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ORIGINAL ARTICLE - TUMOR - OTHER

Recurrence or neurological loss? Resection mode selection for patients with large sacral chordoma: an analysis of prognostic factors and quality of life

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Abstract

Background Surgical resection represents the main therapeutic method for sacral chordoma, but plans for resection mode must weigh neurological loss against complete tumor excision, a difficult balance to strike. The purpose of this study was to provide useful information contributing to surgical decision making in sacral chordoma.

Methods A retrospective review was performed on 47 patients with large sacral chordoma. Prognostic factors affecting recurrence-free survival (RFS) and overall survival (OS) were analyzed using the Kaplan–Meier method and Cox proportional hazards model. Quality of life was assessed by the Functional Assessment of Cancer Therapy-General (FACT-G) questionnaire and compared using Student's *t* test.

Results Resection mode was the independent prognostic factor affecting RFS, while independent prognostic factors affecting OS were resection mode and postoperative recurrence. As for quality of life, the en bloc resection group showed a higher score in emotional well-being, while the piecemeal resection group scored better in function well-being. No significant difference was identified in total the FACT-G score between two groups.

Conclusions On the one hand, en bloc resection showed huge advantages in disease control for sacral chordoma. On the other hand, despite the unsatisfaction in functional well-being, en bloc resection did not sacrifice quality of life significantly in terms of the total FACT-G score.

Keywords Chordoma · Sacral tumor · Sacrectomy · En bloc resection · Piecemeal resection · Prognostic factor · Quality of life

Introduction

Chordoma is a rare malignant tumor with an incidence of 0.08 per 100,000, accounting for 1–4% of all bone malignancies [32]. Although reported to be rare, chordoma is the most common primary malignant tumor in the sacrum [12]. Chordoma has shown to respond poorly to radiotherapy and chemotherapy, so surgical resection represents the first choice of treatment [8, 21, 25, 35]. Because chordomas are highly recurrent, with the local recurrence rates ranging from 43 to 85%, complete tumor resection is essential for local control [21, 25]. Clinically, the tumors tend to be large at the time of treatment, posing a great challenge for surgeons to keep the balance between adequate resection and sparing of surrounding vital structures.

En bloc resection with adequate margins is an effective way of achieving long-term disease control or cure, but it is technically demanding and can be associated with a high risk of postoperative morbidity due to nerve sacrifice [13, 25]. Piecemeal resection may better preserve the nerve function, but often lead to a high rate of recurrence [27]. Sometimes surgeons and patients have to make a difficult choice between

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disease control and neurological function, for it is hard to have both when facing a large sacral chordoma.

In this study, 47 patients with large sacral chordoma were retrospectively reviewed. The purpose of this study was to provide some reliable and useful information contributing to surgical decision making by (1) identifying prognostic factors for large sacral chordoma and (2) comparing quality of life between patients undergoing en bloc and nerve-sparing piecemeal resection.

Materials and methods

Study design and patients

A retrospective review was performed of sacral chordoma cases between January 2010 and January 2018. The inclusion criteria were (1) patients with pathologically diagnosed chordoma in sacrum who received surgical treatment in our center, (2) patients with a tumor size ≥ 5 cm in the maximum diameter, (3) patients with tumor involved no less than two complete sacral segments, (4) patients who received en bloc or piecemeal sacrectomy instead of intralesional curettage of the lesion, (5) and patients with no metastasis at the time of surgery. In this study, sacral chordomas with a tumor size ≥ 5 cm and involving two or more segments were regarded as large sacral chordomas. The rationale for choosing large sacral chordomas as the study objects was that sacrectomy was applied in most of them. In addition, patients with sacral chordoma involving only S4 and below were excluded from the study, because the influence of surgery on nerve function and quality of life for this kind of patients is limited [37]. This study was approved by the hospital ethics committee.

The clinical and operative records, radiographic images, and pathological reports of all patients were reviewed by two individual researchers. Pre- and postoperative urinary, bowel, and ambulatory functions were recorded. Frankel Grade was used to evaluate neurological functions of the patients. The individualized surgical strategy was made for each patient based on the Weinstein–Boriani–Biagini and the Enneking system [3, 11]. After a detailed and comprehensive explanation to the patient and family about the benefits and the risks of nerve sacrifice and consequent functional cost, the patient and family decided whether or not to receive en bloc resection.

The surgical technique and protocol described by Zang et al. was followed for en bloc sacrectomy [36]. A horizontal sacral osteotomy from the back to the front was performed at the level determined on preoperative MRI with the goal of obtaining wide margins. The sacral dural sac was ligated above the sacral foraminal invasion of the tumor in the en bloc sacrectomy, while the sacral nerves were carefully preserved in piecemeal resection. In addition, cisplatin or carboplatin dissolved in distilled water was applied intraoperatively for local chemotherapy. Adjuvant therapies including postoperative radiotherapy and chemotherapy were applied based on a comprehensive consideration of the volume of the tumor, surgical method and the response to chemotherapy and/or radiation therapy by the multidisciplinary team.

