North American Spine Society Journal (NASSJ) 21 (2025) 100566

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

journal homepage: www.elsevier.com/locate/xnsj

Clinical Studies

Risk factors for metastatic disease at presentation with chordoma and its prognostic value

Ari R. Berg, MD, MBA*, Gabriel Hanna, MD, Dhruv Mendiratta, BS, Ashok Para, MD, Matthew Michel, MD, Kathleen Beebe, MD, Michael J. Vives, MD

Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, New Jersey, United States

ARTICLE INFO

Keywords:
Chordoma
Spine
SEER
Survival
Histological subtypes
Metastases

ABSTRACT

Background: Chordoma is a rare bone cancer arising from the embryonic notochord with special predilection to the axial skeleton. The locally destructive nature and metastatic potential of chordomas can lead to devastating outcomes in terms of survival. The purpose of this study was to examine potential risk factors predictive of metastatic disease at presentation and prognostic factors in patients with metastasis.

Methods: SEER was used to classify each patient as having metastatic or localized disease at the time of diagnosis. Patient-specific and tumor characteristics were analyzed to determine which factors were predictive of an increased rate of metastatic disease at presentation. These factors were analyzed using univariate as well as a multivariate logistic regression model. Prognostic factors for survival were analyzed using the Kaplan–Meier estimates with log-rank tests, and Cox proportional hazards models.

Results: We identified 1,241 cases of chordoma affecting the axial skeleton, and 117 (9.4%) of the patients presented with metastatic disease. The most common locations for metastasis at presentation were lung (6.0%), followed by bone (5.1%) and liver (3.4%). Based on the unadjusted logistic regression analysis, patients had the highest odds of metastatic disease at presentation if they had a tumor located in the sacrococcygeal area (OR = 1.72; 95% CI, 1.11–2.68; p = .015), a tumor with a dedifferentiated histological subtype (OR = 7.42; 95% CI, 2.31–23.79; p = .001) and a tumor size greater than 10 cm (OR = 4.57; 95% CI, 2.52–8.28; p = .009). Only the histological subtype remained significant when combined in a multivariate model controlling for age, sex, race, tumor location, histology, and size. For patients with recorded tumor size information (n = 858), the odds of metastasis at presentation increased by 12.2% with each additional centimeter of tumor size (OR = 1.122; 95% CI, 1.072–1.175; p < .0001). However, this lost significance in the multivariate model. Advanced age (hazard ratio, 2.06; 95% confidence interval, (1.18–3.60); p = .011) and dedifferentiated subtype (hazard ratio, 4.7; 95% confidence interval, (1.33–16.8); p = .02) were significant prognostic factors for survival in patients with metastatic chordoma.

Conclusions: Chordoma patients with dedifferentiated histological subtype were more likely to have metastatic disease at presentation. Advanced age and dedifferentiated histological subtype were independent predictors of increased mortality in patients with metastatic chordoma. Identification of this high-risk group may help providers in counseling their patients regarding the likelihood of discovering metastatic disease at the time of diagnosis of chordoma and predicting long term prognosis.

Introduction

Chordomas are primary malignant tumors of the vertebral column and skull base which originate from the remnants of the notochord, a mesoderm-derived structure essential for normal embryonic development [1]. Tumors most commonly localize to the skull base, sacrum and vertebral column, in order of descending prevalence [2]. Chordomas are slow growing tumors which often present with pain (oncologic vs mechanical) and/or neurologic deficit from mass effect. Symptoms can be accompanied by a palpable mass; however, chordomas of the mobile spine and skull base are more difficult to palpate due to their deep location in the axial skeleton [3,4]. The combination of insidious onset of

FDA device/drug status: Not applicable.

Author disclosures: ***ARB***: Nothing to disclose. ***GH***: Nothing to disclose. ***DM***: Nothing to disclose. ***AP***: Nothing to disclose. ***MM***: Nothing to disclose. ***KB***: Nothing to disclose. ***MJV***: Nothing to disclose.

* Corresponding author. Department of Orthopedic Surgery, Stanford University School of Medicine, 450 Broadway, Redwood City, CA 94063
E-mail address: ari.r.berg@gmail.com (A.R. Berg).

https://doi.org/10.1016/j.xnsj.2024.100566
Received 2 September 2024; Received in revised form 20 October 2024; Accepted 22 October 2024
Available online 6 November 2024

symptoms and lack of palpable mass means that many chordomas are not diagnosed until later in the disease process. This late presentation raises the risk of potential metastasis to distant sites at the time of diagnosis, which has implications on treatment options and overall survival [5,6].

