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ORIGINAL ARTICLE

En bloc resection in patients younger than 16 years affected by primary spine tumors: indications, results and complications in a series of 22 patients

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Abstract

Purpose Review a series of 22 patients below the age of 16 affected by primary bone tumors of the spine who underwent en bloc resection, and describe the clinical presentation, tumor characteristics, results and complications associated with the surgical treatment, underlining the specific issues related to a younger age.

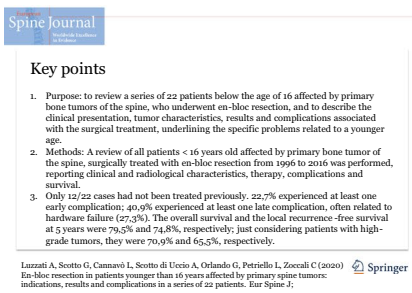
Methods We performed a review of all patients < 16 years old affected by primary bone tumors of the spine, surgically treated with en bloc resection from 1996 to 2016. Clinical and radiological characteristics, therapy, complications and survival are reported.

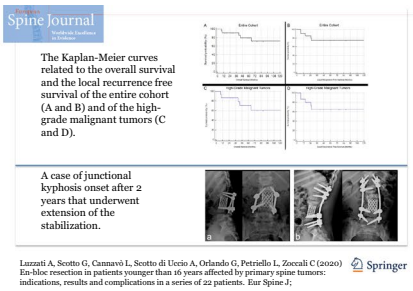
Results Only 12/22 cases had not been previously treated. 22.7% experienced at least one early complication; 18.2% and 4.1% experienced at least 2 and ≥ 3 early complications, respectively; 40.9% experienced at least one late complication, often related to hardware failure (27.3%); 18.2% and 4.5% at least 2 and ≥ 3 late complications. No early nor late complications were experienced in 12 out of 22 patients (54.54%). The overall survival and the local recurrence-free survival at 5 years were, respectively, 79.5% and 74.8%; considering only the patients with high-grade tumors, they were 70.9% and 65.5%, respectively. At 77.3 months of median follow-up, 17 patients are still alive, 16 of whom without any evidence of disease and 1 with evidence of local and systemic disease; four patients died with evidence of local disease and one with distant metastases but no local recurrence.

Conclusions Young people with primary malignant or locally aggressive bone tumors of the spine should be treated in specialized centers, and wide surgery should be performed. The most frequent problems are related to reconstruction in a growing spine and subsequent hardware failure that make later surgeries necessary.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.





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Extended author information available on the last page of the article

Keywords En bloc spondylectomy · Pediatric spinal bone tumors · Pediatric spine · Growing spine · Hardware failure

Introduction

Primary spinal bone tumors are rare, especially if compared to metastatic diseases. Nevertheless, identifying them is of uttermost importance because the treatment can vary based on the specific diagnosis, the tumor's aggressiveness, its biology, the risk of fracture and the possibility to successfully treat a possible local relapse.

Indeed, while the surgical treatment of benign lesions in the limbs is usually intralesional curettage and bone filling, in the spine en bloc resection (EBR) for aggressive benign histologies has to be considered, because treating a local recurrence is complex and often impossible [1, 2]. When the tumor involves great part of the vertebral body, performing a wide resection means extirpating the entire vertebra, thus performing an en bloc spondylectomy (EBS), in which a limited marginal margin around the dura is acceptable [3]. This technique reduces the local recurrence rate and improves long-term survival [4]. Considering the difficult technique and the high rate of intraoperative and postoperative complications, it is a highly demanding surgery [5].

Primary osseous spinal column tumors are rare in children and young adults; together with spinal cord tumors, they account for only 1% of all tumors [6]. Nevertheless, they are challenging and of difficult approach.

They present specific clinical characteristics which have to be taken into account: In adults, back pain is often caused by degenerative spine conditions, while in children, back pain that persists for more than two weeks can be more frequently due to a tumor [7]. This pain can be associated with general symptoms such as fever and weight loss; neurologic symptoms can be caused by spinal cord compression [8–10]. Maintaining a high index of suspicion when such signs are observed is essential for a correct identification of those patients to address to further investigation.

Biopsy is performed through a CT-guided transpedicular approach. Based on histology, the patient can be addressed to follow-up, medical or surgical therapies.

The most frequent histologies that arise in the pediatric spine are benign and include osteoid osteoma, osteoblastoma and aneurysmal bone cyst, usually located in the posterior elements of the vertebra; the most frequent malignant histologies are Ewing's sarcoma and osteosarcoma, which mostly arise in the vertebral body [11].

EBR is suggested in case of malignancy or in case of benign but locally aggressive tumors.

The aim of this study is to review the data of 22 patients younger than 16 years old affected by primary spinal bone tumors, who underwent EBR, and to describe clinical presentation, tumor characteristics, results and complications associated with the surgical treatment, underlining the specific problems in younger patients.

Patients and methods

This study was performed on pediatric patients affected by primary bone tumors of the spine, who underwent EBR in an orthopedic research hospital between January 1996 and December 2016. Patients > 16 years old and those affected by secondary tumors were excluded. Surgeries were performed by the same senior surgeon in all cases. All patients' parents provided their consent to the use of data for research purposes and publications.

The diagnoses were based on histologies, obtained through CT-guided trocar biopsies or open minimally invasive biopsies, or on previous specimens of already operated patients who arrived for observation after a first surgery in non-specialized hospitals. All histologies were reviewed by an expert pathologist trained in muscular–skeletal tumors.

