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Surgical Strategy and Application of Robotic-Assisted Benign Sacral Neurogenic Tumor Resection

Hui Wu, MD[‡*]
Yi-wei Fu, MD[§*]
Zhen-hua Gao, MD[||]
Zhi-hai Zhong, MD[¶]
Jing-nan Shen, MD[§#]
Jun-qiang Yin, MD[§#]

[‡]Department of Gastrointestinal Surgery, the First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, Guangdong, China; [§]Department of Musculoskeletal Oncology, the First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, Guangdong, China; [||]Department of Radiology, the First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, Guangdong, China; [¶]Department of Pediatric Surgery, the First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, Guangdong, China; [#]Guangdong Provincial Key Laboratory of Orthopedics and Traumatology, the First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, China

*Hui Wu and Yi-wei Fu contributed equally to this work.

Correspondence:
Jun-qiang Yin, MD,
Department of Musculoskeletal Oncology, the First Affiliated Hospital of Sun Yat-Sen University,
58 Second Zhongshan Rd,
Guangzhou, Guangdong 510080, China.
Email: yinjunq@mail.sysu.edu.cn

Jing-nan Shen, MD,
Department of Musculoskeletal Oncology, the First Affiliated Hospital of Sun Yat-Sen University,
58 Second Zhongshan Rd,
Guangzhou, Guangdong 510080, China.
Email: shenjn@mail.sysu.edu.cn

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BACKGROUND: Robotic surgery may be advantageous in neurogenic sacral tumor resection but only a few studies reported robotic-assisted neurogenic sacral tumor resection.

OBJECTIVE: To propose a new surgical strategy for robotic-assisted benign sacral neurogenic tumor resection and introduce the ultrasonic osteotomy surgical system in robotic surgery.

METHODS: Twelve patients who had robotic-assisted primary benign sacral neurogenic tumor resection between May 2015 and March 2021 were included. Our surgical strategy divides tumors into 4 types. Type I: Presacral tumors with diameter <10 cm. Type II: Narrow-base tumors involving the sacrum with diameter <10 cm. Type III: Broad-base tumors involving the sacrum with diameter <10 cm. Type IV: Tumors involving sacral nerve roots ≥2 levels and/or with diameter ≥10 cm.

RESULTS: Five type I, 5 type II, and 1 type III patients underwent tumor resection via an anterior approach, and 1 type IV patient via a combined approach. The median operation time, blood loss, and postoperative hospital stay of type I and II were much less than those of type IV. The ultrasonic osteotomy surgical system facilitated osteotomy in 2 type II and 1 type III patients. Eleven patients had total resections, and 1 type III patient had a partial resection. During the follow-up period of 7.9 to 70.9 months (median: 28.5 months), no local recurrences or deaths were noted.

CONCLUSION: With the largest single-center series to our knowledge, this surgical strategy helped to guide robotic-assisted benign sacral neurogenic tumor resection. The ultrasonic osteotomy surgical system was effective for type II and III.

KEY WORDS: Benign sacral neurogenic tumor, Case series, Robotic-assisted surgery, Surgical strategy, Ultrasonic osteotomy surgical system

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Primary sacral neurogenic tumors are rare and mostly benign tumors or low-grade malignancies.[1] The sacrum is adjacent to vital tissues and organs, such as sacral nerves, iliac vessels, bladder, rectum, uterus, etc. Complex pelvic anatomic structure poses a great challenge to the complete resection of primary sacral tumors.[2,3] Traditional open surgery can be performed via the anterior, posterior, and combined anterior-posterior approaches, with common perioperative complications including massive hemorrhage, nerve damage, and unhealed wounds.[4,5] To achieve good therapeutic outcomes, the robotic system is increasingly applied in abdominal surgery because of its magnified vision, precise movement, and high flexibility.[6,7] Several reports have demonstrated its efficiency in neurogenic sacral tumor resection.[8-11] However, current surgical classifications of neurogenic sacral tumor resection are not based on robotic-assisted surgery and provide little guidance in robotic-assisted neurogenic sacral tumor resection.

