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A case-control study of computer navigation assisted resection of primary sacral chordoma above sacrum 3 level

Yongkun Yang, Yuan Li, Qing Zhang, Xiaohui Niu*

Department of Orthopedic Oncology Surgery, Beijing Ji Shui Tan Hospital, Peking, University, Beijing, People's Republic of China

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ABSTRACT

Background: The operation of sacral chordoma resection is difficult especial in the tumor above sacrum 3 level and the local recurrence rate was high. The purpose of this study is to analyze the effect of computer navigation aided technology in primary sacral chordoma resection above sacrum 3 level through a case-control study, which including perioperative safety, surgical margin, postoperative recurrence and function results.

Methods: This is a retrospective case-control study. The clinical data of 25 patients received initial computer-assisted resection of sacral chordoma above the level of sacrum 3 from 2009 to 2016 were analyzed; the patients underwent non-navigation assisted resection of tumor above the level of sacrum 3 in the same period were matched and 25 patients were selected randomly. There was no significant difference between these two groups in gender ($P = 0.370$), age ($P = 0.554$), tumor transverse diameter ($P = 0.836$). The average maximum diameter of tumor in navigation group was significant bigger than that in non-navigation group ($P = 0.005$). The intraoperative safety results, surgical margin, postoperative complications, recurrence rate and function were compared between these groups.

Results: There was no significant difference between navigation and non-navigation group in operative time ($P = 0.105$) and intraoperative blood loss ($P = 0.537$). There were 18 wide resections, 4 marginal resections and 3 intracapsular resections in navigation group; there were 6 wide resections, 12 marginal resections and 7 intracapsular resections in non-navigation group; the surgical margins of two groups were significant different ($P = 0.003$). There were 5 cases (20%) and 6 cases (24%) with wound complication in navigation group and non-navigation group ($P = 0.733$). The average follow-up was 49.6 (16–102) months in navigation group and 51.3 (12–110) months in non-navigation group. Three cases (12%) showed recurrence in navigation group and six cases showed recurrence (24%) in non-navigation group. The surgical margin was significantly related with tumor recurrence ($P = 0.000$). The average MSTS score was 27.3 (19–30) and 26.5 (20–29) in navigation group and non-navigation group ($P = 0.374$).

Conclusion: The computer navigation aided technology can improve the accuracy of primary sacral chordoma resection, and make more cases achieve safe surgical margin. Compared with the traditional operation, the application of computer navigation in the larger tumor resection does not increase the operation time and intraoperative blood loss, which shows good safety.

1. Introduction

The sacrum has a special anatomical structure with irregular and complex shape, in which the sacral nerve passes through. The anterior of the sacrum is adjacent to the pelvic organs and large blood vessels. Chordoma is a kind of primary malignant bone tumor originated from residual chordate embryo tissue. Most of the chordomas occur at sacrococcygeal and skull base. At the same time, chordoma is one of the most common primary malignant tumors in sacrum [1]. The operation of sacral chordoma resection is difficult especial in the tumor above sacral 3 level. This is due to different reasons: anteverted and deeper anatomical structure obscured by ilium; difficulty in judging tumor boundary during operation; difficulty in grasping correct osteotomy level and direction during tumor resection; large amount of intraoperative bleeding increasing the instability of operation; and sacrificing the surgical margin of tumor resection in order to preserve sacral nerve. Inappropriate surgical margin may lead to high recurrence rate [2,3]. According to the previous literature [4–6,7], the postoperative local recurrence rate of sacral chordoma was relatively high. The recurrence rates reported in different studies were quite different

* Corresponding author.
E-mail address: niuxiaohui@263.net (X. Niu).

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which ranged between 25% and 85%. The recurrence rate in group above S3 was significantly higher than that in group below S3 [7]. Therefore, it is worth studying whether the safe surgical margin and satisfactory outcome of chordoma above sacral 3 can be obtained by improving the accuracy of operation.

Computer navigation assisted surgery has been gradually applied in clinical practice. In orthopedic field, it was initially applied in the surgery of spine and joint. Computer navigation showed some advantages in improving the accuracy of surgery. In recent years, navigation technology has been gradually applied to the surgical treatment of bone tumors [8–11]. It was initially applied especially in the resection of tumors in the areas with complex anatomical structure such as spine, pelvis and sacrum, or in the operation requiring precise design of resection and reconstruction such as tumor resection with joint reservation and artificial prosthesis reconstruction [12,13]. Some reports on the clinical results of computer-assisted resection of sacral chordoma [14–18] were presented, but the number of cases is relatively small and there is a lack of comparative study with non-navigation surgery to compare the accuracy and objective effect of surgery.

The purpose of this study is to analyze the effect of navigation technology in primary sacral chordoma resection above the level of sacrum 3 through case-control study, which including perioperative safety, surgical margin, postoperative recurrence and function.