A total body CT scan was carried out to exclude distant metastases, along with an MRI of the spine to better identify the intracanal component.

The WBB (Weinstein, Boriani, Biagini) surgical staging system was used to describe tumor extension and to plan surgery [12]. The extension of the tumors was evaluated according the Enneking staging system for malignant musculoskeletal tumors, based on surgical grade, local extent and presence or absence of metastases [13].

Outcomes

Complications were defined "early" or "late" if they, respectively, occurred before or after 30 days from surgery [14]. Blood loss was defined massive when it exceeded the circulating blood volume in 24 h or 50% of circulating blood volume in 3 h. Hypotension was diagnosed if a systemic pressure lower than 85 mmHg was present for more than 15 min. The ASIA (America Spine Injury Association) motor scale was used to evaluate the neurologic status; neurologic deterioration was present for a score higher than grade 1 of the ASIA motor scale [15]. Airway problems were identified as pneumonia and pulmonary embolism. Urological problem included urinary retention and urinary incontinence. Postoperative pain was evaluated with the VAS scale.

Statistical analysis

We used a descriptive statistic to analyze the data. The recurrence rates were evaluated in patients who had already

undergone inadequate intralesional surgery and in patients not treated before. The results were compared by the chi-square test with a p value < 0.05 being statistically significant, to verify if a previous erroneous approach could influence local relapse. All analyses were performed using Microsoft Excel.

Overall survival and local recurrence-free survival (LRFS) were reported using the Kaplan–Meier curve.

Results

Epidemiology and clinical presentation

We enrolled and included 22 patients in the study, 10 females and 12 males, with an average age of 11 years (range 4–16 years) (Table 1). Summary epidemiological data are reported in Table 2. In 8 cases, the lesion was located in the cervical spine, in 1 case in the cervical–thoracic junction, in 6 cases in the thoracic spine, in 6 cases in the lumbar spine and in one case at the lumbar–sacral junction.

According to the Enneking staging, the disease was intracompartmental in 6 cases (one stage IA and five stage IIA) and extra-compartmental in 16 cases (nine stage IIB, two IB, two S2 active, two S3 aggressive, one stage III with metastases). The most significant symptom was back pain; it was present in 18 cases, whereof 7 cases associated with a fracture; myelopathy was present at diagnosis in 5 cases; no patients with cauda equine syndrome were reported. In only one case, back pain and myelopathy were associated with a vertebral fracture.

According to the WBB system, 11 of the radiating zones of vertebrae were involved in 5 out of 22 patients. Seven WBB sectors were involved in 4 cases and 6 WBB sectors in other 4 patients.

In 16 patients, the tumor had eroded the peripheral cortex and had expanded into the soft tissues ("A" WBB tissue layers), and in 11 of these 16 cases the disease expanded into the canal ("D" WBB tissue layers). In two out of 16 patients, there was an intradural involvement ("E" WBB tissue layers), so the infiltrated dura was removed en bloc with the specimen and reconstruction was performed with a patch.

Diagnosis

Ten cases came to our observation already treated with improper intralesional surgery without a specific diagnosis, which was obtained only postoperatively. In the other 12 cases, the histologic diagnosis was performed with open biopsy (6 cases), CT-guided trocar biopsy (4 cases) or intraoperative biopsy (2 cases). The specific histologies are reported in Table 2.

Treatment

An angiography was always performed before surgery to study the spinal cord blood supply; a selective embolization of the feeding artery and related segmental vessels of the mass was performed in 5 cases to decrease the risk of bleeding and related contamination in case of violation of the tumor and during the rotation of the vertebra around the spinal cord.

Chemotherapy

Fourteen patients underwent neoadjuvant chemotherapy, whereof seven performed adjuvant chemotherapies as well; no chemotherapy was performed in the remaining cases.

Radiotherapy

Four out of 22 patients underwent conventional preoperative radiation therapy: a bone leiomyosarcoma and a high-grade osteosarcoma, already treated at first observation, a Ewing's sarcoma and an osteosarcoma; the last case underwent preoperative RT because of a high risk of intraoperative contamination for tumor size and site (C1–C2–C3).

Surgeries

There were 13 EBSs, 7 hSs and 2 EBR of the posterior arc; 8 one-level resections, 1 two-level resection, 10 three-level resections, 1 four-level resection and 2 five-level resections with an average number of involved levels of 2.5 (min 1, max 5, median 3); the surgical approach was posterior in 12 cases, 4 of which were followed by an anterior approach and 1 by an anterolateral approach; anterior/posterior in six cases; posterior/anterior/posterior in three cases; and lateral/posterior in one case (Table 2). The median operation time was approximately 8 h (average 493 min; median 500; range 150–840 min).

Posterior stabilization with rods and screws was performed in all cases (Fig. 1); these were linked to an allograft in 5 cases and to a cage in 9 cases (4 made of titanium and 5 of carbon); in one case, a vascularized scapular autograft was used to restore the anterior column, and in seven cases reconstruction was not strictly necessary and performed just with an autograft; in five cases, a supplementary anterior fixation was performed.

The median intraoperative blood loss was 1895 ml (range 150–6500 ml) (Table 2). Blood transfusions were needed in 21 out of 22 cases, one of which required transfusions of units of PRBC. No intraoperative deaths occurred.