One of the limitations of robotic system is that it is not designed for osteotomy and not compatible with traditional osteotomes. The ultrasonic osteotomy surgical system was useful in minimally invasive osteotomy but its application in robotic surgery has not been reported to our knowledge.

In this study, we aimed to report the largest single-center series of robotic-assisted benign sacral neurogenic tumor resection to date, propose a new surgical strategy based on robotic-assisted benign sacral neurogenic tumor resection, and describe its application. The further objective of this study was to report for the first time the use of

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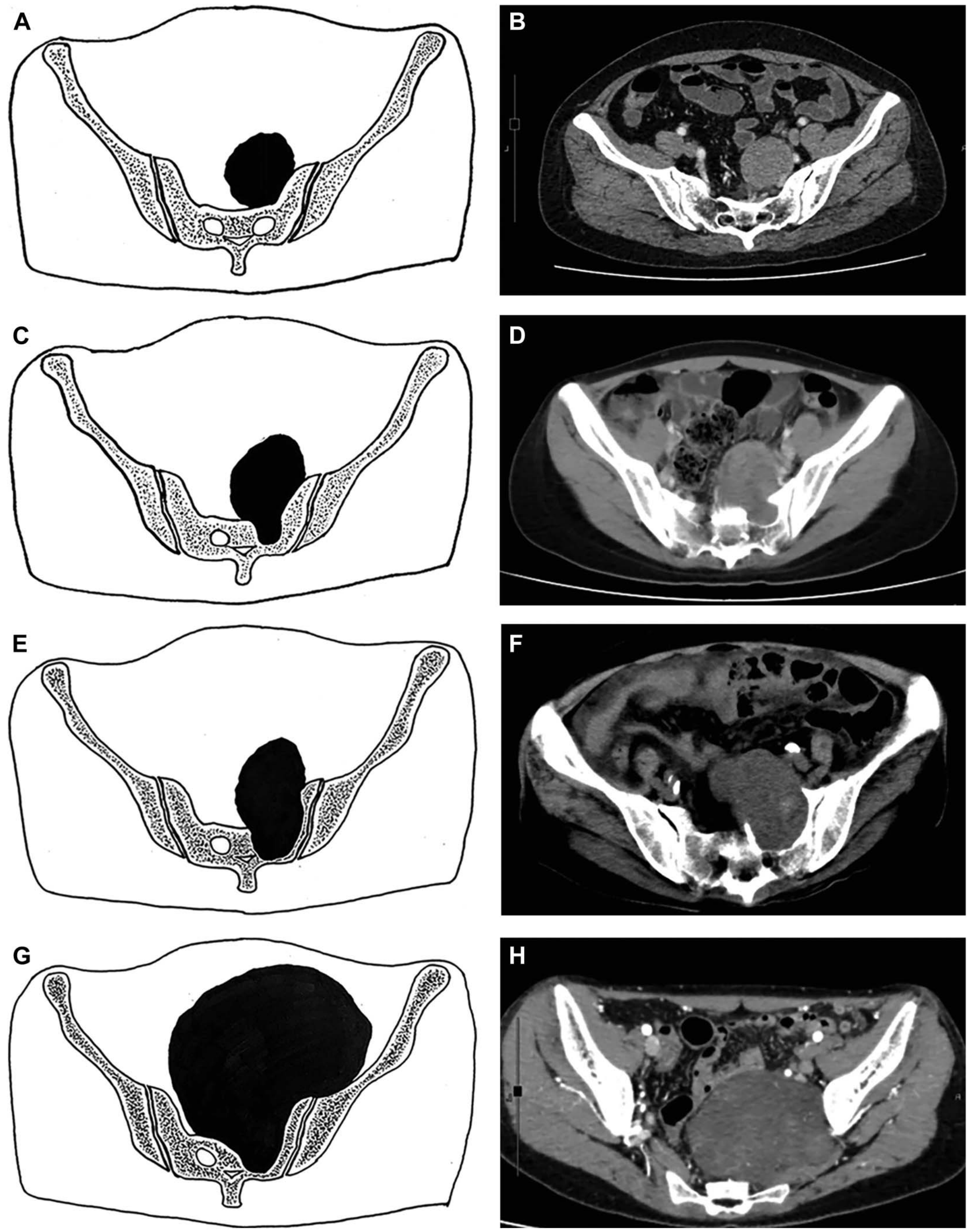