Although chordoma is one of the most common primary osseous neoplasms of the sacrum and mobile spine, the actual incidence of these tumors is low, at less than 0.01 per 100,000 patients [5,7]. As such, obtaining a significant number of patients to study is a challenging feat. In this study, we utilized the Surveillance, Epidemiology, and End Results (SEER) Program database, which is maintained by the National Cancer Institute and collects data from eighteen geographically variable cancer registries. The SEER database has become a commonly used tool to analyze rare cancers.

To our knowledge, there is no comprehensive analysis which compiles risk factors for distant metastases at the time of diagnosis of chordomas. Our study utilized the SEER database for chordomas of the sacrum, skull base, and mobile spine to determine risk factors associated with presence of distant metastases at initial diagnosis of chordoma tumors.

Materials and methods

The SEER (surveillance, epidemiology and end results) program database, a validated population-based national registry, was used to extract all histologically confirmed cases of chordoma from 2000 to 2018. The SEER*Stat application (version 8.3.9) was used to determine variables of interest. The Histologic International Classification of Disease for Oncology, 3rd edition (IDO-O-3 code 9370) was used to identify patients. Inclusion criteria were as follows: diagnosed between 2000 and 2018; positive histology with chordoma; lesion located in skull, vertebral column, or sacrococcygeal/pelvic area; presence of a single primary tumor; no prior history of malignant disease. Exclusion criteria were presence of a concomitant tumor, lack of staging data, lack of demographic data, lack of subtype and location of tumor, and lack of tumor size information.

Data elements

The outcome of interest was the presence of metastatic disease at the time of presentation with chordoma and prognostic factors in patients with metastatic chordoma. The presence of metastatic state was coded as a dichotomous variable. Patients with staging labeled as “distant” were included while patients with staging “regional” or “local” were considered not having metastatic disease at presentation. Patients with an entry that was blank or labeled “unstaged” were excluded from the analysis.

Patient characteristics including age, sex, and race were identified. Patients’ age was recorded in the SEER database as a continuous variable beginning at 0 years and ending at 85 years or more. Patients were categorized into 2 distinct age groups of <60 and ≥60. Race was characterized as white, black, and other (American Indian/Alaska Native, or Asian/Pacific Islander).

Tumor characteristics including location, histologic subtype, size and location of metastases were identified. The location of the tumor and the histological subtype (according to the International Classification of Disease for Oncology, Third Revision [ICD-O-3]) were recorded at the time of the diagnosis. Tumor size, which records the largest dimension, or the diameter of the primary tumor, was recorded as a continuous variable in millimeters.

Tumor location was categorized into 3 categories including skull area, vertebral column, and sacrococcygeal area. Tumor histological subtypes were categorized into 3 categories: chordoma (not otherwise specified), chondroid chordoma, and dedifferentiated chordoma. Tumor size was divided into 3 categories: less than 5 cm, 5–10 cm, and more than 10 cm.

Survival time (in months) was recorded in the database as the time until death due to the cancer or loss to follow-up. Disease specific survival (DSS) at 5- and 10-years was calculated for patients with metastatic chordoma.

Statistical analysis

Descriptive statistics were used to analyze the proportion of patients presenting with metastatic disease across different patient and tumor characteristics. Univariate and multivariate logistic regression models were used to examine the association between presentation with metastatic disease with regard to different patient and tumor factors. Disease-specific survival rates were calculated with the Kaplan–Meier method. Survival was calculated from the time of the initial diagnosis to the date of last contact (or the date of death if the patient had died). The effects of demographic, clinical, and pathologic variables on survival were tested with use of the log-rank test for categorical values. To identify independent predictors of survival, univariate and multivariate Cox regression analyses were performed simultaneously. Variables such as age, sex, race, tumor location, and histology from the univariate analyses were examined in the Cox multivariate analysis. Correlations between categorical variables were made with use of the z-test with p-values adjusted using the Bonferroni method. All analyses were performed using SPSS Statistics version 24.0 (IBM, New York, NY, USA), and a $p < .05$ was considered significant.

