*. Cancer, 2000. **89**(7): p. 1569-76.
27. Frazier, J.L., et al., *Treatment of diffuse intrinsic brainstem gliomas: failed approaches and future strategies*. Journal of Neurosurgery. Pediatrics., 2009. **3**(4): p. 259-69.
28. Hargrave, D., U. Bartels, and E. Bouffet, *Diffuse brainstem glioma in children: critical review of clinical trials*. Lancet Oncology, 2006. **7**(3): p. 241-8.
29. Albright, A.L., et al., *Magnetic resonance scans should replace biopsies for the diagnosis of diffuse brain stem gliomas: a report from the Children's Cancer Group*. Neurosurgery, 1993. **33**(6): p. 1026-9; discussion 1029-30.
30. Albright, A.L., *Diffuse brainstem tumors: when is a biopsy necessary?* Pediatr Neurosurg, 1996. **24**(5): p. 252-5.
31. Pincus, D.W., et al., *Brainstem stereotactic biopsy sampling in children*. J Neurosurg, 2006. **104**(2 Suppl): p. 108-14.
32. Roujeau, T., et al., *Stereotactic biopsy of diffuse pontine lesions in children*. J Neurosurg, 2007. **107**(1 Suppl): p. 1-4.
33. Negretti, L., et al., *Hypofractionated radiotherapy in the treatment of diffuse intrinsic pontine glioma in children: a single institution's experience*. J Neurooncol, 2011. **104**(3): p. 773-7.
34. Janssens, G.O., et al., *The role of hypofractionation radiotherapy for diffuse intrinsic brainstem glioma in children: a pilot study*. Int J Radiat Oncol Biol Phys, 2009. **73**(3): p. 722-6.
35. Mandell, L.R., et al., *There is no role for hyperfractionated radiotherapy in the management of children with newly diagnosed diffuse intrinsic brainstem tumors: results of a Pediatric Oncology Group phase III trial comparing conventional vs. hyperfractionated radiotherapy*. Int J Radiat Oncol Biol Phys, 1999. **43**(5): p. 959-64.
36. Fisher, P.G. and S.S. Donaldson, *Hyperfractionated radiotherapy in the management of diffuse intrinsic brainstem tumors: when is enough enough?* Int J Radiat Oncol Biol Phys, 1999. **43**(5): p. 947-9.
37. Freeman, C.R., et al., *A detrimental effect of a combined chemotherapy-radiotherapy approach in children with diffuse intrinsic brain stem gliomas?* Int J Radiat Oncol Biol Phys, 2000. **47**(3): p. 561-4.
38. Marcus, K.J., et al., *A phase I trial of etanidazole and hyperfractionated radiotherapy in children with diffuse brainstem glioma*. Int J Radiat Oncol Biol Phys, 2003. **55**(5): p. 1182-5.
39. Walter, A.W., et al., *Carboplatin and etoposide with hyperfractionated radiotherapy in children with newly diagnosed diffuse pontine gliomas: a phase I/II study*. Med Pediatr Oncol, 1998. **30**(1): p. 28-33.
40. Chuba, P.J., et al., *Permanent I-125 brain stem implants in children*. Childs Nerv Syst, 1998. **14**(10): p. 570-7.
41. Fuchs, I., et al., *Gamma Knife radiosurgery of brainstem gliomas*. Acta Neurochir Suppl, 2002. **84**: p. 85-90.
42. Korones, D.N., et al., *Treatment of children with diffuse intrinsic brain stem glioma with radiotherapy, vincristine and oral VP-16: a Children's Oncology Group phase II study*. Pediatr Blood Cancer, 2008. **50**(2): p. 227-30.
43. Haas-Kogan, D.A., et al., *Phase II trial of tipifarnib and radiation in children with newly diagnosed diffuse intrinsic pontine gliomas*. Neuro Oncol, 2011. **13**(3): p. 298-306.
44. Jalali, R., et al., *Prospective evaluation of radiotherapy with concurrent and adjuvant temozolomide in children with newly diagnosed diffuse intrinsic pontine glioma*. Int J Radiat Oncol Biol Phys, 2010. **77**(1): p. 113-8.