FIGURE 1. *A new surgical strategy for benign sacral neurogenic tumor resection.* **A** *and* **B**, *Type I: Presacral tumors with a maximum diameter <10 cm.* **C** *and* **D**, *Type II: Tumors involving the sacrum with a maximum diameter <10 cm (narrow base).* **E** *and* **F**, *Type III: Tumors involving the sacrum with a maximum diameter <10 cm (broad base).* **G** *and* **H**, *Type IV: Tumors involving sacral nerve roots ≥2 levels with diameter ≥10 cm, with/without involving the sacrum.*

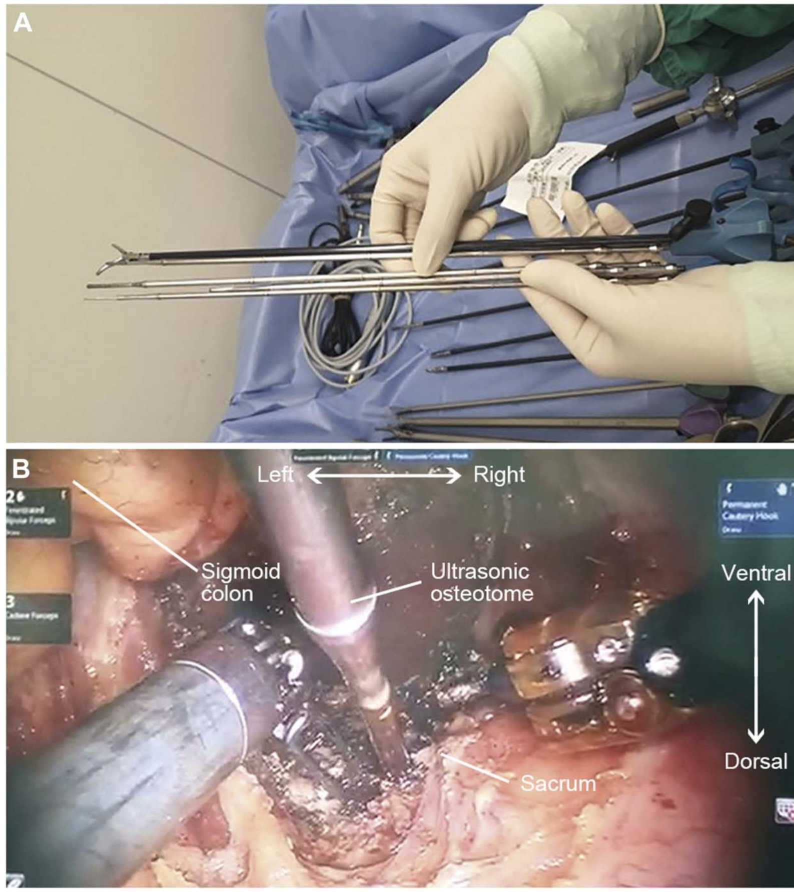

FIGURE 2. A, *The ultrasonic osteotome was specially designed for robotic surgery and matched robotic arms.* B, *The ultrasonic osteotome was used to create a bony window during robotic-assisted neurogenic sacral tumor resection.*

ultrasonic osteotomy surgical system combined with robotic system in the resection of neurogenic sacral tumors.