Table 1 Clinical characteristic

Pt.	Sex	Age (years/months)	Histology	Levels involved	Previous intralesional wrong surgery	Enneking classification	Neoadjuvant Therapies	Surgery	Margin	Fixation	Adjuvant therapies	Early complications	Late complications	Local recurrence	Current status/follow-up
B.A.	M	15/10	Hi-grade osteosarcoma	T2–T4	No	II b	CT	EBS ribs	i	P + tc and Au	CT			Yes	C/44
B.A.	F	10/7	Osteoblastoma	T4	No	II b	No	EB posterior arch	i	P + Al and Au	No			No	A/67
B.A.	M	14/10	Aneurysmal bone cyst	L4	No	II b	No	hS	i	P + Au	No			No	A/179
C.F.E.	F	14/4	Hi-grade osteosarcoma	C1–C3	No	II a	CT + RT	EBS	i	P/A + vascularized Au + Au	No			No	A/26
C.M.	M	12/8	Osteoblastoma	C3–C5	Yes	S3	No	hS	m	P + cc cage and Au	No			No	A/58
C.E.	M	12/7	Neuroblastoma	L2–L3	Yes	III	CT	EBS	m	P/A + cc cage + Au and Al	No			Yes	B/78
C.M.	F	13	Hi-grade osteosarcoma	C2–C5	No	II b	CT	EBS	i	P + tc and Au	No	Dural tear, neurologic deterioration	Dysphagia, pneumonia	Yes	C/9
D.M.U.	M	14/5	Chordoma	T5–T7	No	IIB	No	EBS	w	P + cc cage and Au	No		Construct failure with distal kyphosis	No	A/61
F.C.	F	9/7	Aneurysmal bone cyst	C1	No	S2	No	EB posterior arch	i	P + Au	No			No	A/151
G.L.	M	14/4	Osteoblastoma	C5	No	S2	No	hS	i	P + Au	No			No	A/147
G.G.	M	15/5	Osteoblastoma	C6	No	S3	No	hS	m	P + Au	No			No	A/142
G.M.	M	12/9	Low-grade osteosarcoma	C5–C7	Yes	Ia	No	hS	w	P + Au	No			No	A/14

Table 1 (continued)

Pt.	Sex	Age (years/ months)	Histology	Levels involved	Previous intralesional wrong surgery	Enneking classification	Neoadjuvant Therapies	Surgery	Margin	Fixation	Adjuvant therapies	Early complications	Late complications	Local recurrence	Current status/ follow-up
G.M.	M	14/10	Hi-grade osteosarcoma	L2–L4	No	II b	CT	EBS	m	P + cc cage + Au and Al	CT			No	A/88
G.P.	F	14/2	Hi-grade osteosarcoma	C2–C4	Yes	II b	CT	EBS	i	P + tc and Au	No	Hardware and bone graft breakage, respiratory failure	CSF leak/ meningocele	Yes	C/8
G.L.	M	5/9	Synovial sarcoma	L5–S2	No	II a	CT	EBS	m	P + Al and Au	No	Hypotension, massive blood loss		Yes	D/65
L.M.N.	F	15/6	Leiomyosarcoma of bone	L2–L4	Yes	II b	CT + RT	hS	w	P + Au	CT	Hypotension, massive blood loss	Construct failure with loss of correction	No	A/207
M.L.	M	3/10	Ewing's sarcoma	T5	Yes	II a	CT + RT	EBS	w	P + tc + Au and Al	CT		Construct failure with loss of correction	No	A/48
M.S.	F	4/4	Ewing's sarcoma	L3	Yes	II a	CT	EBS	w	P/A + cc cage (titanium?) + Au and Al	No		Hardware loosening		D/41
R.E	F	7/1	Malignant peripheral nerve sheath tumor	T4–T9	Yes	II b	CT	hS	m	P/A + Al	CT	Nerve root injury	Construct failure with loss of correction, hardware loosening	No	A/77
S.G.	F	6/11	Ewing's sarcoma	T3–T5	No	II a	CT	EBS	w	P/A + tc and Au	CT			No	A/77

Table 1 (continued)

Pt.	Sex	Age (years/ months)	Histology	Levels involved	Previous intralesional wrong surgery	Enneking classification	Neoadjuvant Therapies	Surgery	Margin	Fixation	Adjuvant therapies	Early complications	Late complications	Local recurrence	Current status/ follow-up
S.L.	F	12	Ewing's sarcoma	L1	Yes	II b	CT	EBS	w	P + Al and Au	CT + RT		Hardware breakage and graft non-union, hardware loosening	No	A/87
T.J:	M	11/4	Hi-grade osteosarcoma	C5–T2	Yes	II b	CT + RT	EBS	m	P + Au	No		Dysphagia, dysphonia, neurologic deterioration, postoperative neuropathic pain	No	A/75

EBS, en bloc spondylectomy; EB, en bloc; hS, hemispondylectomy; i, intralesional; m, marginal; w, wide; P, posterior; A, anterior; Au, autograft; Al, allograft; tc, titanium cage; cc, carbon cage; A, alive with no evidence of local or systemic disease; B, alive with evidence of systemic disease; C, died from disease with evidence of local disease at time of death; D, died from disease without evidence of local disease at time of death