45. Freeman, C.R. and G. Perilongo, *Chemotherapy for brain stem gliomas*. Childs Nerv Syst, 1999. **15**(10): p. 545-53.
46. Massimino, M., et al., *Diffuse pontine gliomas in children: changing strategies, changing results? A mono-institutional 20-year experience*. J Neurooncol, 2008. **87**(3): p. 355-61.



47. Sirachainan, N., et al., *Concurrent radiotherapy with temozolomide followed by adjuvant temozolomide and cis-retinoic acid in children with diffuse intrinsic pontine glioma*. *Neuro Oncol*, 2008. **10**(4): p. 577-82.
48. Jennings, M.T., et al., *Preradiation chemotherapy in primary high-risk brainstem tumors: phase II study CCG-9941 of the Children's Cancer Group*. *J Clin Oncol*, 2002. **20**(16): p. 3431-7.
49. Broniscer, A., et al., *Role of temozolomide after radiotherapy for newly diagnosed diffuse brainstem glioma in children: results of a multiinstitutional study (SJHG-98)*. *Cancer*, 2005. **103**(1): p. 133-9.
50. Jallo, G.I., A. Biser-Rohrbaugh, and D. Freed, *Brainstem gliomas*. *Childs Nervous System*, 2004. **20**(3): p. 143-53.
51. Barkovich, A.J., et al., *Brain stem gliomas: a classification system based on magnetic resonance imaging*. *Pediatr Neurosurg*, 1990. **16**(2): p. 73-83.
52. Stark, A.M., et al., *Management of tectal glioma in childhood*. *Pediatric Neurology*, 2005. **33**(1): p. 33-8.
53. Epstein, F.J. and J.P. Farmer, *Brain-stem glioma growth patterns*. *J Neurosurg*, 1993. **78**(3): p. 408-12.
54. Pierre-Kahn, A., et al., *Surgical management of brain-stem tumors in children: results and statistical analysis of 75 cases*. *J Neurosurg*, 1993. **79**(6): p. 845-52.
55. Albright, A.L., et al., *Correlation of neurosurgical subspecialization with outcomes in children with malignant brain tumors*. *Neurosurgery*, 2000. **47**(4): p. 879-85; discussion 885-7.
56. Pollack, I.F., et al., *The long-term outcome after surgical treatment of dorsally exophytic brain-stem gliomas*. *J Neurosurg*, 1993. **78**(6): p. 859-63.
57. Khatib, Z.A., et al., *Predominance of pilocytic histology in dorsally exophytic brain stem tumors*. *Pediatr Neurosurg*, 1994. **20**(1): p. 2-10.
58. Weiner, H.L., et al., *Intra-axial tumors of the cervicomedullary junction: surgical results and long-term outcome*. *Pediatr Neurosurg*, 1997. **27**(1): p. 12-8.
59. Di Maio, S., et al., *Clinical, radiologic and pathologic features and outcome following surgery for cervicomedullary gliomas in children*. *Childs Nerv Syst*, 2009. **25**(11): p. 1401-10.
60. Perez-Gomez, J.L., et al., *Stereotactic biopsy for brainstem tumors in pediatric patients*. *Childs Nerv Syst*. **26**(1): p. 29-34.
61. Bowers, D.C., et al., *Second surgery for recurrent pilocytic astrocytoma in children*. *Pediatr Neurosurg*, 2001. **34**(5): p. 229-34.
62. Krieger, M.D., et al., *Recurrence patterns and anaplastic change in a long-term study of pilocytic astrocytomas*. *Pediatr Neurosurg*, 1997. **27**(1): p. 1-11.
63. Pollack, I.F., D. Pang, and A.L. Albright, *The long-term outcome in children with late-onset aqueductal stenosis resulting from benign intrinsic tectal tumors*. *J Neurosurg*, 1994. **80**(4): p. 681-8.
64. Li, K.W., et al., *Endoscopic third ventriculostomy for hydrocephalus associated with tectal gliomas*. *Neurosurg Focus*, 2005. **18**(6A): p. E2.