METHODS

Patients

Patients who underwent primary benign sacral neurogenic tumor resection by the da Vinci Si surgical system (Intuitive Surgical Inc) at our hospital between May 2015 and March 2021 were reviewed in this study. Inclusion criteria for the analysis were diagnosis of a primary benign neurogenic tumor located in the sacral or presacral area, and resected by the da Vinci surgical system. Exclusion criteria were previous sacral surgery or lost to follow-up. A total of 12 patients were included and no patients were excluded. The study was approved by the medical ethical committee of our hospital and registered with ChiCTR (ChiCTR2100053026). This case series was reported in line with the PROCESS Guideline.[12] Written informed consent was obtained from participants.

Data extracted included patient demographic information, medical history, imaging study results, pathological findings, treatment details, and follow-up results. Patients were seen in the outpatient clinic and received MRI of the surgical site every 4 to 6 months for 2 years, and thereafter every 6 to 12 months when possible. During follow-up, data regarding local recurrences and complications were collected.

Surgical Strategy

Our new surgical strategy divided benign sacral neurogenic tumors into 4 types based on tumor size, and the anatomic relationship between tumors and the sacrum, using preoperative imaging studies (Figure 1). For the presacral tumors not involving the sacrum with a maximum diameter <10 cm, they were classified as type I. For those involving the sacrum, apart from the tumor size, the tumor base in the sacrum and the number of sacral nerve root levels involved by tumors were also considered. Type II and III were tumors involving the sacrum with a maximum diameter <10 cm. If the maximum diameter of the tumor base in the sacrum was shorter than half of the maximum diameter of the whole tumor, it was classified as type II (narrow base). Otherwise, it was classified as type III (broad base). Type IV was composed of neurogenic sacral tumors involving sacral nerve roots ≥2 levels and/or with a maximum diameter ≥10 cm, with or without involving the sacrum.

TABLE. The Clinical Characteristics of 12 Patients

Case	Sex	Age (y)	Histological diagnosis	Maximum tumor diameter (cm)	Tumor base size within sacrum (cm)[a]	Type	Adjacent tissue	Approach	Operative time (min)	Blood loss (mL)	Ultrasonic osteotomy	Total/partial resection	Postoperative hospital stay (d)	Complication	Local recurrence/progression	Follow-up (m)
1	Female	50	Schwannoma	4.4	–	I	Iliac vessels	A	60	50	No	Total	3	No	No	70.9
2	Female	42	Schwannoma	8.3	–	I	Iliac vessels	A	90	100	No	Total	8	No	No	65.3
3	Female	47	Schwannoma	4.3	–	I	Iliac vessels, uterus	A	70	100	No	Total	4	Left leg muscle soreness	No	46.2
4	Female	50	Schwannoma	5.8	–	I	Abdominal aorta	A	110	50	No	Total	4	No	No	36.7
5	Male	56	Schwannoma	8.1	–	I	Ureter, internal iliac vessels	A	110	800	No	Total	8	Right foot muscle soreness	No	17.5
6	Male	50	Schwannoma	5.5	1.6	II	Abdominal aorta	A	90	400	No	Total	4	No	No	51.3
7	Female	24	Schwannoma	6.5	2.4	II	Ureter, internal iliac vessels	A	80	30	Yes	Total	5	No	No	18.3
8	Female	55	Neurofibroma	7.7	2.5	II	Branches of internal iliac vessels	A	120	300	No	Total	4	Left foot tingling	No	34.1
9	Female	25	Ganglioneuroma	5.4	2.0	II	Ureter, internal iliac vessels	A	200	800	No	Total	4	Right foot tingling	No	14.8
10	Male	32	Ganglioneuroma	5.6	1.4	II	Internal iliac vessels	A	240	30	Yes	Total	3	No	No	7.9
11	Male	71	Schwannoma	5.6	5.2	III	Internal iliac vessels	A	300	100	Yes	Partial	7	Left foot muscle soreness	No	15.2
12	Female	22	Schwannoma	10.3	2.6	IV	Intestine, internal iliac vessels, uterus	A + P	200	1200	No	Total	5	No	No	22.8

A, anterior; P, posterior.
[a]Maximum diameter.