Table 2 Epidemiologic, clinical and surgical data

Parameter	Value
Patients (*n*)	22 (12 M and 10 F)
Age, mean (min–max); years	11 (4–16)
Sites	
C	8
CT	1
T	6
L	6
LS	1
Enneking classification	
Extra-compartmental	16
IIB	9
IB	2
S2	2
S3	2
III	1
Intra-compartmental	6
Ia	1
IIA	5
Symptoms	
Pain	18
Vertebral fractures	7
Myelopathy	5
Diagnosis	
Osteosarcoma	7
Ewing's sarcoma	4
Osteoblastoma	4
Aneurismal bone cyst	2
Chordoma	1
Neuroblastoma	1
Synovial sarcoma	1
Leiomyosarcoma of bone	1
Malignant peripheral nerve sheath tumor	1
Surgical approach	
Posterior	7
Anterior–posterior	6
Posterior–anterior	4
Posterior–anterior–posterior	3
Posterior–anterolateral left	1
Lateral/posterior	1
Level of resection	
One-level	8
Two-level	1
Three-level	10
Four-level	1
Five-level	2
Obtained surgical margin	
Marginal	7
Intralesional	8
Wide	7
Intra operative blood loss mean (min–max)	1895.44 ml (150–6500 ml)
Median size tumor	
Size A/P (min–max)	4.93 m (1–12 cm)
Size L/R (min–max)	3.86 cm (1.05–10 cm)
Size C/C (min–max)	3.23 m (0.09–6 cm)
Volume (min–max)	2.91 cm (0.09–8.05 cm)
Local recurrence	5(22.72%)
Follow-up	2
Debulking surgery	1
Marginal surgery	1
Chemotherapy and radiotherapy	1
Metastases	2 (18.18%)
Alive	1
Dead	1
Dead	5 (22.72%)
Died from disease with evidence of local disease at time of death	4 (18.18%)
Died from disease without evidence of local disease at time of death	1 (4.54%)

The median time of hospital stay was approximately 15 days (range 4–53 days).

Margins

The histologies revealed an intralesional margin in 8 cases (whereof 4 were already forecasted during the preoperative planning), a marginal margin in 7 cases (all preoperatively planned wide with a focal marginal margin) and a wide margin in 7 cases (6 preoperatively planned and 1 forecasted as marginal). Only one patient (12.5%) out of 8 with intralesional margins had undergone a previous surgery, versus 4 (57.14%) out of 7 patients in the marginal group and 5 (71.42%) out 7 in the wide margin group. The margin was mostly related to the specific anatomy of the disease. The preoperatively planned margin was confirmed at the definitive histology in 15 out of 22 cases (68.2%).

Complications

The specific complications and their related frequencies are reported in Table 3.

Five out of 22 patients (22.7%) experienced at least one early complication (whereof two hypotension and two massive blood losses); four patients experienced at least two early complications and one at least three early complication. Two out of five patients with early complications underwent surgery to resolve them.

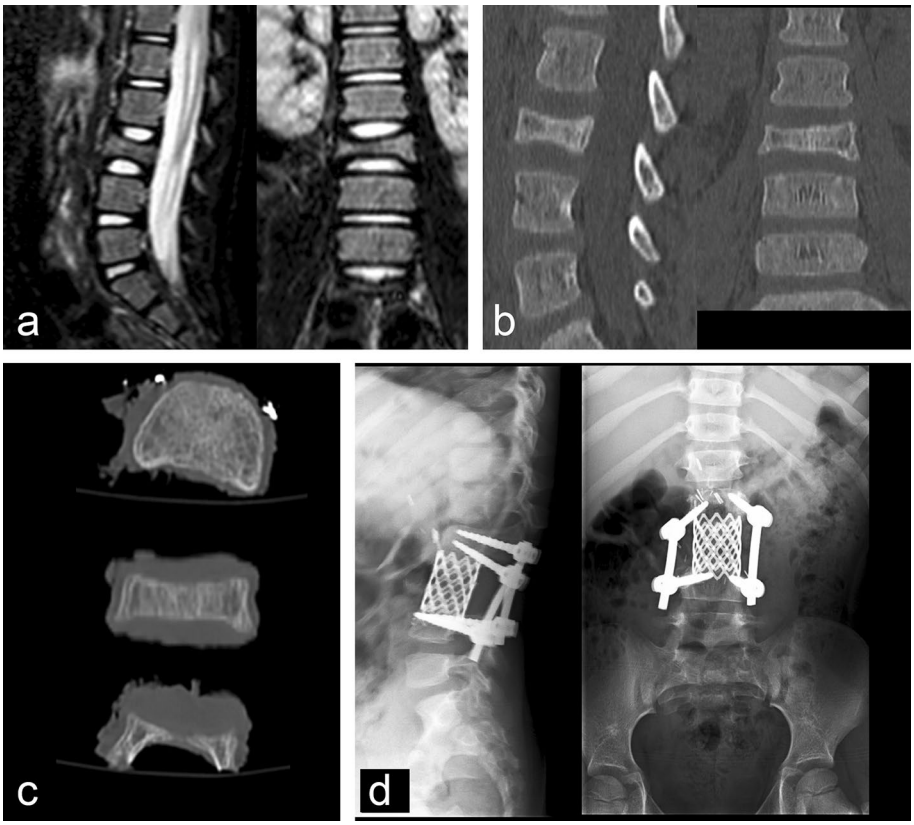

Fig. 1 Female, 3 years old, affected by an L3 Ewing's sarcoma; preoperative MRI (**a**) and CT scan (**b**) showing vertebral fracture; **c** the X-ray of the specimen evidencing the EBS; **d** postoperative X-ray showing a short L2–L4 stabilization and an anterior cage filled with bone autograft to reconstruct the anterior column

Table 3 Early and late complications in the analyzed cohort

Early complications	Late complications
Massive blood loss: 2 cases (9.09%)	Construct failure with loss of correction: 4 cases (18.18%)
Hypotension (systemic < 85 mmHg for 15 min): 2 cases (9.09%)	Dysphagia: 2 cases (9.09%)
Dural tear, neurologic deterioration > 1 motor grade ASIA motor scale, nerve roots injury, respiratory failure and hardware and bone graft breakage: 1 case (4.54%)	Hardware loosening: 2 cases (9.09%)
	Hardware breakage: 2 cases (9.09%)
	Pneumonia; CSF leak/meningocele, neurologic deterioration < 1 motor grade ASIA motor scale; postoperative neuropathic pain: 1 case (4.54%)