65. Wellons, J.C., 3rd, et al., *Long-term control of hydrocephalus via endoscopic third ventriculostomy in children with tectal plate gliomas*. *Neurosurgery*, 2002. **51**(1): p. 63-7; discussion 67-8.
66. Schulz-Ertner, D., et al., *Fractionated stereotactic conformal radiation therapy of brain stem gliomas: outcome and prognostic factors*. *Radiother Oncol*, 2000. **57**(2): p. 215-23.
67. Shrieve, D.C., et al., *Hyperfractionated radiation therapy for gliomas of the brainstem in children and in adults*. *Int J Radiat Oncol Biol Phys*, 1992. **24**(4): p. 599-610.
68. Ronghe, M., et al., *Vincristine and carboplatin chemotherapy for unresectable and/or recurrent low-grade astrocytoma of the brainstem*. *Pediatr Blood Cancer*, 2010. **55**(3): p. 471-7.
69. Packer, R.J., et al., *Carboplatin and vincristine for recurrent and newly diagnosed low-grade gliomas of childhood*. *J Clin Oncol*, 1993. **11**(5): p. 850-6.
70. Riccardi, V.M., *Neurofibromatosis: past, present, and future*. *N Engl J Med*, 1991. **324**(18): p. 1283-5.

71. Lammert, M., et al., *Prevalence of neurofibromatosis 1 in German children at elementary school enrollment*. Arch Dermatol, 2005. **141**(1): p. 71-4.
72. Friedman, J.M., *Epidemiology of neurofibromatosis type 1*. Am J Med Genet, 1999. **89**(1): p. 1-6.
73. McGaughan, J.M., et al., *A clinical study of type 1 neurofibromatosis in north west England*. J Med Genet, 1999. **36**(3): p. 197-203.
74. Friedman, J.M., *Neurofibromatosis 1: clinical manifestations and diagnostic criteria*. J Child Neurol, 2002. **17**(8): p. 548-54; discussion 571-2, 646-51.
75. Friedman, J.M. and P.H. Birch, *Type 1 neurofibromatosis: a descriptive analysis of the disorder in 1,728 patients*. Am J Med Genet, 1997. **70**(2): p. 138-43.
76. Rosser, T. and R.J. Packer, *Intracranial neoplasms in children with neurofibromatosis 1*. J Child Neurol, 2002. **17**(8): p. 630-7; discussion 646-51.
77. Rosenfeld, A., et al., *Neurofibromatosis type 1 and high-grade tumors of the central nervous system*. Childs Nerv Syst, 2010. **26**(5): p. 663-7.
78. Guillamo, J.S., et al., *Prognostic factors of CNS tumours in Neurofibromatosis 1 (NF1): a retrospective study of 104 patients*. Brain, 2003. **126**(Pt 1): p. 152-60.
79. Pollack, I.F., B. Shultz, and J.J. Mulvihill, *The management of brainstem gliomas in patients with neurofibromatosis 1*. Neurology, 1996. **46**(6): p. 1652-60.
80. Listernick, R., J. Charrow, and D.H. Gutmann, *Intracranial gliomas in neurofibromatosis type 1*. Am J Med Genet, 1999. **89**(1): p. 38-44.
81. Ullrich, N.J., et al., *Brainstem lesions in neurofibromatosis type 1*. Neurosurgery, 2007. **61**(4): p. 762-6; discussion 766-7.
82. Molloy, P.T., et al., *Brainstem tumors in patients with neurofibromatosis type 1: a distinct clinical entity*. Neurology, 1995. **45**(10): p. 1897-902.
83. Bilaniuk, L.T., et al., *Neurofibromatosis type 1: brain stem tumours*. Neuroradiology, 1997. **39**(9): p. 642-53.
84. Milstein, J.M., et al., *Favorable prognosis for brainstem gliomas in neurofibromatosis*. J Neurooncol, 1989. **7**(4): p. 367-71.
85. Broniscer, A., et al., *Brain stem involvement in children with neurofibromatosis type 1: role of magnetic resonance imaging and spectroscopy in the distinction from diffuse pontine glioma*. Neurosurgery, 1997. **40**(2): p. 331-7; discussion 337-8.