Different surgical approaches and surgical methods were applied to 4 types of benign sacral neurogenic tumors. Type I, II, and III neurogenic sacral tumors were resected and removed by the robotic system via an anterior approach. Ultrasonic osteotomy was performed in type II and III neurogenic sacral tumors for adequate exposure of the tumors in the sacrum by the ultrasonic osteotomy surgical system (SMTP Technology Co., Ltd.; Figure 2). For type IV tumors, the robotic-assisted anterior approach was combined with an open posterior approach. Surgical procedures and ultrasonic osteotomy were detailed in **Supplemental Digital Content**, http://links.lww.com/ONS/A829. All the procedures were performed by a multidisciplinary team composed of general surgeons and orthopedic surgeons. General surgeons manipulated the robotic system and orthopedic surgeons performed ultrasonic osteotomy.

RESULTS

Clinical Characteristics and Types of Neurogenic Sacral Tumors

Twelve patients were included in this study, including 4 male and 8 female patients. Detailed clinical characteristics of the 12 patients were provided in Table. The median age was 48.5 years (range 22-71 years). The diagnoses of the patients were composed of schwannoma (9 cases), ganglioneuroma (2 cases), and neurofibroma (1 case). According to our surgical strategy, they were classified into type I (5 cases), type II (5 cases), type III (1 case), and type IV (1 case). The median tumor maximum diameter was 6.3 cm (range 4.3-8.3 cm), 5.6 cm (range 5.4-7.7 cm), 5.6 cm, and 10.3 cm for type I, type II, type III, and type IV patients, respectively.

Perioperative Parameters

The anterior approach was used for type I, type II, and type III patients. The median operation time was 90 minutes (range 60-110 minutes) for type I patients, 120 minutes (range 80-240 minutes) for type II patients, and 300 minutes for 1 type III patient. As for the type IV patient, the operation time of a combined anterior-posterior approach was 200 minutes. During the surgery, the median blood loss amounts were 100 mL (range 50-800 mL), 300 mL (range 30-800 mL), 100 mL, and 1200 mL, for type I, type II, type III, and type IV patients, respectively. In type I, II, and III patients, intraoperative bleeding was mainly caused by dissecting presacral venous plexus, which could be well controlled by bipolar electrocoagulation and local compression in robotic surgery. In the type IV patient, intraoperative bleeding mainly occurred during the open posterior approach.

The ultrasonic osteotomy surgical system was applied with robotic system in 2 type II and 1 type III patient (case 7, 10, and 11 from Table). Case 7 and 10 received a total resection after sacral osteotomy. In case 11, the sacral part of tumor adhered tightly to the S1 nerve root and dural sac, and their boundaries were not clear. We used robotic system to resect the presacral part of the tumor. The ultrasonic osteotomy surgical system was then