Missing Data

A total of 383 patients had missing data for the tumor size variable. The pairwise deletion method was utilized to deal with variables with missing data points. This method involves removing cases from analysis that are missing a certain data point, while retaining the case in the overall analysis when another data point is available. While there are some theoretical disadvantages to removing data as opposed to multiple imputation, which generates values for missing data, Van Ginkel et al. found that there was no difference in quality measures when comparing the 2 methods [8].

Results

The initial search in the SEER registry yielded 1,701 cases of chordoma diagnosed between 2000 and 2018. After excluding patients with soft tissue involvement (n = 354), appendicular involvement (n = 6), and patients with unknown metastatic state (n = 100), the final selected cohort included 1,241 patients with a 5- and 10-year disease-specific survival rate of 45% and 25%, respectively. A total of 9.4% (117/1,241) of patients presented with metastatic disease and the most common locations for metastasis at presentation were lung (6.0%), followed by bone (5.1%) and liver (3.4%). The demographic data of the study population are summarized in (Table 1).

The univariate logistic regression model revealed increased odds of metastatic disease at presentation among patients who had a tumor located in the sacrococcygeal area (OR = 1.72; 95% CI, 1.11–2.68; p = .015), a tumor with a dedifferentiated histological subtype (OR = 7.42; 95% CI, 2.31–23.79; p = .001) and a tumor size greater than 10 cm (OR = 4.57; 95% CI, 2.52–8.28; p < .0001). Upon multivariate regression, only patients with a dedifferentiated histological subtype remained at increased odds of metastatic disease at presentation (OR = 5.76; 95% CI, 1.50–22.15; p = .011) (Table 2).

When compared to patients younger than 60 years old, patients older than 60 with metastatic chordoma had worse 5- and 10-year disease specific survival, respectively (23% vs. 60%; p < .05) and (14% vs. 32%; p < .05). Further, in patients older than 60, the 15-year disease specific survival was 0%. (Figure 1A). The disease-specific survival rate, stratified according to histological subtype, revealed that patients with

Table 1
Demographic, and pathologic characteristics of patients.

Category	No metastatic disease (n [%])	Metastatic disease at presentation (n [%])	p-value
Age in years			
<60	639 (56.9%)	68 (58.1%)	>.05
≥60	485 (43.1%)	49 (41.9%)	>.05
Sex			
Male	654 (58.2%)	72 (61.5%)	>.05
Female	470 (41.8%)	45 (38.5%)	>.05
Race			
White	949 (84.4%)	100 (85.5%)	>.05
Black	48 (4.3%)	3 (2.55%)	>.05
Other	117 (10.4%)	13 (11.1%)	>.05
N/A	10 (0.9%)	1 (0.85%)	>.05
Location			
Skull Area	469 (41.7%)	38 (32.5%)	>.05
Vertebral Column	283 (25.2%)	27 (23.1%)	>.05
Sacrococcygeal and pelvic area	372 (33.1%)	52 (44.4%)	<.05
Histology			
Chordoma, NOS	1059 (94.2%)	102 (87.2%)	<.05
Chondroid Chordoma	58 (5.2%)	10 (8.5%)	>.05
Dedifferentiated Chordoma	7 (0.6%)	5 (4.3%)	<.05
Size			
≤5 cm	465 (41.4%)	30 (25.6%)	<.05
5–10 cm	236 (21.0%)	26 (22.2%)	>.05
>10 cm	78 (6.9%)	23 (19.7%)	<.05
N/A	345 (30.7%)	38 (32.5%)	>.05

N/A: Data not available.
NOS: Not otherwise specified

Table 2
Odd ratios for risk of presentation with metastatic disease.