2. Materials and methods

2.1. Enrollment of the patients

This is a retrospective case-control study. Inclusive criteria: chordoma was diagnosed pathologically; the highest level of the tumor was above the level of sacrum 3; patient received initial computer-assisted tumor resection in our department; clinical follow-up data was complete. A total of 25 patients were included according to the above conditions from 2009 to 2016 (Table 1). There were 15 males and 10 females with an average age of 54.0 (35–84). The patients were routinely examined with local radiograph, CT and MRI, chest CT and whole body bone scan (Fig. 1) before operation. The average maximum diameter of tumor was 11.8 (5.2–22.1) cm and the average transverse diameter was 7.4 (4.8–13.0) cm.

The patients who underwent non-navigation assisted resection of sacral chordoma above the level of sacrum 3 in the same period (2009–2016) were matched and 25 patients were selected randomly (Table 1). There were 18 males and 7 females with an average age of 56.1 (28–79) years. The average maximum diameter of tumor was 9.2 (5.0–17.2) cm, and the average transverse diameter was 7.2 (4.2–14.0) cm.

There was no significant difference between navigation and non-navigation group in gender (P = 0.370, chi square = 0.802), age (P = 0.554, chi square = 0.355), tumor transverse diameter (P = 0.836, f = 0.044). The average maximum diameter of tumor in navigation group was significant bigger than that in non-navigation group (P = 0.005, f = 8.715) (Table 1).

2.2. Operation process

The surgical plan in the navigation group was designed with navigation system before operation. The preoperative CT and MRI data were imported into the computer navigation workstation. The tumor area was drawn on CT and MRI images respectively. Then the CT and MRI images were fused together (Fig. 2). The planned osteotomy line and resection range were marked at a distance of 1.5 cm from the edge of the tumor (Fig. 3). Posterior approach was used in all operations. During the operation, the registration and scanning of the navigation system were carried out, and then the image planned before the operation was fused with the images scanned during the operation. The safe osteotomy line and resection range were marked under the guidance of intraoperative navigation system (Figs. 4–5). The navigation system helped to verify whether the planned resection boundary was obtained again after tumor resection. The patients in the non-navigation group received tumor resection without the assistance of computer navigation system. The tumor specimen was soaked in formalin and then cut for the analysis of the actual surgical margin after the operation (Fig. 6).

2.3. Postoperative follow-up

The patients were followed up every 3 months after the operation. The re-examination items included local radiograph and CT (Fig. 7), chest CT and whole body bone scan. The tumor recurrence and MSTS function score were recorded.

2.4. Statistical analysis

SPSS 22.0 (SPSS Corporation, USA) statistical software was used for data analysis. The continuous variables were compared with the mean *t* test and the classified variables were compared with the Chi square test or Fisher exact probability method. $P < 0.05$ was considered as statistically significant.

3. Results

3.1. Intraoperative safety

All patients in navigation group received the operation according to the surgical plan designed in the preoperative navigation system and the navigation assisted operations were performed successfully. The average registration error of navigation system was 1.3 (0.4–1.8) mm and the average time of navigation registration and scanning was 20.7 (14–30) minutes. The average operative time was 270.8 (180–420) minutes and the average intraoperative blood loss was 3072 (400–6000) ml (Table 2). In non-navigation group, the average operation time was 240.7 (120–360) minutes and the average

Table 1
General clinical features of navigation group and non-navigation group.

Characteristics		Navigation group	Non-navigation group	P values
Period		2009–2016	2009–2016	
Cases		25	25	
Gender				0.370
Male		15	18	
Female		10	7	
Age (mean (range), years)		54.0 (35–84)	56.1(28–79)	0.554
Tumor level	S3 and below	9	13	
	S2 and below	15	12	
	S1 and below	1	0	
Maximum diameter of tumor (mean (range), cm)		11.8(5.2–22.1)	9.2(5.0–17.2)	0.005
Transverse diameter of tumor (mean (range), cm)		7.4(4.8–13.0)	7.2(4.2–14.0)	0.836

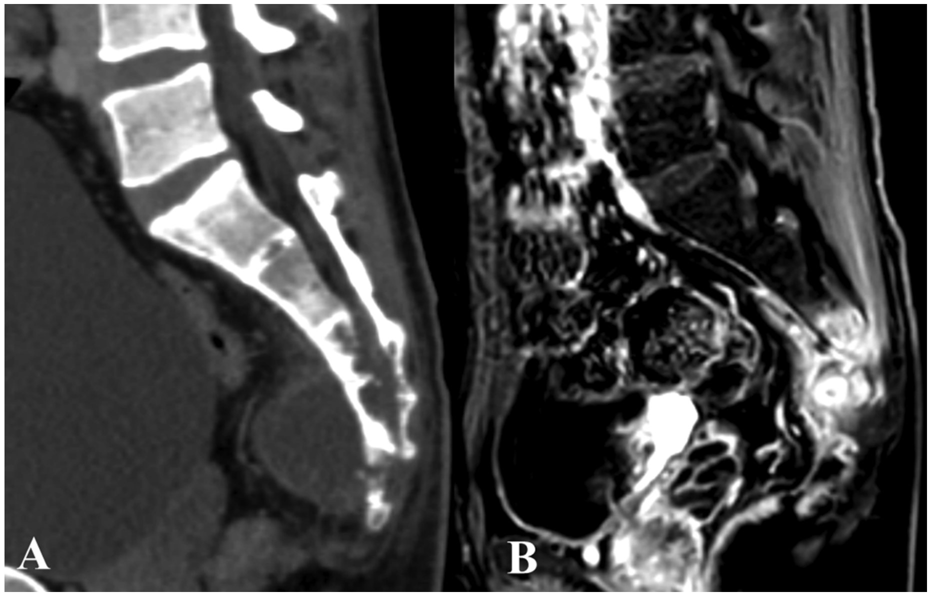

Fig. 1. The preoperative CT (A) and MRI (B) of sacrum showed the extent and level of sacral chordoma.