Follow-up strategy

Patients were followed up at 3, 6, and 12 months after surgery, every 6 months for the next 2 years, and once a year thereafter. The diagnosis of recurrence was confirmed by postoperative pathological evaluation in patients who received a second surgery. In suspected cases without a second surgery, the diagnosis of recurrence depended on the clinical manifestation of reemerging of pain and/or lump in the original tumor site, and imaging finding of new-onset neoplasm at the surgical site evaluated by enhanced MRI. Recurrence-free survival (RFS) was defined as the interval between the date of surgery and the date of recurrence. Overall survival (OS) was defined as the interval between the date of the initial surgery and the date of death. The follow-up period was defined as the interval from the date of surgery to death, or until December 2018 for alive patients. The last status of patients was obtained from office visit or telephone interview.

Assessment of quality of life

The Functional Assessment of Cancer Therapy-General (FACT-G, version 4.0) questionnaire was applied in the assessment of quality of life in this study [19]. The FACT-G questionnaire is one of the most widely used instruments for quality-of-life evaluation and has been verified as applicable to the Chinese population [33]. The Chinese-language version of the FACT-G questionnaire was administered at 1-year follow-up for our patients. All FACT-G questionnaire data were collected and checked by two individual researchers, and missing data were minimized through telephone calls.

Statistical analysis

All statistical calculations were performed by SPSS Statistics, version 22.0 (IBM corp., New York, USA). The Kaplan–Meier method was adopted to estimate the RFS and OS time, with the log-rank test to identify the difference. Factors with a p value < 0.1 were subjected to multivariate analysis using the Cox proportional hazards model. The total FACT-G score and the subscores were compared by Student's t test between the piecemeal resection and en bloc

resection groups. A p value < 0.05 (two-sided) was considered statistically significant.

Results

Patient descriptions

The characteristics of 47 patients are described in Table 1, and the pre- and postoperative images of a representative case are shown in Fig. 1. The population comprised 33 men and 14 women, with a mean age of 54.5 years (median 54, range 22–78). The mean tumor diameter was 10.1 cm (median 10.0, range 5.0–20.0) in our series. En bloc and piecemeal resections were performed in 23 (49%) and 24 (51%) patients, respectively. The function of patients which was assessed by Frankel Grade before and after surgery is shown in Table 2. The Frankel Grade of 11 (48%) patients who received en bloc resection descended at least one grade postoperatively, while the function of 6 (25%) patients in the piecemeal group was improved 3 months after surgery. The mean follow-up period was 41.3 months (median 40, range 12–87). Recurrence and disease-related death occurred in 19 and 12 cases, respectively. The mean time from surgery to recurrence was 27.9 months, while mean follow-up for the dead patients was 42.2 months.

Univariate and multivariate analysis of prognostic factors affecting RFS

The Kaplan–Meier analysis showed that the median RFS was 46 months for all 47 patients. The univariate analysis of the prognostic factors for RFS is shown in Table 1. Tumor size ($p = 0.008$), preoperative ambulatory status ($p = 0.037$), revision surgery ($p = 0.093$), resection mode ($p = 0.004$), postoperative radiotherapy ($p = 0.036$), and postoperative chemotherapy ($p = 0.037$) were potential prognostic factors affecting RFS according to the univariate analysis.

The above-mentioned six potential prognostic factors were submitted to multivariate Cox regression model (Table 3). En bloc resection significantly decreased the risk of recurrence (HR = 0.32; 95% CI, 0.10–0.99; $p = 0.048$). The Kaplan–Meier curves of RFS for resection mode is shown in Fig. 2a. The multivariate analysis also showed that other five factors were not independent prognostic factors for RFS.

Table 1 Patient characteristics and univariate analysis of the prognostic factors affecting RFS and OS

Factor	N	RFS		OS	
		Median (m)	p	Median (m)	p
Sex (M/F)	33/14	42/NR	0.631	60/67	0.200
Age (< 60 years/≥ 60 years)	29/18	NR/46	0.439	NR/60	0.238
Tumor size (< 10 cm/≥ 10 cm)	20/27	NR/37	*0.008*	NR/58	*0.088*
Duration of neurologic symptoms (≤ 3 m/> 3 m)	19/28	40/53	0.599	60/67	0.446
Preoperative urinary and bowel function, normal/abnormal	8/39	46/42	0.733	60/67	0.723
Preoperative ambulatory status, normal/abnormal	44/3	53/30	*0.037*	67/52	*0.071*
Comorbidity, (−)/(+)	33/14	42/53	0.873	67/58	0.742
Preoperative selective arterial embolism, (−)/(+)	10/37	46/42	0.536	NR/67	0.614
Revision surgery, (−)/(+)	33/14	53/37	*0.093*	NR/58	0.151
Resection mode, piecemeal/en bloc	24/23	37/NR	*0.004*	57/67	*0.008*
Intraoperative blood loss (≤ 2000 mL/2000 mL)	26/21	53/40	0.670	60/NR	0.942
Operation time (≤ 5 h/> 5 h)	24/23	42/NR	0.805	60/NR	0.898
Intraoperative chemotherapy, (−)/(+)	10/37	42/46	0.324	NR/67	0.593
Wound complications, (−)/(+)	32/15	46/36	0.168	NR/60	0.341
Postoperative radiotherapy, (−)/(+)	42/5	53/22	*0.001*	67/58	0.665
Postoperative chemotherapy, (−)/(+)	42/5	53/39	*0.060*	67/NR	0.984
Postoperative urinary and bowel function, normal/abnormal	19/28	39/46	0.575	60/NR	0.293
Postoperative ambulatory status, normal/abnormal	40/7	46/30	0.299	67/52	0.237
Postoperative recurrence, (−)/(+)	28/19	–	–	NR/57	*0.005*