Category	Model 1 (Unadjusted)	p-value	Model 2 (adjusted)*	p-value
Age in years				
<60	Ref		Ref	
≥60	0.95 (0.65–1.40)	.79	0.79 (0.47–1.34)	.38
Sex				
Female	Ref		Ref	
Male	1.15 (0.78–1.70)	.48	1.02 (0.62–1.66)	.95
Race				
White	Ref		Ref	
Black	0.59 (0.18–1.94)	.39	0.47 (0.11–2.03)	.35
Other	1.05 (0.57–1.94)	.86	1.09 (0.51–2.32)	.82
Location				
Skull Area	Ref		Ref	
Vertebral Column	1.18 (0.70–1.97)	.53	0.90 (0.43–1.90)	.68
Sacrococcygeal	1.72 (1.11–2.68)	.015	0.70 (0.34–1.45)	.23
Histology				
Chordoma, NOS	Ref		Ref	
Chondroid Chordoma	1.79 (0.89–3.61)	.10	2.31 (0.95–5.61)	.64
Dedifferentiated Chordoma	7.42 (2.31–23.79)	.001	5.76 (1.50–22.15)	.011
Size				
For each 1-cm increase	1.12 (1.07–1.17)		1.08 (0.99–1.17)	.09
≤5cm	Ref		Ref	
5–10 cm	1.71 (0.99–2.95)	.056	1.43 (0.72–2.85)	.30
>10cm	4.57 (2.52–8.28)	<.0001	2.6 (0.79–8.92)	.12

* Logistic regression controlling for age, sex, race, tumor location, histology, and size.

a dedifferentiated histological subtype had a dismal 5- and 10-year disease specific survival of 0%. NOS and chondroid histological subtypes had a 5-year survival of 47% and 42%, and a 10-year survival of 28% and 14% (Table 3, Figure 1B).

The Cox regression model with hazard ratios adjusted for age, gender, race, tumor location, and histological subtype showed that advanced age (hazard ratio, 2.06; 95% confidence interval, 1.18–3.60; $p < .011$) and dedifferentiated histological subtype (hazard ratio, 4.7; 95% confidence interval, 1.33–16.8; $p = .02$) as negative prognostic factors for survival in patients with metastatic chordoma (Table 4).

Discussion

Our analysis of the SEER database from 2008 to 2018 revealed that the rate of metastatic disease on presentation in patients with chordoma was 9.4%. The rates of metastatic disease in the setting of chordoma range widely in the literature with studies reporting a range from 3% to 48% [9,10]. A paucity of information on the rates of metastasis can be due, in part, to the rare incidence of chordoma, occurring only in 0.18 to 0.84 persons per million [11]. We found that dedifferentiated histological subtype, larger tumor size (> 10 cm), and sacrococcygeal tumor

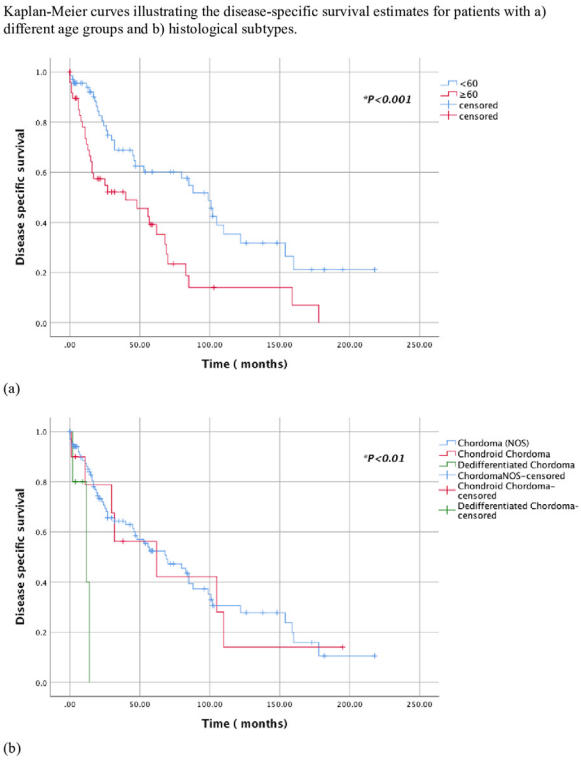

Figure 1. (A) and (B) Kaplan-Meier curves illustrating the disease-specific survival estimates for patients with (A) different age groups and (B) histological subtypes.

location were all associated with greater odds of metastatic disease at diagnosis.