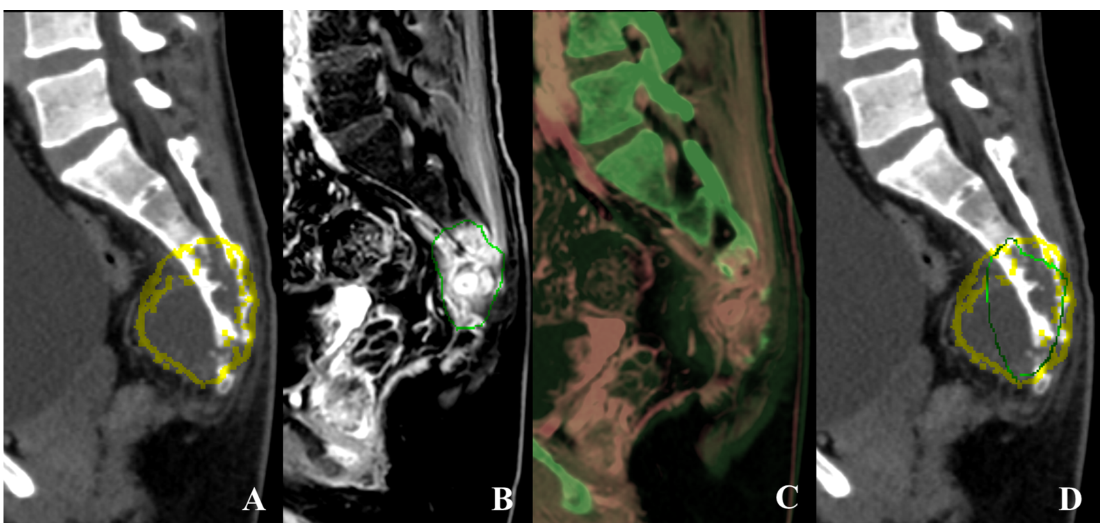

Fig. 2. The preoperative surgical planning was designed in the navigation workstation. The tumor areas were drawn on CT (A, yellow area) and MRI (B, green area) images, respectively. Then the CT and MRI images were fused together (C). Thus the tumor areas drawn on CT and MRI images were presented together for more precise design (D). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

intraoperative blood loss was 2826.1 (800–6500) ml. There was no significant difference between these two groups in operative time ($P = 0.105$, $f = 2.738$) and intraoperative blood loss ($P = 0.537$, $f = 0.387$).

3.2. Surgical margin

The analysis of surgical margin according to tumor specimens showed that there were 18 cases with wide resection, 4 cases with marginal resection and 3 cases with intracapsular resection in the navigation group. The clear bone resection margins were achieved in all cases in navigation group. There were 6 cases with wide resection, 12 cases with marginal resection and 7 cases with intracapsular resection in the non-navigation group (Table 2). The surgical margins of these two groups were significant different ($P = 0.003$, chi square value = 11.6).

3.3. Postoperative complications

There were 5 cases (20%) with wound complication in the navigation group. Two cases developed wound infection after operation. Local flap or myocutaneous flap was transferred and covered the wound after debridement, and then the wound healed well. The delayed wound healing occurred in 3 cases and recovered after repeating wound dressing. There were 6 cases (24%) with wound complication in the non-navigation group which contained 2 cases with wound infection and 3 cases with delayed wound healing. All the wounds healed well after debridement and wound dressing. The incidence of wound complications showed no significant difference between these two groups ($P = 0.733$, chi square value = 0.117).

3.4. Postoperative recurrence

The average follow-up was 49.6 (16–102) months in navigation group. Three cases showed recurrence (12%) and the recurrence time was 14–48 months postoperative. All the recurrence cases received