NR not reached

p values < 0.1 are shown in italics

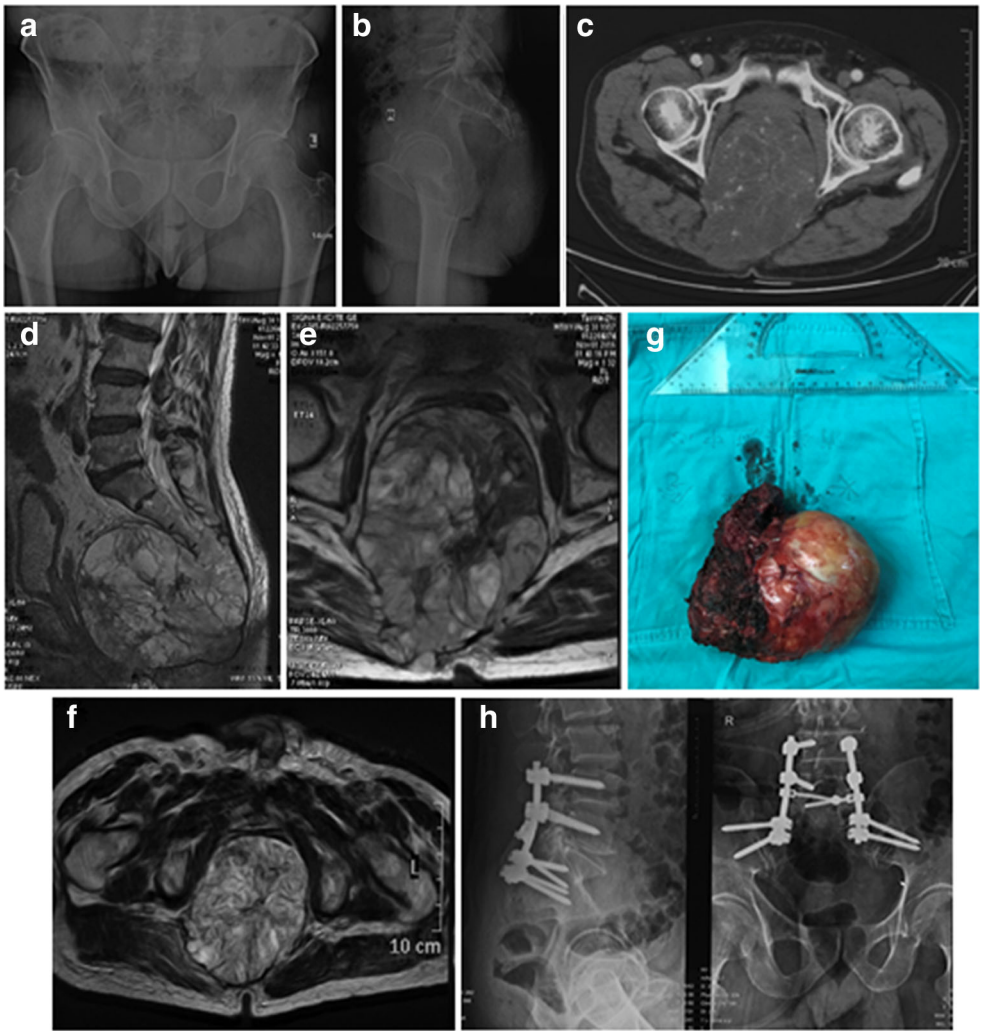

Fig. 1 Images of a 59-year-old man with large sacral chordoma. **a** and **b** Preoperative X-ray. **c** Preoperative CT. **d** and **e** Preoperative sagittal and axial T2-weighted MRI. **f** Preoperative axial contrast-enhanced T1-weighted MRI. **g** The en bloc sacrectomy was performed. **h** Postoperative X-ray

Univariate and multivariate analysis of prognostic factors affecting OS

The Kaplan–Meier analysis showed that the median OS was 67 months with the 5-year survival rate being 52.4%. The univariate analysis of the prognostic factors for OS is shown in Table 1. Patients with a tumor size less than 10 cm had the longer OS time ($p = 0.088$). OS time was significantly poorer in patients with abnormal preoperative ambulatory status ($p = 0.071$). Patients who underwent piecemeal resection had a worse OS than those who underwent en bloc resection ($p = 0.008$). OS time significantly decreased in patients with postoperative recurrence ($p = 0.005$).