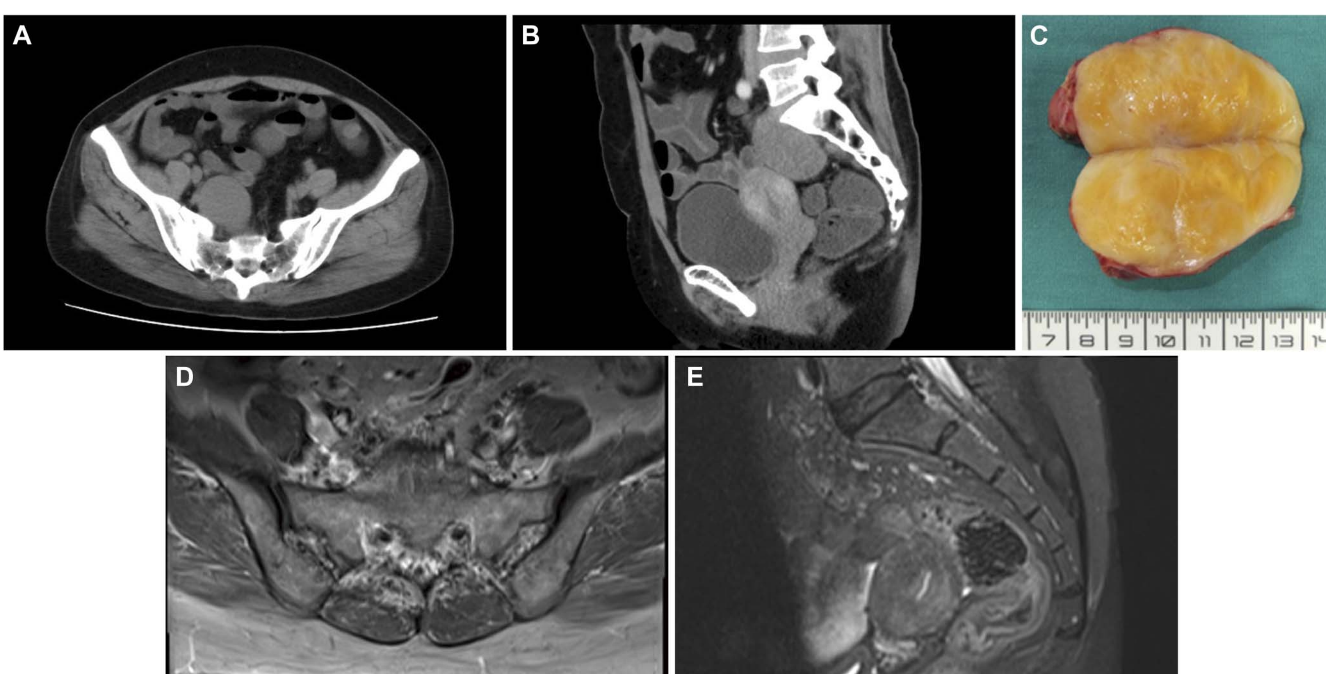

FIGURE 3. *A 50-year-old woman diagnosed with schwannoma (case 1 from Table).* **A** *and* **B**, *The tumor was classified as type I according to preoperative computed tomography.* **C**, *Gross view of the tumor after en bloc resection.* **D** *and* **E**, *No local recurrence was observed during a 70.9-month follow-up.*

applied to create a bony window, followed by a partial resection and intralesional curettage (Video). The blood loss of these 3 cases ranged from 30 mL to 100 mL, and no massive hemorrhage was noted during osteotomy.

Eleven patients (92%) had a total resection and 1 type III patient (8%) had a partial resection (case 11 from Table). Because the boundary between the tumor in the sacrum and the sacral nerve root was not clear in case 11, a total extirpation was not pursued to minimize postoperative neurologic dysfunction. The sacroiliac joints and pelvic rings of these patients were not severely damaged, and no sacroiliac joint instability was observed. Therefore, no reconstruction was performed among the patients.

Postoperative Course

The median postoperative hospital stay was 4 days (range 3-8 days), 4 days (range 3-5 days), 7 days, and 5 days for type I, type II, type III, and type IV patients, respectively. Twelve patients were followed up for 7.9 to 70.9 months (median: 28.5 months). During follow-up, 5 complications were reported. Five patients developed lower-limb soreness or tingling, which was gradually alleviated in 6 months after surgery. No analgesics were needed and their quality of life was not affected greatly. No motor deficits, urinary incontinence, bowel incontinence, secondary hemorrhage, or reoperation were observed in these patients. All wounds healed successfully and all patients were able to walk without support. In addition, no local recurrences, progression, or deaths were reported during follow-up.

DISCUSSION

Benign sacral neurogenic tumors are challenging and risky for surgeons because they are adjacent to vital tissues and organs. With high flexibility and 3-dimensional magnified vision, the robotic system provides precise dissection and faster suturing in the narrow pelvic cavity, and thus becomes increasingly popular in neurogenic sacral tumor resection.[8] We proposed a new surgical strategy based on robotic surgery and introduced our experience of combining the ultrasonic osteotomy surgical system with robotic system.