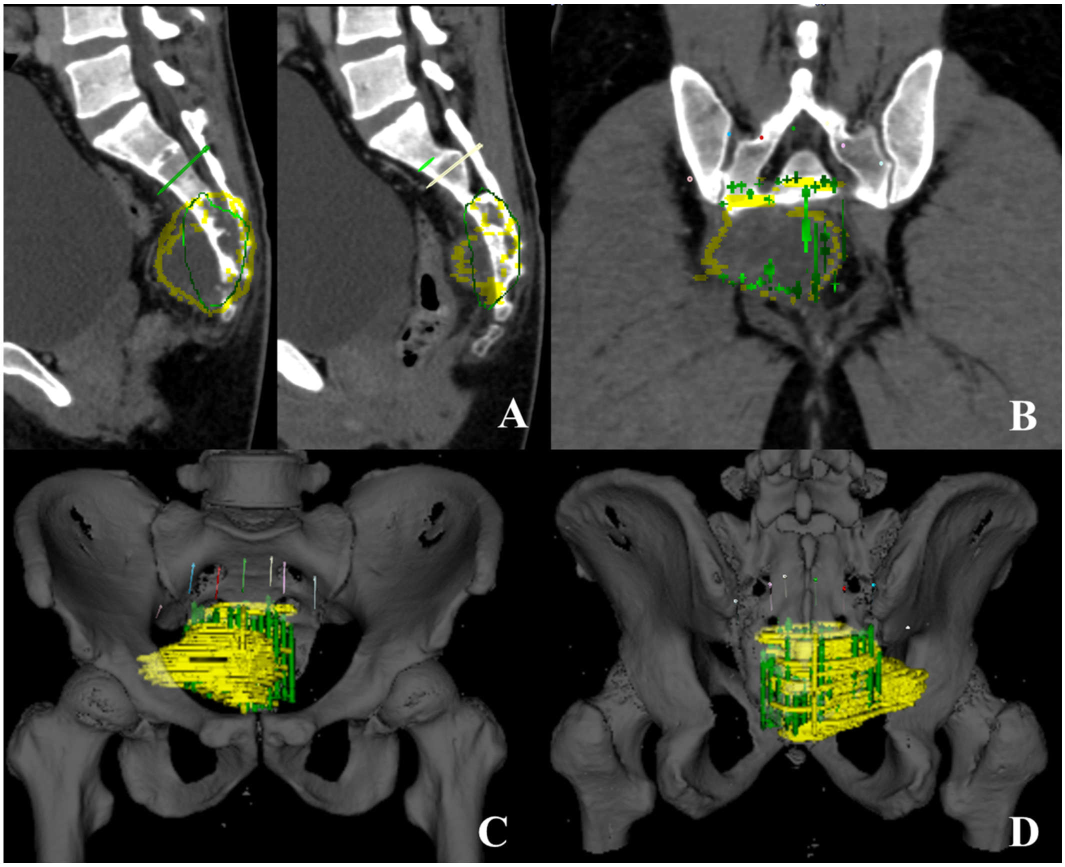

Fig. 3. The planned osteotomy line and resection range were marked at a distance of 1.5 cm from the edge of tumor in the navigation system. Some fictitious screws with different colors were set up on the preoperative images (Sagittal (A) and coronal (B) images) as the markers of tumor resection. Three dimensional images (anterior (C) and posterior (D)) showed the tumor range and the marked resection boundary clearly. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

intracapsular resection because the tumor was large and extensive. The surgical margin was significantly related with tumor recurrence (P = 0.000, chi square = 25.000) (Table 3). Two of them could not get a better surgical margin because of the tumor involvement of sacrospinal ligament at the pelvic end, although the safe boundary designed in navigation system was obtained at the site of sacroctomy. The whole sacrum was involved in another case and extended curettage was performed in order to preserve the sacral nerves. Two patients underwent re-operation after recurrence and one of them underwent hemipelvic amputation. They were still alive without recurrence. Another patient refused re-operation and received radiotherapy after recurrence, and now survived with tumor (Table 4).

The average follow-up was 51.3 (12–110) months in non-navigation group. Six cases showed recurrence (24%) and the recurrence time was 16–43 months postoperative. Five cases of them received intracapsular resection and one case received marginal resection. Surgical margin was significantly related with tumor recurrence (P = 0.000, chi square = 20.301) (Table 3). The recurrence rate of the two groups showed no significant difference (P = 0.269, chi square value = 1.220) (Table 2).

3.5. Postoperative function

Up to the final follow-up, the average MSTS score was 27.3 (19–30) and 26.5 (20–29) in navigation group and non-navigation group. The MSTS scores of patients in navigation group were above 26 with good daily life and limb activity except for one case who received hemipelvic amputation due to recurrence. There was no significant different in MSTS scores between these two groups (P = 0.374, f = 0.812).

4. Discussion

The risk of surgical treatment of sacral chordoma is high and the tumor tends towards local recurrence. A recently systematic review [19] which contained 57 studies with 1235 sacral chordoma cases showed that the local recurrence rate was 42.6%. The application of computer-aided navigation technology in orthopedic surgery is increasing gradually, and it also plays an active role in the resection and reconstruction of bone tumors [8–11]. The navigation technology can transform the two-dimensional images of CT and MRI into three-dimensional images, display the three-dimensional structure and relative position of the tumor and its surrounding tissues. The images can be displayed in real time during the operation, thus providing guidance and reference for surgeon [20]. More importantly, we can carry out accurate preoperative design which includes the scope of tumor and the planned resection with navigation system. Malignant bone tumors need to obtain safe resection margin. On this basis, normal structures should be preserved for reconstruction and functional recovery. Therefore, the precise preoperative design and intraoperative real-time indication of navigation are helpful for the precise resection and reconstruction of malignant bone tumors. In current study, we compare the clinical results of navigation and non-navigation assisted resection of primary sacral chordoma above the level of sacrum 3, and analyze the characteristics and advantages of navigation technology through a case-control study.