The multivariate analysis of the prognostic factors for OS is shown in Table 3. The risk of death was significantly decreased in patients with en bloc resection (HR = 0.16; 95% CI, 0.03–0.90; $p = 0.037$). Postoperative recurrence was significantly associated with a higher risk of death (HR = 10.01; 95% CI, 1.00–100.61; $p = 0.050$). Kaplan–Meier curves of OS for resection mode and postoperative recurrence are shown in Fig. 2(b and c). Multivariate analysis also showed that the tumor size and preoperative ambulatory status were not independent prognostic factors for OS.

Quality of life

The total FACT-G scores and the subscores in the four specific life domains are shown in Table 4. The total score, physical well-being score, and social/family well-being score of the piecemeal resection group were higher than those of the en bloc resection group, but the differences were not significant ($p = 0.485$, 0.055, and 0.259, respectively). The emotional well-being score of the en bloc resection group was significantly higher than that of the piecemeal resection group ($p < 0.001$), while the functional well-being score was significantly higher in the piecemeal resection group ($p < 0.001$).

Table 2 Frankel Grade of patients before and after surgery

Frankel Grade	Before surgery		3 months after surgery	
	Piecemeal resection	En bloc resection	Piecemeal resection	En bloc resection
A	0	0	0	0
B	1	0	1	1
C	1	1	0	5
D	20	16	16	17
E	2	6	7	0

Discussion

Chordomas constitute over 50% of primary sacral tumors, and the sacrum is the most common site for chordoma. As an indolent and slow-growing tumor, chordoma is often clinically silent until growing to the large size. [32]. Large tumor burden and sacral nerve root invasion make surgical management of sacral chordomas challenging. In this study, 47 consecutive patients with large sacral chordoma were reviewed. Survival outcomes and quality of life were analyzed and compared between patients receiving en bloc resection and piecemeal resection.

It is reported that the median RFS and OS for sacral chordoma were 44–73 months and 6–7.2 years, respectively [4, 9, 21, 26, 31]. In our series, the median RFS was 46 months, and the median OS was 67 months. A shorter survival time was observed, which may result from larger sizes of tumors included in our series. Literatures focusing on surgical treatment of sacral chordoma with at least 20 patients in the recent 10 years were reviewed, and the main results are listed in Table 5.

Our results showed that resection mode was an independent prognostic factor affecting both RFS and OS, with en bloc resection significantly decreasing the risk of both recurrence and death. Similarly, studies in recent 10 years also addressed the importance of en bloc resection in disease control for chordoma in the sacrum. Varga et al. reviewed 167 patients with sacral chordoma in 12 spine oncology referral centers and emphasized that en bloc resection improved local recurrence-free survival significantly [31]. Dhawale et al. reviewed 21 patients with sacral chordomas treated with en bloc resection and adjuvant radiotherapy and concluded that despite the complications, increased long-term survival can be achieved with en bloc resection [9]. Ruggieri et al. reviewed 56 patients with sacral chordomas treated with surgical resection and suggested that previous intralesional surgery was associated with a higher rate of local recurrence [25]. Hsieh et al. reviewed 20 patients with sacral chordomas or chondrosarcomas and found that the mean RFS for patients with wide or marginal en bloc tumor excisions was 51 months, but that was only 17.5 months for patients who had contaminated/intralesional resections [15]. Schwab et al. reviewed 42 patients who underwent resection for sacral chordoma and emphasized that intralesional resection should be avoided as it is associated with a higher local recurrence rate and worse survival [26]. Therefore, according to both our results and previous studies, en bloc resection showed its superiority in the aspect of disease control for sacral chordomas.

Clinical management of large sacral chordoma requires a multidisciplinary approach which integrates surgeons, oncologists, radiotherapists and histologists, etc. Although chordoma was thought to be relatively radioresistant, radiotherapy has been widely used as a postoperative adjuvant therapy for treatment of spinal chordomas, especially when wide or marginal margins were difficult to obtain [22]. New advances in radiation technology have allowed for delivery of

Table 3 Multivariate analysis of the prognostic factors affecting RFS and OS

Factor	RFS		OS	
	HR (95% CI)	*p*	HR (95% CI)	*p*
Tumor size	2.36 (0.72–7.74)	0.156	1.13 (0.25–4.99)	0.876
Preoperative ambulatory status	1.36 (0.29–6.38)	0.693	1.23 (0.23–6.49)	0.809
Revision surgery	1.46 (0.46–4.62)	0.521	–	–
Resection mode	0.32 (0.10–0.99)	*0.048*	0.16 (0.03–0.90)	*0.037*
Postoperative radiotherapy	2.65 (0.67–10.40)	0.163	–	–
Postoperative chemotherapy	1.70 (0.44–6.63)	0.444	–	–
Postoperative recurrence	–	–	10.01 (1.00–100.61)	*0.050*