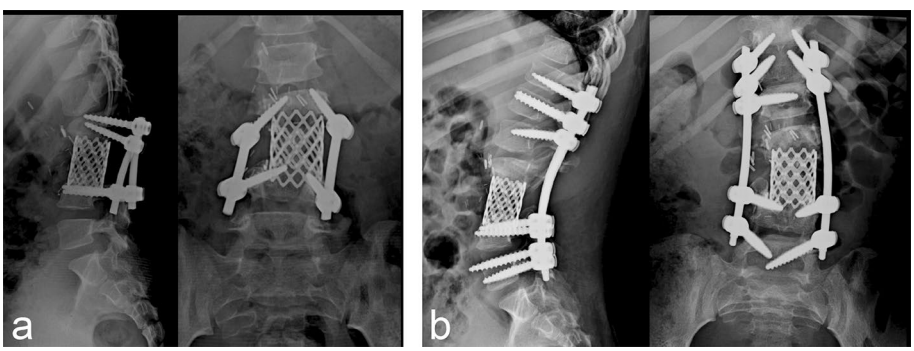

Fig. 2 The same patient of Fig. 1 who had junctional kyphosis 2 years after the index surgery; the X-ray showing the preoperative status (**a**) and the postoperative control with the extension of stabilization from T11 to L5 (**b**)

In nine cases (40.90%), at least one late complication was found; four and one out of 22 patients (18.2% and 4.5%) experienced at least two or at least three late complications, respectively. Two patients underwent surgery for hardware failure (Fig. 2).

Problems related to the stabilization system were quite common (6 out 22 patients).

No early nor late complications were experienced in 12 out of 22 patients (54.54%). These results are shown in Table 1.

Follow-up and survival

The median follow-up was 77.3 months (range 8–207).

We found five local recurrences (19.2%), after 7, 7, 15, 25 and 26 months from index surgery. Of these five local recurrences, three had undergone intralesional surgery (three of the eight intralesional surgeries, 37.5%) and two marginal surgery (two of the seven marginal surgeries, 28.6%).

No statistical differences (p value = 0.7805) in recurrence rate were present between previously and not previously treated patients (two out of 10 and three out of 12 recurrences, respectively). The overall survival (OS) at 5 years and the local recurrence-free survival (LRFS) at 5 years were 79.5% and 74.8%, respectively; the Kaplan–Meier curves related to OS and LRFS are reported in Fig. 3a, b.

The OS at 5 years related to the malignant histologies and related LRFS at 5 years were 70.9% and 65.5%, respectively (Fig. 3c, d).

At the time of this analysis, 17 patients are still alive, 16 of which are without any evidence of disease and one with evidence of local and systemic disease.

Five out of 22 patients died, whereof four with evidence of local disease at the time of death and one died from