The present study showed that there was no significant difference between navigation group and non-navigation group in operative time and intraoperative blood loss. There was no significant increasing in operative time or due to navigation, or increased intraoperative blood

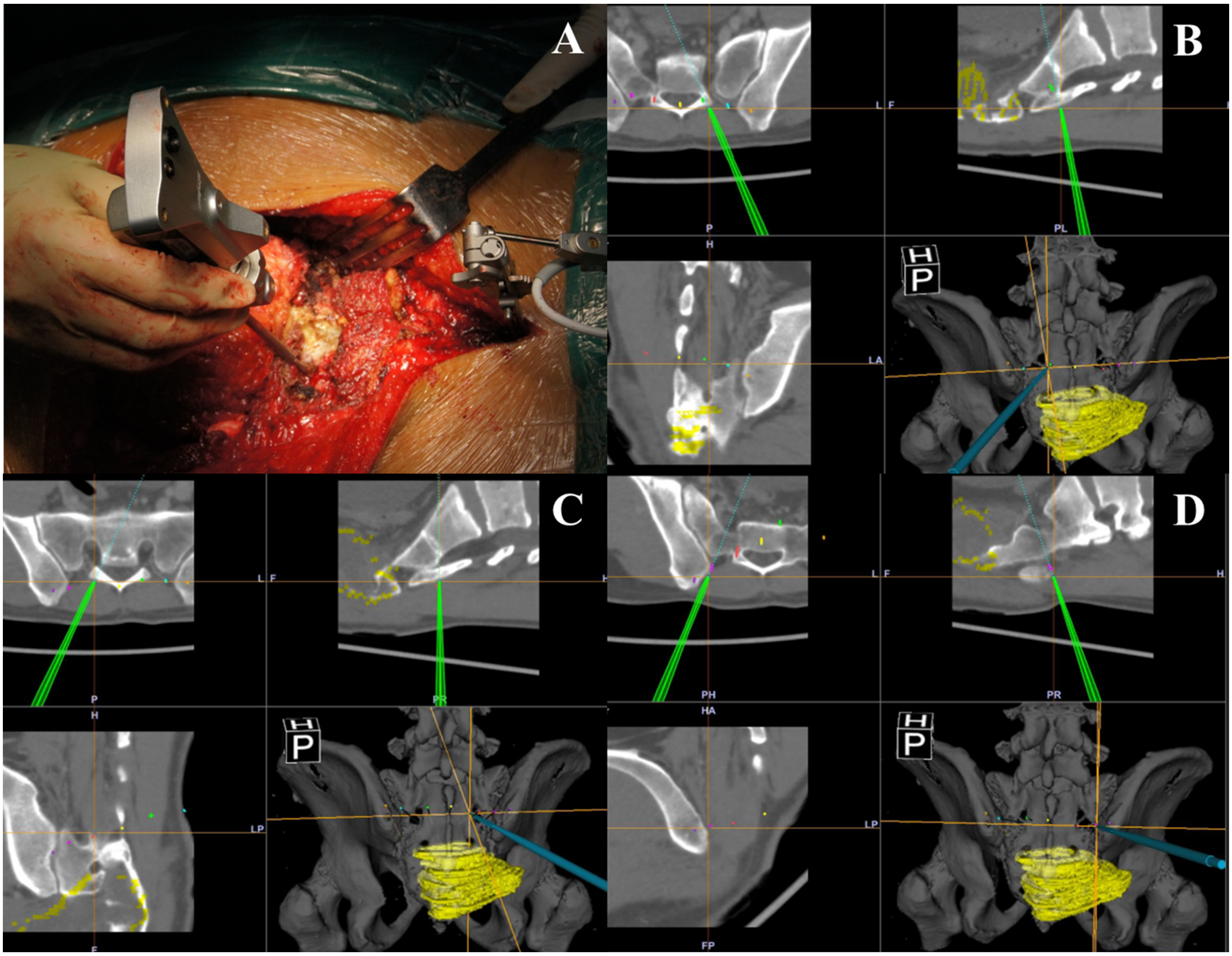

Fig. 4. The application of intraoperative navigation system. The safe osteotomy line and resection range were marked under the guidance of intraoperative navigation system (A). The real time intraoperative images in the navigation system showed the preoperative surgical plan and the pointer was putting on the accurate position of the fictitious screw (B-D).

loss due to prolonged operative time. Compared with non-navigation surgery, intraoperative navigation requires additional steps such as registration and scanning. Although registration and scanning process took an average of 22.7 min in this study, it didn't significantly increase the overall operation time. Moreover, the navigation registration and scanning was performed before the separation of tumor surrounding tissue and osteotomy. There was usually not a large amount of bleeding in this process and therefore the overall intraoperative blood loss didn't increase significantly. It can be seen that navigation assisted resection of sacral chordoma has good intraoperative safety. So we may eliminate the concerns about increasing the risk of intraoperative bleeding and operative time due to the complex procedure of navigation system.