Histologic grade of a tumor is a strongly negative prognostic indicator, with poorly differentiated tumors having a more aggressive course [12]. Specifically, in chordoma, features associated with the dedifferentiated histological subtype include classical physaliphorous cells intermixed with regions of atypia, necrosis, and elevated Ki-67 proliferation index [1,13]. These features are associated with poor survival. Our study lends further credence to these findings via a univariate and multivariate regression analysis which showed that dedifferentiated chordoma was associated with metastasis. Further, no patients with this subtype in our study survived longer than a year, while the 2 other subtypes – chondroid and NOS –had modest 5- and 10- year survival rates. A study by Hung et al. lends further credence to our finding, who suggest that the dedifferentiated subtype will develop metastases at a higher rate upon follow-up. A reason for this may include dysregulation of tumor suppressor genes, such as TP53, in dedifferentiated chordoma [14]. In general, metastasis of this tumor has a greater predilection for the lung, which in other primary spinal tumors portends the lowest rates of survival at 9% [15,16].

A previous SEER analysis performed by Pan et. al found that while chordoma did have a preference for the sacral region, it was not an inde-

Table 3
Disease-specific survival of patients with metastatic chordoma stratified by age, gender, race, tumor location, and histological subtype.

	DSS-5	DSS-10
Overall	45%	25%
Age (years)		
<60	60%	32%
≥60	23%	14%
Sex		
Female	38%	20%
Male	55%	27%
Race		
White	44%	26%
Black	60	-
Other	55%	18%
Location		
Skull area	89%	87%
Vertebral column	38%	15%
Sacrococcygeal	36%	15%
Histology		
Chordoma, NOS	47%	28%
Chondroid chordoma	42%	14%
Dedifferentiated chordoma*	-	-

DSS: Disease specific survival
* All patients died within 1 year of diagnosis.

Table 4
Prognostic factors for survival in metastatic chordoma.

	Model 1 (unadjusted)	p-value	Model 2 (adjusted)	p-value
Age in years				
<60	Ref		Ref	
≥60	2.31 (1.41–3.81)	.001	2.06 (1.18–3.60)	.011
Sex				
Female	Ref		Ref	
Male	0.77 (0.46–1.30)	.33	086 (0.50–1.47)	.58
Race				
White	Ref		Ref	
Black	1.08 (0.15–7.8)	.94	2.04 (0.26–16.24)	.50
Other	0.81 (0.35–1.90)	.62	0.77 (0.32–1.89)	.57
Tumor size*				
≤5 cm	Ref			
5–10 cm	2.23 (0.84–5.91)	.11	-	-
>10 cm	5.40 (2.11–13.7)	<.0001	-	-
Histology				
Chordoma, NOS	Ref		Ref	
Chondroid chordoma	1.05 (0.48–2.31)	.91	1.72 (0.72–4.11)	.22
Dedifferentiated chordoma	5.51 (1.60–19.0)	.007	4.7 (1.33–16.8)	.02
Location				
Skull area	Ref		Ref	
Vertebral column	2.42 (1.24–4.71)	.009	2.04 (0.26–16.2)	.50
Sacrococcygeal	2.12 (1.15–3.90)	.015	0.77 (0.32–1.89)	.57

Cox regression model with hazard ratios adjusted for age, gender, race, tumor location, and histological subtype.
* Tumor size was excluded from Cox regression due to missing data

pendent predictor of survival [6]. Upon multivariate adjusted analysis, we found that neither vertebral or sacrococcygeal tumor location conferred a decreased risk of survival, further validating Pan et al. conclusions. However, upon univariate regression, both sacrococcygeal tumor location and large tumor size (>10 cm) held associations with metastatic disease at presentation and decreased overall survival. Tumor size was not included in the final regression model because 383 patients did not have that information available. However, it is possible that more patients with metastatic disease did not have tumor size recorded because tumor size can be difficult to assess once metastasis has already occurred. From this, one can posit that large tumor size is fated to have an increased risk of metastasis at presentation, as is the case with a number of spinal metastases [17]. Further, when tumor size was treated as a continuous variable, each 1 cm increase in tumor size had a near significant effect on the final regression analysis. Sacrococcygeal chondroid tumors may result in a delay in diagnosis due to its insidious, slow-growing nature and vagueness of lower extremity symptoms [18]. For this reason, the tumor must grow to a considerable size before it is a candidate for MRI. By this point, a metastatic outcome may be inevitable. However, when detected early, there will be less of an impact on patient function when resected, due to the lack of vital organs in this area [1]. A primary for the sacrococcygeal location having a predilection for metastases may be due to anatomic factors, such as the proximity to important neurovascular structures. Early case series conducted on chordoma by Chambers et al. and Bjornsson et al. corroborate this assertion, as they reported higher rates of metastasis in the sacrococcygeal location compared to vertebral and cranial [19,20]. Chambers et al. viewpoint was that a practical reason for why this location is predisposed to metastasis could have to do with previous radiation exposure to the area which can artificially create features of anaplasia [20]. Further, Bjornsson et al. maintained that primary tumor size itself may not predict metastases but correlated positively with extent of regional necrosis, which provides some merit to our claim that larger tumors portend poorer survival, despite having some missing data for this variable [19]. Overall, our findings are consistent with primitive case series on this subject and allow us to contextualize their results using a larger patient sample.