p values < 0.05 are shown in italics

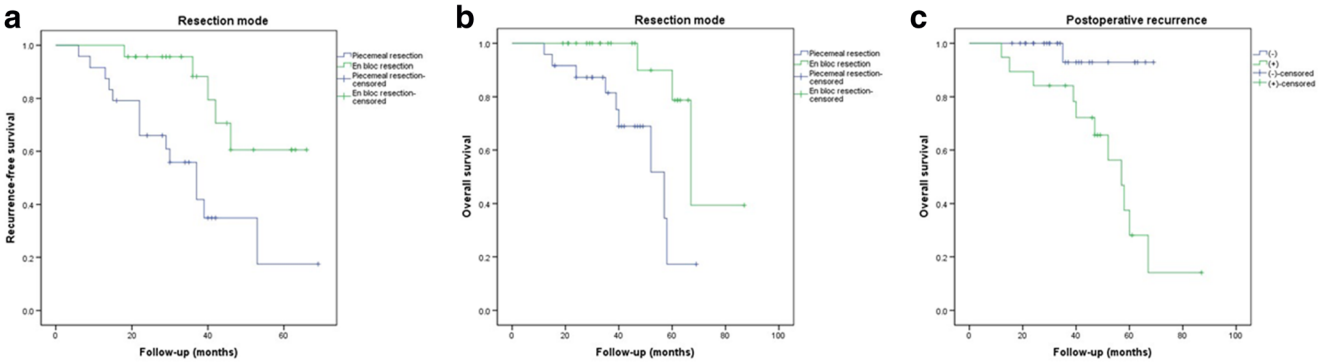

Fig. 2 **a** Kaplan–Meier curves of RFS. **b** and **c** Kaplan–Meier curves of OS

higher doses of radiation to the target volume with minimal injury to surrounding tissues. However, this technique was not widely used with a long follow-up in our center, and only 5 cases in this series received postoperative radiotherapy. Although chordomas are not sensitive to systemic chemotherapy, it is reported that direct intratumoral chemotherapy with carboplatin and epinephrine obtained a good partial response for a cervical recurrent chordoma [14]. Similar to intratumoral chemotherapy, in our center, intraoperative chemotherapy was widely used under the hypothesis that local accumulation of anticancer agents leads to enhanced efficacy with decreased systemic toxicity. In addition, enlightened by several individual successful examples [18, 28], platinum-based systemic chemotherapy was also tentatively performed in 5 cases by our multidisciplinary team. Unfortunately, according to our results, none of those adjuvant therapies showed significant improvement in the treatment of large sacral chordomas, and their efficacy needs further investigation.

The concept of quality of life is becoming increasingly important in the determination of treatment success [7, 29]. Several studies have pointed out that en bloc sacrectomy often involves transection of the sacral nerve roots and causes functional loss [20, 23]. Similarly, in our series, the function of 48% patients with en bloc resection was deteriorated in terms of Frankel Grade after surgery, while the function of 25% patients in the piecemeal group was improved 3 months postoperatively. However, the patients' quality of life depends not only on neurologic function but also on physical, social, and emotional conditions. Therefore, we conducted a comprehensive questionnaire survey to determine whether en bloc resection seriously impairs patients' quality of life in different domains.

In this study, the piecemeal resection group had a better functional status than the en bloc resection group, which were closely related to increases in scores of specific items, such as "I am able to work (include work at home)" and "I am enjoying the things I usually do for fun". Although the difference did not reach statistical significance in the domain of physical well-being, the piecemeal resection group had a better score in the item of "Because of my physical condition, I have trouble meeting the needs of my family" and "I am bothered by side effects of treatment". The sacrifice of sacral nerve in the en bloc resection group caused poorer functional (10.83 vs. 13.54) and physical (14.52 vs. 16.04) scores, but the score gaps between these two groups were relatively small. The reasons may be as follows: Firstly, some patients presented with damaged sphincter function or motor disability failed to regain normal nerve function after nerve-sparing piecemeal surgery. Secondly, re-excision of the recurrent tumor would also put the nerve roots at risk. On the other hand, the en bloc resection group had a better emotional status than the piecemeal resection group, which was closely associated with the items, such as "I am losing hope in the fight against my illness", "I feel nervous", "I worry about dying", and "I worry that my condition will get worse". Apparently, patients in the piecemeal resection group were more nervous and worry about postoperative recurrence, and patients who experienced repeated recurrence lost hope in the fight against their illness gradually. The emotional score gap (8.79 vs. 11.91) was more

Table 4 Quality-of-life scores measured with FACT-G

FACT-G	Piecemeal resection ($N = 24$)	En bloc resection ($N = 23$)	p
Physical well-being	16.04 ± 2.63	14.52 ± 2.66	0.055
Social/family well-being	13.92 ± 1.86	13.35 ± 1.52	0.259
Emotional well-being	8.79 ± 2.78	11.91 ± 2.70	*< 0.001*
Functional well-being	13.54 ± 2.87	10.83 ± 1.90	*< 0.001*
Total score	52.29 ± 9.21	50.61 ± 6.97	0.485

p values < 0.05 are shown in italics

Table 5 Literatures focusing on surgical treatment of sacral chordoma with at least 20 patients in the recent 10 years