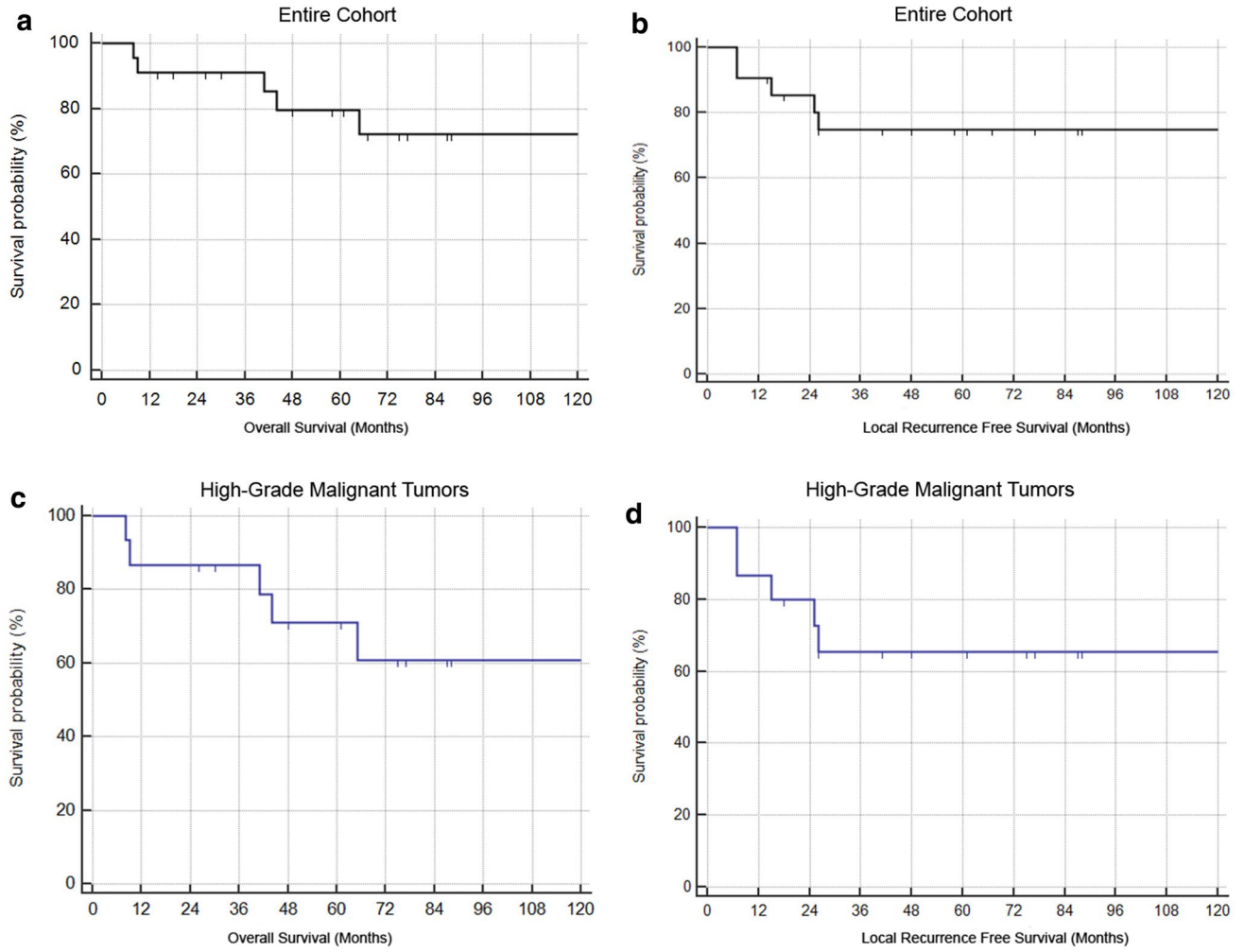

Fig. 3 **a** The Kaplan–Meier curve related to the entire cohort's overall survival; **b** the Kaplan–Meier curve related to the entire cohort's local recurrence-free survival; **c** the Kaplan–Meier curve related to the overall survival of patients with malignant tumors; **d** the Kaplan–Meier curve related to the local recurrence-free survival of patients with malignant tumors

metastases without evidence of local disease at the time of death.

Considering the 15 high-grade tumors, 3 patients, all affected by osteosarcoma, died from systemic disease with local recurrence at 8, 9 and 44 months from surgery, other 2 patients died without local recurrence at 41 and 65 months of follow-up, 9 are alive with no evidence of disease and another 1 with systemic disease without local recurrence.

Considering just the 6 patients affected by high-grade osteosarcoma, 3 are dead for systemic disease as reported above and 3 are alive without evidence of disease.

Discussion

Primary bone tumors of the spine are very rare, accounting for about 1% of spine and spinal cord tumors combined [16]. In the present series, osteosarcoma and Ewing's sarcoma were the most frequent malignant histologies, whereas osteoblastoma was the most frequent benign spinal bone tumor that underwent EBS.

Chordoma and chondrosarcoma are rare since they are more often found in older patients (75% of patients are older than 60) [17].

Pain is very common considering that 18 out of the 22 patients of our series complained of it at the diagnosis; indeed, while spinal pain is commonly experienced in the general population, when it is present in childhood it has to be considered a "red flag" and it is associated with a spine lesion in up to 5% of patients [18]. The onset of symptoms also has to be considered; a sudden pain with vertebral collapse is most likely associated with an aggressive histologic type, while chronic symptoms are usually associated with slow-growing tumors; in seven out of 17 patients, pain was associated with a fracture, whereof five caused by a high-grade malignant tumor and two by an aneurismal bone cyst.

A high level of suspicion has to be maintained, an MRI should be performed in case of doubt, and a biopsy must be done before surgery, moreover, in pediatric patients in which secondary tumors are rare. Unfortunately, 10 out 22 patients had undergone a previous intralesional surgery in non-specialized centers, making the later wide surgery more difficult [19]; nevertheless, no statistically significant differences regarding survival are present in the two groups.

Preoperative histology is fundamental to identify the best approach; indeed, several histologies that are common in children must undergo neoadjuvant chemotherapy, such as osteosarcomas and Ewing's sarcomas. The classical approach is based on neoadjuvant chemotherapy, wide surgery and then adjuvant chemotherapy. While this is absolutely true for osteosarcomas, some authors uphold the importance of radiotherapy as the main local treatment in Ewing's sarcomas; nevertheless, Marco et al. show a higher incidence of tumor recurrence and a lower survival rate in patients treated only with chemotherapy and radiotherapy compared with results reported by authors who performed aggressive surgery [20].

Sometimes, when there is a high risk of infection such as in spine and pelvis surgery, chemotherapy can be totally administered in a neoadjuvant schedule; indeed, an intraoperative infection could excessively postdate adjuvant chemotherapy.

Indications for EBR were given case by case, based on histology, life expectancy and the possibility to perform other therapies. The indication for EBR is mandatory (if technically possible) in primary malignant tumors without metastases; however, it must also be considered in patients with a presumed very long survival. Indeed, EBS was also performed in a patient affected by a L2–L3 neuroblastoma with a solitary lung metastasis. Indication was given based on the pediatric oncologist's request; the patient underwent lung metastasis removal after 3 months. He is still alive with systemic disease at 78 months from index surgery.

In benign histologies, EBR was indicated to decrease the risk of local recurrence, difficult to approach in the spine. In the present series, 3 patients affected by cervical osteoblastoma were included; in these cases, resection was considered technically feasible without high risks for the patient; the fourth case was an aneurismal bone cyst of C1 with a high risk of fracture and which was not treatable with embolization.

Different en bloc resection techniques have been described. Liljenqvist et al. prefer a simultaneous combined posterior/anterior approach [4]. This approach allows full control of both posterior neural structures and anterior visceral structures during resection, but it has been related to additional morbidity. In our study, the posterior approach was used in 11 patients, providing excellent exposure for circumferential spinal cord decompression and also allowing posterior instrumentation to be extended multiple levels above and below the level of the disease. In tumors localized at L2 or below, a combined approach is often necessary to ensure surgical safety.