An age of sixty years or more was an independent negative prognostic factor with metastatic disease. Previous studies have revealed a similar association in primary spinal chondroma metastasis [6,21]. However, it is unclear whether age itself is an independent predictor of decreased survival or if it is acting as a proxy for other age-related conditions. It is well established that spinal metastasis is much more likely to occur in elderly populations [22]. With the presence of numerous other age-related comorbidities, these patients are far more likely to undergo palliative care following this diagnosis, as opposed to an aggressive, surgical approach [23]. This may be especially true due to the likelihood of infection following resection of the tumor [24]. Often the management of these infections in the elderly can have a prolonged antibiotic course, leading to concerns of nephrotoxicity and impact on patient functional status [25]. For this reason, age may need to be explored further in metastatic chordoma, alongside other comorbidities of advanced age and treatment, to better assess its impact on survival.

This study has several limitations. First, chordoma is a disease of low incidence, so the utilization of the SEER database, which records cases of rare cancers, was required. As with any database study, unrecorded variables, incomplete treatment data, and variations in coding provide a significant challenge when attempting to make meaningful conclusions [26]. Similarly, in our study, many cases had missing information on histology, tumor size, and location of metastasis. For this reason, when constructing the final multiple regression models, histological subtype may have impacted the statistical power of the test due to the paucity of data presented. Second, the SEER program ceased the reporting of radiotherapy without explicit request. This may have had implications in our study, as dedifferentiated chordoma is commonly diagnosed as a recurrence following prior radiotherapy [27]. A documentation of a confounding variable of this nature may have provided more insight into the condition's metastatic nature. Third, missing patient data, as well as the use of pairwise deletion, may have introduced a level of bias into study. Use of multiple imputation and sensitivity analyses could have been considered to ameliorate some of these concerns. Fourth, determining actual cause of death was not possible, as there is no access to death certificates through SEER, so overall survival was reported under the assumption that mortality was due to chordoma. Similarly, there was lack of clarity on type and extent of surgical intervention, tumor recurrence, and margin status, which could have introduced another element to our study if analyzed. Lastly, treatments/treatment modalities were not assessed. Although this was not a focus of this study, further research should be done to address their outcomes.

Conclusions

In conclusion, dedifferentiated chordoma, sacrococcygeal location, and large tumor size (> 10 cm) were all associated with metastatic disease at presentation. Adverse prognostic factors also included advanced age and vertebral column location in patients with metastasis.

IRB approval

Per institutional guidelines, Institutional Review Board (IRB) approval was not required.

Ethical committee approval

Per institutional guidelines, institutional review board approval and informed consent were not required for this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Acknowledgments

There are no acknowledgements.

References

[1] Pennington Z, Ehresman J, McCarthy EF, et al. Chordoma of the sacrum and mobile spine: a narrative review. Spine J 2021;21(3):500–17.
[2] Chugh R, Tawbi H, Lucas DR, Biermann JS, Schuetze SM, Baker LH. Chordoma: the nonsarcoma primary bone tumor. Oncologist 2007;12(11):1344–50.
[3] Gokaslan ZL, Zadnik PL, Sciubba DM, et al. Mobile spine chordoma: results of 166 patients from the AOSpine Knowledge Forum Tumor database. J Neurosurg Spine 2016;24(4):644–51.
[4] Paavolainen P, Teppo L. Chordoma in Finland. Acta Orthop Scand 1976;47(1):46–51.
[5] Zuckerman SL, Bilsky MH, Laufer I. Chordomas of the skull base, mobile spine, and sacrum: an epidemiologic investigation of presentation, treatment, and survival. In: World Neurosurg, 113; 2018. p. e618–ee27.
[6] Pan Y, Lu L, Chen J, Zhong Y, Dai Z. Analysis of prognostic factors for survival in patients with primary spinal chordoma using the SEER Registry from 1973 to 2014. J Orthop Surg Res 2018;13(1):76.
[7] McMaster ML, Goldstein AM, Bromley CM, Ishibe N, Parry DM. Chordoma: incidence and survival patterns in the United States, 1973-1995. Cancer Causes Control 2001;12(1):1–11.
[8] Van Ginkel JR. Handling missing data in principal component analysis using multiple imputation. Essays on contemporary psychometrics methodology of educational measurement and assessment.. Switzerland, AG: Springer; 2023.
[9] Delank KS, Kriegsmann J, Drees P, Eckardt A, Eysel P. Metastasizing chordoma of the lumbar spine. Eur Spine J 2002;11(2):167–71.