Authors	Year	No. of patients	Surgical margin*	Adjuvant therapy	RFS	OS
van Wulfften Palthe [30]	2019	101	R0 74; R1 or R2 27	Radiotherapy 58; chemotherapy 9	Primary tumors: 5-year RFS was 86%; recurrent tumors: 5-year RFS was 79%	Primary tumors: 5- and 10-year OS was 79% and 59%, respectively; recurrent tumors: 5- and 10-year overall survival was 65% and 40%, respectively
Colangeli [6]	2018	33	R0 17; R1 14; R2 2	Radiotherapy 3	10-year RFS was 51%	10-year OS was 86.6%
Yang [35]	2017	157	R0 31; R1 62; R2 64	Radiotherapy 64	3-year RFS was 80.1% and the 5-year RFS was 48.1%	5-year OS was 88.3%; 10-year OS was 59.6%
Ji [16]	2017	115	R0 or R1 77; R2 38	Radiotherapy 31	5-year RFS was 52%	5-year OS was 81%
Radaelli [24]	2016	99	R0 46; R1 43; R2 10	Radiotherapy 19	5-, 10-, and 15-year DFS were 62%, 36%, and 21%, respectively	5-, 10-, and 15-year OS were 92%, 63%, and 45%, respectively
Xie [34]	2015	54	R0 13; R1 34; R2 7	Radiotherapy 3; chemotherapy 3	5-, 10-, and 15-year RFS were 49%, 37%, and 20%, respectively	5-, 10-, and 15-year OS were 82%, 57%, and 45%, respectively
Varga [31]	2015	167	R0 or R1 131; R2 21	Chemotherapy or radiotherapy 39	The median RFS was 4 years	The median OS was 6 years
Kayani [17]	2015	58	R0 28; R1 24; R2 6	Radiotherapy 36	–	5- and 10-year OS were 62% and 26%, respectively
Angelini [1]	2015	71	R0 44; R1 20; R2 7	Radiotherapy 2; Targeted drugs 5	–	OS was 92%, 65%, and 44% at 5, 10, and 15 years, respectively
Dubory [10]	2014	29	R0 18; R1 6; R2 4	Radiotherapy 2; chemotherapy 4	RFS was 64% and 56% at 5 and 10 years, respectively	OS was 84.4% at 5 and 10 years
Dhawale [9]	2014	21	R0 10; R1 6; R2 5	Radiotherapy 18	Mean RFS was 2.5 years	Median OS was 7.2 years
Asavamongkolkul [2]	2012	21	R0 7; R1 14	Radiotherapy 14	7-year follow-up: 18 tumor-free; 3 recurrence	7-year follow-up: 20 alive; 1 dead
Ruggieri [25]	2010	56	R0 31; R1 20; R2 5	–	RFS was 65% at 5 years and 52% at 10 years	OS was 97% at 5 years, 71% at 10 years, and 47% at 15 years
Chen [5]	2010	36	R0 7; R1 16; R2 13	Radiotherapy 15	5-year and 10-year actuarial CDFS were 59.5 and 42%	–
Schwab [26]	2009	42	R0 27; R1 11; R2 4	–	5-year DFS was 56%	Median OS was 84 months; 5-year OS was 77%

R0: Wide surgical margin; R1: marginal margin; R2 intralesional margin (according to the Enneking staging)

obvious than that of functional and physical scores. On the whole, the piecemeal resection group had no significant increase in the total FACT-G score than the en bloc resection group in our series.

There are several limitations in our study. Firstly, the retrospective nature is the main limitation. Secondly, due to the limited sample size, we did not design subgroups for en bloc resection based on the resection level in the quality-of-life evaluation. Thirdly, we failed to analyze sexual function, because more than 30% of patients in the follow-up preferred not to discuss relevant issues in detail.

In conclusion, on the one hand, resection mode was an independent prognostic factor for large sacral chordomas, with en bloc resection showing significant advantages in disease control. On the other hand, despite the unsatisfaction in functional well-being, en bloc resection did not sacrifice quality of life significantly in terms of the total FACT-G score. Therefore, we recommend en bloc resection for suitable patients as long as condition allows. All in all, decision making in sacral chordomas is a complex process and influenced by a variety of factors, such as tumor location, neurological status, and psychological condition. We are looking forward to larger and more detailed studies to provide more information concerning this issue.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent For retrospective study, formal consent is not required.