Obviously, performing an EBR is more complicated in children due to the smaller size of the anatomic structures, so double accesses are preferred, whereas single accesses are more frequently chosen in adults. This alternative provides a better visualization of the anterior vascular bundles and a lower risk of damaging them.

The rate of patients who experienced at least one early complication is consistent (22.7%), such as the risk of having late complications (40.9%).

Our group recently published the results of EBR in patients above 60 years old; the early and late complication rates were, respectively, 64% and 37% [17]. Therefore, early

complications are consistently lower in the younger group, probably due to a lower comorbidity rate.

Blood loss and related hypotension are the most frequent early complications. Considering their lower circulating volume, the loss of blood has a greater impact on children than on adults. This loss can also be more consistent in hypervascularized tumors.

Even if EBR/EBS may not open the tumor, a careful preoperative embolization of the feeding artery of the affected vertebra is recommended because it decreases the risk of bleeding during vertebra removal [21]. Indeed, Tomita et al. showed that the embolization technique dramatically reduces intraoperative bleeding from the tumor-involved vertebra without compromising spinal cord function [21].

Moreover, in a long operation the total blood loss can be highly relevant, so step-by-step hemostasis is mandatory.

Hypotension is an indirect complication correlated with hemorrhage. A correct anesthesia management that aims at maintaining controlled hypotension can be helpful.

Yokogawa et al. focused on incidental durotomy during EBS. In a series of 105 patients, they reported dural tears in 18 cases (17.1%). This complication is more frequent in older patient with a history of radiotherapy and revision surgery [22]. We had one case of dural tear out of 22 patients (4.54%); nevertheless, no surgical mending was necessary.

Our most frequent late complications were related to construct failure (27.3%), whereof two underwent surgery to resolve complications; proximal or distal junctional kyphosis with or without screw loosening could be associated with a short construct; nevertheless, a long stabilization can interfere negatively with spinal growth. Indeed, a short stabilization was initially placed in both cases and a lengthening had to be performed at a later time to resolve junctional kyphosis (Fig. 2).

The high rate of mechanical failure underlines the difficulties associated with a growing spine. The high incidence of hardware complications in our series could be due to several factors, such as the need to fuse a short spine segment in a growing patient, the size of the anatomic structures and the reduced effectiveness of pediatric instrumentations.

From birth to the age of five, the spine increases of an average value of 16 cm; successively, from 5 to 10 years old, the spine grows about 1.5 cm per year and then another 7–8 cm until skeletal maturity [23].

This lengthening has to be considered to decide the levels of arthrodesis. A short instrumentation allows the spine to grow more than a long instrumentation, but the risk of developing junctional kyphosis is higher. Several operations have to be taken into account to revise and lengthen the instrumentation before reaching skeletal maturity.

The reconstructed section can also fail because of fatigue breakdown; therefore, biological bony fusion was required to maintain long-term stability. Rigid immobilization of the graft(s) is mandatory to achieve grafted bone union [24, 25]. On the other side, some stress is needed during the reparative period to enhance biomechanical stimuli. The balance between these two factors is of paramount importance [26].

These patients' high functional request can also play a role in hardware loosening and breakage.

Amendola et al. reported a complication rate of 41.7% in 103 EBS for primary spine bone tumors, finding a correlation with the non-intact group and the complexity of surgery. The mortality rate related to surgical complications was 1.9%.

In our series, there was no case of death related to surgery, whereas tumor-related mortality was 15.5% [27].

In our series, disease-free survival is quite high; this is explained by the mixed population of benign and malignant histologies.

Only considering the population affected by high-grade malignant tumors, the 5-year survival rate is 69.23%, but just 2 out of 5 patients (the sixth has a shorter follow-up) are still alive at 5 years from index surgery.

This value, although based on too few cases, is similar to that reported for osteosarcomas of the limbs; therefore, spine osteosarcoma operated with adequate wide margins can have a survival rate similar to limb osteosarcoma.

Moreover, all cases of osteosarcoma that died had local recurrence, underlining that this event presents an important negative prognostic value.

In our series, there was no case of death related to surgery and the tumor-related mortality was 22.72%.