86. Dobrovoljac, M., et al., *Delay in the diagnosis of paediatric brain tumours*. Eur J Pediatr, 2002. **161**(12): p. 663-7.
87. Kukal, K., et al., *Does diagnostic delay result in decreased survival in paediatric brain tumours?* Eur J Pediatr, 2009. **168**(3): p. 303-10.
88. Edgeworth, J., et al., *Why are brain tumours still being missed?* Arch Dis Child, 1996. **74**(2): p. 148-51.
89. Flores, L.E., et al., *Delay in the diagnosis of pediatric brain tumors*. Am J Dis Child, 1986. **140**(7): p. 684-6.
90. Mehta, V., et al., *Latency between symptom onset and diagnosis of pediatric brain tumors: an Eastern Canadian geographic study*. Neurosurgery, 2002. **51**(2): p. 365-72.
91. Thulesius, H., J. Pola, and A. Hakansson, *Diagnostic delay in pediatric malignancies--a population-based study*. Acta Oncol, 2000. **39**(7): p. 873-6.
92. Robertson, P.L., et al., *Cervicomedullary tumors in children: a distinct subset of brainstem gliomas*. Neurology, 1994. **44**(10): p. 1798-803.
93. Broniscer, A., et al., *Intratumoral hemorrhage among children with newly diagnosed, diffuse brainstem glioma*. Cancer, 2006. **106**(6): p. 1364-71.
94. Shah, N.C., et al., *Diffuse intrinsic brainstem tumors in neonates. Report of two cases*. J Neurosurg Pediatr, 2008. **1**(5): p. 382-5.
95. Schomerus, L., et al., *Spontaneous remission of a diffuse brainstem lesion in a neonate*. Pediatr Radiol, 2007. **37**(4): p. 399-402.
96. Liu, Y.M., et al., *Prognostic factors and therapeutic options of radiotherapy in pediatric brain stem gliomas*. Jpn J Clin Oncol, 1998. **28**(8): p. 474-9.
97. Wilne, S., et al., *Presentation of childhood CNS tumours: a systematic review and meta-analysis*. Lancet Oncol, 2007. **8**(8): p. 685-95.

## 6. List of figures

FIGURE 1. PROGRESSION-FREE SURVIVAL WITH 95% CONFIDENCE INTERVALS FOR 42 CHILDREN WITH BRAINSTEM TUMOURS.....	14
FIGURE 2. OVERALL SURVIVAL WITH 95% CONFIDENCE INTERVALS FOR 42 CHILDREN WITH BRAINSTEM TUMOURS. ....	14
FIGURE 3. PROGRESSION-FREE SURVIVAL PROBABILITY OF CHILDREN WITH DIFFUSE INTRINSIC BRAINSTEM GLIOMAS COMPARED TO CHILDREN WITH FOCAL BRAINSTEM TUMOURS. ....	15
FIGURE 4. OVERALL SURVIVAL OF CHILDREN WITH DIFFUSE INTRINSIC BRAINSTEM GLIOMAS COMPARED TO CHILDREN WITH FOCAL BRAINSTEM TUMOURS.....	16
FIGURE 5. PROGRESSION-FREE SURVIVAL OF CHILDREN WITH DIFFUSE INTRINSIC BRAINSTEM GLIOMAS RECEIVING THERAPY COMPARED TO CHILDREN WITH OBSERVATIONAL TREATMENT.....	17
FIGURE 6. OVERALL SURVIVAL OF CHILDREN WITH DIFFUSE INTRINSIC BRAINSTEM GLIOMAS RECEIVING THERAPY COMPARED TO CHILDREN WITH OBSERVATIONAL TREATMENT. ....	17

## 7. List of tables

TABLE 1 DEMOGRAPHIC AND BRAINSTEM TUMOUR CHARACTERISTICS OF ALL 42 CHILDREN.....	9
TABLE 2 PATIENT AND TUMOUR CHARACTERISTICS OF 42 CHILDREN WITH BRAINSTEM TUMOURS.....	10
TABLE 3 FREQUENCY OF SIGNS AND SYMPTOMS AT DIAGNOSIS IN CHILDREN WITH BRAINSTEM TUMOURS DEPENDING ON AGE. ....	12