References

1. Angelini A, Pala E, Calabro T, Maraldi M, Ruggieri P (2015) Prognostic factors in surgical resection of sacral chordoma. J Surg Oncol 112:344–351. https://doi.org/10.1002/jso.23987
2. Asavamongkolkul A, Waikakul S (2012) Wide resection of sacral chordoma via a posterior approach. Int Orthop 36:607–612. https://doi.org/10.1007/s00264-011-1381-9
3. Boriani S, Weinstein JN, Biagini R (1997) Primary bone tumors of the spine. Terminology and surgical staging. Spine 22:1036–1044
4. Chandawarkar RY (1996) Sacrococcygeal chordoma: review of 50 consecutive patients. World J Surg 20:717–719
5. Chen KW, Yang HL, Lu J, Liu JY, Chen XQ (2010) Prognostic factors of sacral chordoma after surgical therapy: a study of 36 patients. Spinal Cord 48:166–171. https://doi.org/10.1038/sc.2009.95
6. Colangeli S, Muratori F, Bettini L, Frenos F, Totti F, D'Arienzo A, Campo FR, Scoccianti G, Beltrami G, Campanacci DA, Capanna R (2018) Surgical treatment of sacral chordoma: en bloc resection with negative margins is a determinant of the long-term outcome. Surg Technol Int 33:343–348
7. Davidge KM, Eskicioglu C, Lipa J, Ferguson P, Swallow CJ, Wright FC (2010) Qualitative assessment of patient experiences following sacrectomy. J Surg Oncol 101:447–450. https://doi.org/10.1002/jso.21517
8. Denaro L, Berton A, Ciuffreda M, Loppini M, Candela V, Brandi ML, Longo UG (2018) Surgical management of chordoma: a systematic review. J Spinal Cord Med 1–16. https://doi.org/10.1080/10790268.2018.1483593
9. Dhawale AA, Gjolaj JP, Holmes L Jr, Sands LR, Temple HT, Eismont FJ (2014) Sacrectomy and adjuvant radiotherapy for the treatment of sacral chordomas: a single-center experience over 27 years. Spine 39:E353–E359. https://doi.org/10.1097/BRS.0000000000000173
10. Dubory A, Missenard G, Lambert B, Court C (2014) "En bloc" resection of sacral chordomas by combined anterior and posterior surgical approach: a monocentric retrospective review about 29 cases. Eur Spine J 23:1940–1948. https://doi.org/10.1007/s00586-014-3196-z
11. Enneking WF (1986) A system of staging musculoskeletal neoplasms. Clin Orthop Relat Res 9–24
12. Farsad K, Kattapuram SV, Sacknoff R, Ono J, Nielsen GP (2009) Sacral chordoma. Radiographics 29:1525–1530. https://doi.org/10.1148/rg.295085215
13. Fourney DR, Rhines LD, Hentschel SJ, Skibber JM, Wolinsky JP, Weber KL, Suki D, Gallia GL, Garonzik I, Gokaslan ZL (2005) En bloc resection of primary sacral tumors: classification of surgical approaches and outcome. J Neurosurg Spine 3:111–122. https://doi.org/10.3171/spi.2005.3.2.0111
14. Guiu S, Guiu B, Feutray S, Chauffert B (2009) Direct intratumoral chemotherapy with carboplatin and epinephrine in a recurrent cervical chordoma: case report. Neurosurgery 65:E629–E630; discussion E630. https://doi.org/10.1227/01.NEU.0000350864.78326.14
15. Hsieh PC, Xu R, Sciubba DM, McGirt MJ, Nelson C, Witham TF, Wolinksy JP, Gokaslan ZL (2009) Long-term clinical outcomes following en bloc resections for sacral chordomas and chondrosarcomas: a series of twenty consecutive patients. Spine 34:2233–2239. https://doi.org/10.1097/BRS.0b013e3181b61b90
16. Ji T, Guo W, Yang R, Tang X, Wang Y, Huang L (2017) What are the conditional survival and functional outcomes after surgical treatment of 115 patients with sacral chordoma? Clin Orthop Relat Res 475:620–630. https://doi.org/10.1007/s11999-016-4773-8
17. Kayani B, Sewell MD, Tan KA, Hanna SA, Williams R, Pollock R, Skinner J, Briggs TW (2015) Prognostic factors in the operative management of sacral chordomas. World Neurosurg 84:1354–1361. https://doi.org/10.1016/j.wneu.2015.06.030
18. Lee MH, Kim SR, Jeong JS, Lee EJ, Lee YC (2012) Pulmonary metastatic chordoma improved by platinum-based chemotherapy. Lung Cancer 76:255–257. https://doi.org/10.1016/j.lungcan.2012.02.007
19. Lipscomb J, Gotay CC, Snyder CF (2007) Patient-reported outcomes in cancer: a review of recent research and policy initiatives. CA Cancer J Clin 57:278–300. https://doi.org/10.3322/CA.57.5.278
20. Moran D, Zadnik PL, Taylor T, Groves ML, Yurter A, Wolinsky JP, Witham TF, Bydon A, Gokaslan ZL, Sciubba DM (2015) Maintenance of bowel, bladder, and motor functions after