The analysis of surgical margin in this study showed that wide resection was obtained in 18/25 of the cases in navigation group and 6/25 of the cases in non-navigation group. The surgical margins were significant different between these two groups. More safe surgical margins and less inappropriate resections were found in the navigation group. Computer navigation aided surgery is helpful to obtain safe surgical resection of sacral tumor which is due to the precise preoperative plan, operation under the guidance of real-time navigation, osteotomy according to the plan, and immediate verification after osteotomy. Although there are also preoperative plans for non-navigation assisted surgery, it is mainly based on the experience of the surgeon. Therefore, there may be errors in judging the level of sacrum and tumor boundary during the operation. There is possible deviation in the actual operation of osteotomy which cannot be found in time.

Varga et al. [2] analyzed the prognostic variables for local recurrence after sacral chordoma resection and presented that the surgical margin was a significant factor. Ruosi et al. [3] also reported that surgical margin had significant influence on local recurrence of sacral chordoma. Tao J et al. [21] followed the outcomes of 115 patients with sacral chordoma after surgical treatment and found that the patients with adequate surgical margins displayed a higher 5-year survival than those with an inadequate margin (86% versus 67%). Yongkun Y et al. [7] analyzed 171 cases of sacral chordoma and clinical results suggested that tumor level in sacrum and surgical margin were significant factors influencing recurrence. Unsafe surgical margin will lead to postoperative recurrence. Although some recurrent tumors can be managed by reoperation, the difficulty of obtaining clear margin by reoperation will increase and the recurrence rate will increase accordingly due to the contamination and unclear structures after the primary operation [22]. The systematic review [19] showed that overall median survival for patients with and without recurrence were 98 and 209 months after surgery. The survival time of patients with sacral chordoma is relatively long and repeated recurrence will seriously affect the quality of life of patients.

In the present study, the recurrence rate of patients was 12% in navigation group and 24% in non-navigation group (24%) after more than 4 years follow-up in average. All the recurrence occurred in patients with intracapsular resection of tumor in navigation group. The