[10] McPherson CM, Suki D, McCutcheon IE, Gokaslan ZL, Rhines LD, Mendel E. Metastatic disease from spinal chordoma: a 10-year experience. J Neurosurg Spine 2006;5(4):277–80.
[11] Bakker SH, Jacobs WCH, Pondaag W, et al. Chordoma: a systematic review of the epidemiology and clinical prognostic factors predicting progression-free and overall survival. Eur Spine J 2018;27(12):3043–58.
[12] Carriaga MT, Henson DE. The histologic grading of cancer. Cancer 1995;75(1 Suppl):406–21.
[13] Crapanzano JP, Ali SZ, Ginsberg MS, Zakowski MF. Chordoma: a cytologic study with histologic and radiologic correlation. Cancer 2001;93(1):40–51.
[14] Hung YP, Diaz-Perez JA, Cote GM, et al. Dedifferentiated chordoma: clinicopathologic and molecular characteristics with integrative analysis. Am J Surg Pathol 2020;44(9):1213–23.
[15] Bauer HC, Wedin R. Survival after surgery for spinal and extremity metastases. Prognostication in 241 patients. Acta Orthop Scand 1995;66(2):143–6.
[16] Meis JM, Raymond AK, Evans HL, Charles RE, Giraldo AA. Dedifferentiated" chordoma. A clinicopathologic and immunohistochemical study of three cases. Am J Surg Pathol 1987;11(7):516–25.
[17] Tschirhart CE, Finkelstein JA, Whyne CM. Biomechanics of vertebral level, geometry, and transcortical tumors in the metastatic spine. J Biomech 2007;40(1):46–54.
[18] Atalar H, Selek H, Yildiz Y, Saglik Y. Management of sacrococcygeal chordomas. Int Orthop 2006;30(6):514–18.
[19] Bjornsson J, Wold LE, Ebersold MJ, Laws ER. Chordoma of the mobile spine. A clinicopathologic analysis of 40 patients. Cancer 1993;71(3):735–40.
[20] Chambers PW, Chordoma Schwinn CP. A clinicopathologic study of metastasis. Am J Clin Pathol 1979;72(5):765–76.
[21] Huang Z, Fan Z, Zhao C, Sun H. A novel nomogram for predicting cancer-specific survival in patients with spinal chordoma: a population-based analysis. Technol Cancer Res Treat 2021;20:15330338211036533.
[22] Aebi M. Spinal metastasis in the elderly. Eur Spine J 2003;12 Suppl 2(Suppl 2):S202–13.
[23] Amelot A, Balabaud L, Choi D, et al. Surgery for metastatic spine tumors in the elderly. Advanced age is not a contraindication to surgery!. Spine J 2017;17(6):759–67.
[24] Zuckerman SL, Lee SH, Chang GJ, et al. Outcomes of surgery for sacral chordoma and impact of complications: a report of 50 consecutive patients with long-term follow-up. Global Spine J 2021;11(5):740–50.
[25] Young MH, Washer L, Malani PN. Surgical site infections in older adults: epidemiology and management strategies. Drugs Aging. 2008;25(5):399–414.
[26] Jairam V, Park HS. Strengths and limitations of large databases in lung cancer radiation oncology research. Transl Lung Cancer Res 2019;8(Suppl 2):S172–SS83.
[27] Hanna SA, Tirabosco R, Amin A, et al. Dedifferentiated chordoma: a report of four cases arising 'de novo. J Bone Joint Surg Br 2008;90(5):652–6.