sacrectomy. Spine J 15:222–229. https://doi.org/10.1016/j.spinee.2014.08.445

21. Palthe O, Tromp I, Ferreira A, Fiore A, Bramer JAM, van Dijk NC, DeLaney TF, Schwab JH, Hornicek FJ (2019) Sacral chordoma: a clinical review of 101 cases with 30-year experience in a single institution. Spine J 19:869–879. https://doi.org/10.1016/j.spinee.2018.11.002
22. Pennicooke B, Laufer I, Sahgal A, Varga PP, Gokaslan ZL, Bilsky MH, Yamada YJ (2016) Safety and local control of radiation therapy for chordoma of the spine and sacrum: a systematic review. Spine 41(Suppl 20):S186–S192. https://doi.org/10.1097/BRS.0000000000001831
23. Phukan R, Herzog T, Boland PJ, Healey J, Rose P, Sim FH, Yazsemski M, Hess K, Osler P, DeLaney TF, Chen YL, Hornicek F, Schwab J (2016) How does the level of sacral resection for primary malignant bone tumors affect physical and mental health, pain, mobility, incontinence, and sexual function? Clin Orthop Relat Res 474:687–696. https://doi.org/10.1007/s11999-015-4361-3
24. Radaelli S, Stacchiotti S, Ruggieri P, Donati D, Casali PG, Palmerini E, Collini P, Gambarotti M, Porcu L, Boriani S, Gronchi A, Picci P (2016) Sacral chordoma: long-term outcome of a large series of patients surgically treated at two reference centers. Spine 41:1049–1057. https://doi.org/10.1097/BRS.0000000000001604
25. Ruggieri P, Angelini A, Ussia G, Montalti M, Mercuri M (2010) Surgical margins and local control in resection of sacral chordomas. Clin Orthop Relat Res 468:2939–2947. https://doi.org/10.1007/s11999-010-1472-8
26. Schwab JH, Healey JH, Rose P, Casas-Ganem J, Boland PJ (2009) The surgical management of sacral chordomas. Spine 34:2700–2704. https://doi.org/10.1097/BRS.0b013e3181bad11d
27. Sciubba DM, Petteys RJ, Garces-Ambrossi GL, Noggle JC, McGirt MJ, Wolinsky JP, Witham TF, Gokaslan ZL (2009) Diagnosis and management of sacral tumors. J Neurosurg Spine 10:244–256. https://doi.org/10.3171/2008.12.SPINE08382
28. Spalato Ceruso M, Napolitano A, Silletta M, Vincenzi B (2019) Unexpected benefit from an 'old' metronomic chemotherapy regimen in advanced chordoma. BMJ Case Rep 12. https://doi.org/10.1136/bcr-2018-228728
29. van Wulfften Palthe ODR, Janssen SJ, Wunder JS, Ferguson PC, Wei G, Rose PS, Yaszemski MJ, Sim FH, Boland PJ, Healey JH, Hornicek FJ, Schwab JH (2017) What questionnaires to use when measuring quality of life in sacral tumor patients: the updated sacral tumor survey. Spine J 17:636–644. https://doi.org/10.1016/j.spinee.2016.11.004
30. van Wulfften Palthe ODR, Tromp I, Ferreira A, Fiore A, Bramer JAM, van Dijk NC, DeLaney TF, Schwab JH, Hornicek FJ (2019) Sacral chordoma: a clinical review of 101 cases with 30-year experience in a single institution. Spine J 19:869–879. https://doi.org/10.1016/j.spinee.2018.11.002
31. Varga PP, Szoverfi Z, Fisher CG, Boriani S, Gokaslan ZL, Dekutoski MB, Chou D, Quraishi NA, Reynolds JJ, Luzzati A, Williams R, Fehlings MG, Germscheid NM, Lazary A, Rhines LD (2015) Surgical treatment of sacral chordoma: prognostic variables for local recurrence and overall survival. Eur Spine J 24:1092–1101. https://doi.org/10.1007/s00586-014-3728-6
32. Walcott BP, Nahed BV, Mohyeldin A, Coumans JV, Kahle KT, Ferreira MJ (2012) Chordoma: current concepts, management, and future directions. Lancet Oncol 13:e69–e76. https://doi.org/10.1016/S1470-2045(11)70337-0
33. Wan C, Yang Z, Meng Q, Feng C, Wang H, Tang X, Zhang C, Lu Y, Luo J, Zhang X (2008) Development and validation of the general module of the system of quality of life instruments for cancer patients. Int J Cancer 122:190–196. https://doi.org/10.1002/ijc.23036
34. Xie C, Whalley N, Adasonla K, Grimer R, Jeys L (2015) Can local recurrence of a sacral chordoma be treated by further surgery? Bone Joint J 97-B:711–715. https://doi.org/10.1302/0301-620X.97B5.35131
35. Yang Y, Niu X, Li Y, Liu W, Xu H (2017) Recurrence and survival factors analysis of 171 cases of sacral chordoma in a single institute. Eur Spine J 26:1910–1916. https://doi.org/10.1007/s00586-016-4906-5
36. Zang J, Guo W, Yang R, Tang X, Li D (2015) Is total en bloc sacrectomy using a posterior-only approach feasible and safe for patients with malignant sacral tumors? J Neurosurg Spine 22:563–570. https://doi.org/10.3171/2015.1.SPINE14237
37. Zoccali C, Skoch J, Patel AS, Walter CM, Maykowski P, Baaj AA (2016) Residual neurological function after sacral root resection during en-bloc sacrectomy: a systematic review. Eur Spine J 25:3925–3931. https://doi.org/10.1007/s00586-016-4450-3