The treatment of pediatric patients with primary spinal bone tumors is a challenge. These patients must be approached in specialized centers since several professionals are necessary to assess the patient, diagnose the tumor and decide the most appropriate treatment options and planning. The eradication of the tumor is important in preventing relapses; therefore, wide surgery is necessary; considering the difficult technique and high level of expertise necessary to perform an EBS, trained surgical teams and specialists are mandatory to be able to foresee and manage every possible complication. In this younger age-group, complications were linked to the decreased amount of circulating blood and to the fact that the patients had not reached skeletal maturity. In our series, all early and late complications were successfully treated.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest directly relevant to this study.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Luzzati A, Gagliano F, Perrucchini G, Scotto G, Zoccali C (2015) Epithelioid hemangioendothelioma of the spine: results at seven years of average follow- up in a series of 10 cases surgically treated and a review of literature. Eur Spine 24(10):2156–2164. https://doi.org/10.1007/s00586-014-3510-9
2. Charest-Morin R, Fisher CG, Varga PP, Gokaslan ZL, Rhines LD, Reynolds JJ, Dekutoski MB, Quraishi NA, Bilsky MH, Fehlings MG, Chou D, Germscheid NM, Luzzati A, Boriani S, AOSpine Knowledge Forum Tumor (2017) En bloc resection versus intralesional surgery in the treatment of giant cell tumor of the spine. Spine (Phila Pa 1976) 42(18):1383–1390. https://doi.org/10.1097/brs.0000000000002094
3. Mesfin A, El Dafrawy MH, Jain A, Hassanzadeh H, Kebaish KM (2015) Total en bloc spondylectomy for primary and metastatic spine tumors. Orthopedics 38(11):e995–e1000. https://doi.org/10.3928/01477447-20151020-08
4. Liljenqvist U, Lerner T, Halm H, Buerger H, Gosheger G, Winkelmann W (2008) En bloc spondylectomy in malignant tumors of the spine. Eur Spine J 17(4):600–609. https://doi.org/10.1007/s00586-008-0599-8
5. Liu P, Jiang L, Liang Y, Wang H, Zhou H, Li X, Lin H, Zhou X, Dong J (2018) Are older patients with solitary spinal metastases fit for total en-bloc surgery? Clin Neurol Neurosurg 170:20–26. https://doi.org/10.1016/j.clineuro.2018.04.007
6. Ravindra VM, Eli IM, Schmidt MH, Brockmeyer DL (2016) Primary osseous tumors of the pediatric spinal column: review of pathology and surgical decision making. Neurosurg Focus 41(2):E3. https://doi.org/10.3171/2016.5
7. Berrman R, Kliegman RM, Arvin AM (1996) Nelso's textbook of pediatrics, 15th edn. W.B. Saunders Company, Philadelphia
8. Beer SJ, Menezes AH (1997) Primary tumors of the spine in children. Natural history, management, and long-term follow-up. Spine (Phila Pa 1976) 22(6):649–658
9. Fenoy AJ, Greenlee JD, Menezes AH, Donovan KA, Sato Y, Hitchon PW, Chaloupka JC (2006) Primary bone tumors of the spine in children. J Neurosurg 105(4 Suppl):252–260
10. Graham GN, Browne H (2001) Primary bony tumors of the pediatric spine. Yale J Biol Med 74(1):1–8
11. Ozonoff MB (1996) Pediatric orthopedic radiology. Saunders Company, Philadelphia
12. Boriani S, Weinstein JN, Biagini R (1997) Primary bone tumors of the spine. Terminology and surgical staging. Spine (Phila Pa 1976) 22(9):1036–1044
13. Enneking WF (1996) A system of staging musculoskeletal neoplasm. Clin Ortop 204:1383–1390
14. Leaper D, Whitaker I (2010) Postoperative complications, 2nd edn. Oxford University Press Inc., Oxford
15. Graves DE, Frankiewicz RG, Donovan WH (2006) Construct validity and dimensional structure of the ASIA motor scale. J Spinal Cord Med 29(1):39–45
16. Harter D, Weiner H (2014) Spine tumors. In: Albright AL, Pollack I, Adelson P (eds) Principles and practice of pediatric neurosurgery, 3rd edn. Thieme, New York, pp 721–734
17. Zoccali C, Scotto G, Cannavò L, Baldi J, Scaffidi-Argentina U, Luzzati A (2019) En bloc spondylectomy in patients older than 60 years: indications, results and complications in a series of 37 patients. Eur Spine J 28(6):1512–1519
18. Behrman RE et al (1996) Nelson's textbook of pediatrics, 15th edn. W.B. Saunders Company, Philadelphia
19. Luzzati A, Scotto G, Perrucchini G, Baaj AA, Zoccali C (2017) Salvage revision surgery after inappropriate approach for primaryspine tumors: long term follow-up in 56 cases. World Neurosurg 98:329–333
20. Marco RA, Gentry JB, Rhines LD, Lewis VO, Wolinski JP, Jaffe N, Gokaslan ZL (2005) Ewing's sarcoma of the mobile spine. Spine (Phila Pa 1976) 30(7):769–773
21. Tomita K, Kawahara N, Murakami H, Demura S (2006) Total en bloc spondylectomy for spinal tumors: improvement of the technique and its associated basic background. J Orthop Sci 11(1):3–12
22. Yokogawa N, Murakami H, Demura S, Kato S, Yoshioka K, Tsuchiya H (2018) Incidental durotomy during total en bloc spondylectomy. Spine J 18(3):381–386. https://doi.org/10.1016/j.spine.2017.07.169
23. Dimeglio A, Bonnel F, Canavese F (2009) Normal growth of the spine and thorax. In: Akbarnia B, Yazici M, Thompson GH (eds) The growing spine. Springer, New York, pp 11–41
24. Akamaru T, Kawahara N, Sakamoto J, Yoshida A, Murakami H, Hato T, Awamori S, Oda J, Tomita K (2005) The transmission of stress to grafted bone inside a titanium mesh cage used in anterior column reconstruction after total spondylectomy: a finite-element analysis. Spine (Phila Pa 1976) 30(24):2783–2787
25. Akamaru T, Kawahara N, Tsuchiya H, Kobayashi T, Murakami H, Tomita K (2002) Healing of autologous bone in a titanium mesh cage used in anterior column reconstruction after total spondylectomy. Spine (Phila Pa 1976) 27(13):E329–E333
26. Enneking WF, Eady JL, Burchardt H (1980) Autogenous cortical bone grafts in the reconstruction of segmental skeletal defects. J Bone Joint Surg Am 62(7):1039–1045
27. Amendola L, Cappuccio M, De Iure F, Bandiera S, Gasbarrini A, Boriani S (2014) En bloc resection for primary spinal tumors in 20 years of experiences: effectiveness and safety. Spine J 14(11):2608–2617

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