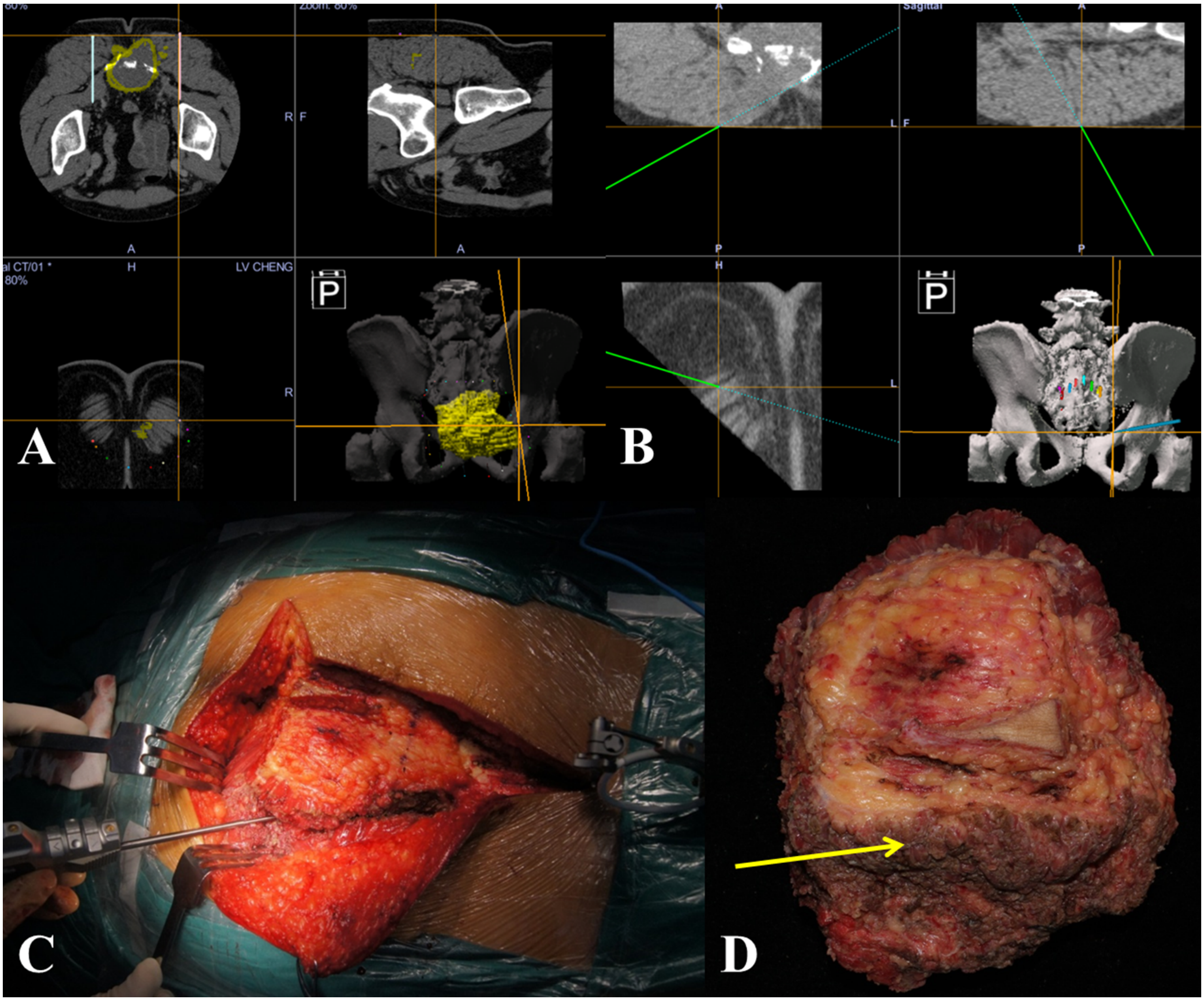

Fig. 5. The navigation system can help to confirm the resection margin of soft tissue mass. The extent of soft tissue mass was drawn on the preoperative images in the navigation system (A). The images of intraoperative navigation showed whether the pointer was putting on the correct resection margin of soft tissue mass (B and C). The tumor specimen showed that the planned resection margin of soft tissue mass was obtained (D).

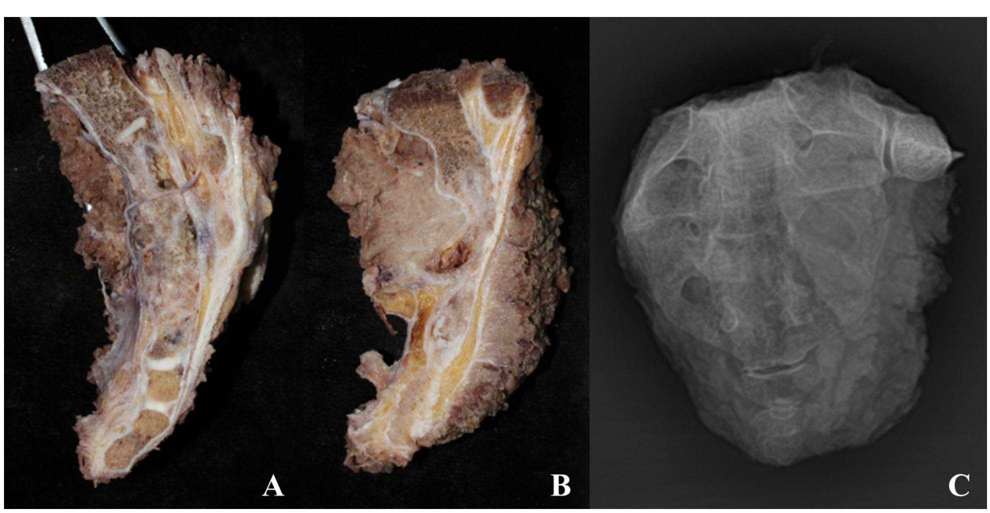

Fig. 6. The tumor specimen was soaked in formalin and then cut for the analysis of the surgical margin (A and B). The wide surgical margin was obtained on bone and soft tissue resection of tumor. The imaging examination of tumor specimen also helped to confirm the extent of tumor resection (C).

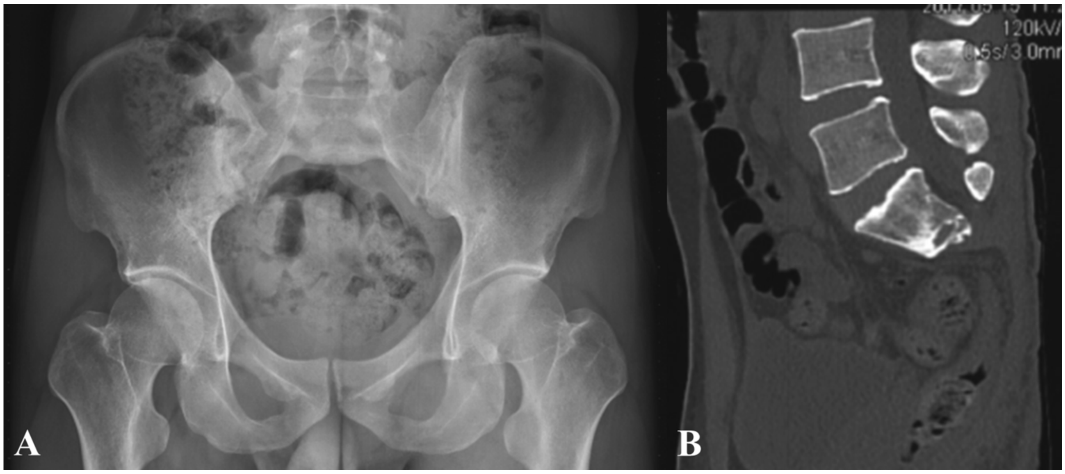

Fig. 7. The postoperative radiograph (A) and CT (B) showed clear tumor resection and no tumor recurrence.

Table 2
Clinical results of navigation group and non-navigation group.

Results		Navigation group	Non-navigation group	P values
Operative time (mean (range), mins)		270.8(180–420)	240.7(120–360)	0.105
Intraoperative blood loss (mean (range), ml)		3072(400–6000)	2826.1(800–6500)	0.537
Surgical margin				0.003
Wide		18	6	
Marginal		4	12	
Intracapsular		3	7	
Recurrence		3 (12%)	6 (24%)	0.269
Wound complications		5 (20%)	6 (24%)	0.733
MSTS scores (mean (range))		27.3 (19–30)	26.5 (20–29)	0.374
Transverse diameter of tumor (mean (range), cm)		7.4(4.8–13.0)	7.2(4.2–14.0)	0.836
Sacrifice of nerve roots	Bilateral S3	8	11	
	Unilateral S2	8	9	
	Bilateral S2	6	5	
	Unilateral S1	3	0	

Table 3
The comparison of recurrence rates between cases with different surgical margin.

Group	Surgical margin			P values
	Wide	Marginal	Intracapsular	
Navigation group (recurrence rate)	0 (0/18)	0 (0/4)	100% (3/3)	0.000
Non-navigation group (recurrence rate)	0 (0/6)	8.3% (1/12)	71.4% (5/7)	0.000

surgical margin was significantly related with tumor recurrence both in navigation group and non-navigation group. Although the safe margin designed in navigation system was obtained at the site of sacroctomy, two cases could not get wide margin because of tumor involvement of sacrospinal ligament at the pelvic end. The whole sacrum was involved in another case and extended curettage was performed in order to preserve the sacral nerves in navigation group. It is very important for local control to obtain a safe surgical margin by careful preoperative planning and strict operation. Although the recurrence rate in non-navigation group was twice as high as that in navigation group, but the difference was not statistically significant due to the number of cases was relatively small.

Radaelli S et al. [23] reported long-term outcome of 99 patients surgically treated at two reference centers and showed overall survival (OS) were 92, 45 and 36% at 5, 10, and 15 year, respectively. The incidence of local recurrence was 30% and 18% at 5 years and 10 years. Another large series of patients in a single institute [7] showed the 3-

Table 4
The oncological results of reported cases series of sacral chordoma.

Series	Publishing time	Number of Patients	Follow up (yrs)	OS Rate	DFS Rate
Baratti et al. [4]	2003	56	Median 5.9	92% at 5 years 49% at 10 years	45% at 5 years 24% at 10 years
Fuchs et al. [24]	2005	53	Median 7.8	52% at 10 years	46% at 10 years
Ruggieri et al [30]	2010	56	Median 9.5	71% at 10 years	52% at 10 years
Varga et al [2]	2015	167	Median 3.2	40% at 10 years	75% at 10 years
Radaelli et al. [23]	2016	99	Median 8.7	45% at 10 years	62% at 10 years
Tao at al. [21]	2017	115	Mean 4.9	81% at 5 years	52% at 5 years
Yang et al. [7]	2017	171	Median 4.1	88% at 5 years	83% at 3 years

OS: overall survival.
DFS: disease free survival.

year recurrence free survival rate was 83.1% and the 5-year OS was 88.3%. Baratti et al. [4] reported 5-year and 10-year tumor-free survival rates of 60.6% and 24.2%, respectively. Fuchs et al. [24] reported 5-year and 10-year tumor-free survival rates of 59% and 46% and OS of 74% and 52%, respectively. Tao J at al. [20] reported 5-year tumor-free survival rate was 52% and the 5-year OS was 81%. The posterior approach was applied in the resection of sacral chordoma in our study. Some reports [25–28] showed satisfactory oncological results tumor resection with posterior approach, and the 5-year recurrence rate was between 20% and 30% which seemed lower than that with the combined anterior approach.

The present study showed that there was no significant difference in the incidence of wound complications between navigation group and non-navigation group. The problem of poor wound healing or delayed healing and even infection was common after the operation of sacral tumor. Most of the wound complications can be resolved through dealing with it in time and patiently. The mean MSTS score was 27.3 and 26.5 in navigation group and non-navigation group up to the final follow-up. There was no significant difference between two groups and most of the patients were satisfied with daily function. The MSTS scores were all above 26 except for one case who received hemipelvic amputation due to recurrence in the navigation group.

The number of cases in our study is relative small. This is due to the low incidence rate and the inclusive condition is strict. Because the resection of tumor above sacral 3 was more difficult, only primary tumors above sacral 3 were contained in our study. But most sacral chordomas originate below sacral 3 as we known, so there are fewer proper cases. Most of clinical characteristics in two groups matched with each other except the tumor size. The tumor in navigation group was larger than that in non-navigation group. It might be the potential factor in deciding whether to use navigation system during the planning of surgical treatment. This choice bias was difficult to eliminate in the retrospective study. However, more safety margins and fewer recurrences were found in navigation group even if the tumors were larger. The operation time and intraoperative blood loss did not increased significantly as the results showed. Therefore, it suggests the positive effect of computer-aided navigation technology in the resection of large tumor with complex anatomical structure. Different from the previous studies, the current case-control study compared the results of two groups operated in the period in the same department. Thus the results should be more objective.

5. Conclusion

The computer navigation aided technology can improve the accuracy of sacral chordoma resection, and make more cases achieve safe surgical margin. Compared with the traditional operation, the application of computer navigation in the larger tumor resection does not increase the operation time and intraoperative blood loss, which shows good safety.

Declaration of competing interest

None.

CRediT authorship contribution statement

Yongkun Yang: Methodology, Data curation. **Yuan Li:** Data curation, Investigation. **Qing Zhang:** Investigation. **Xiaohui Niu:** Conceptualization, Supervision.

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