A New Surgical Strategy for Benign Sacral Neurogenic Tumor Resection Based on Robotic Surgery

Previous surgical classifications of neurogenic sacral tumor provide guidance on surgical decision, approach, and reconstruction of open surgery,[13-16] but no surgical classification or surgical strategy intended for robotic surgery has been put forward as far as we know. By reviewing robotic-assisted neurogenic sacral tumor resection, we found that surgical choice was influenced by the involvement of the sacrum/sacral nerves and tumor diameter. According to our clinical experience, small tumors that did not

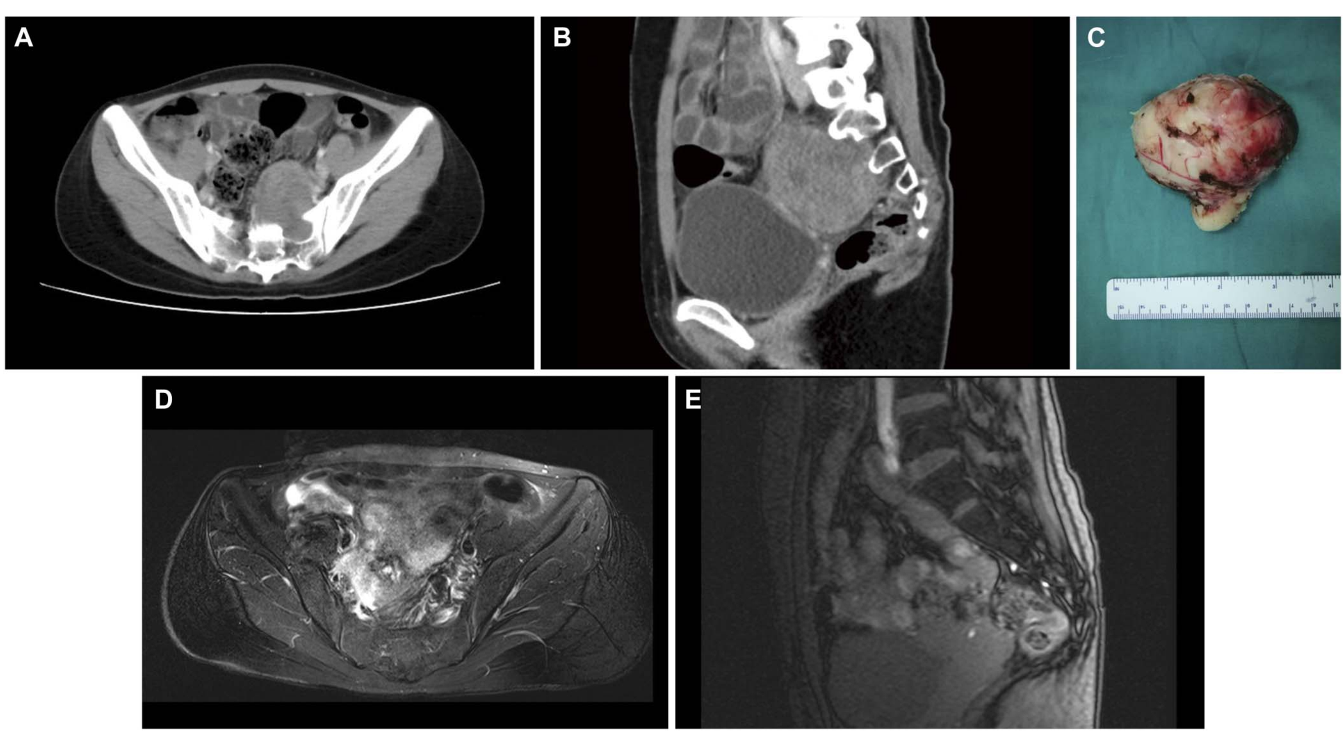

FIGURE 4. *A 24-year-old woman diagnosed with schwannoma (case 7 from Table).* **A** *and* **B**, *The tumor was classified as type II according to preoperative computed tomography.* **C**, *Gross view of the tumor after en bloc resection.* **D** *and* **E**, *No local recurrence was observed during an 18.3-month follow-up.*

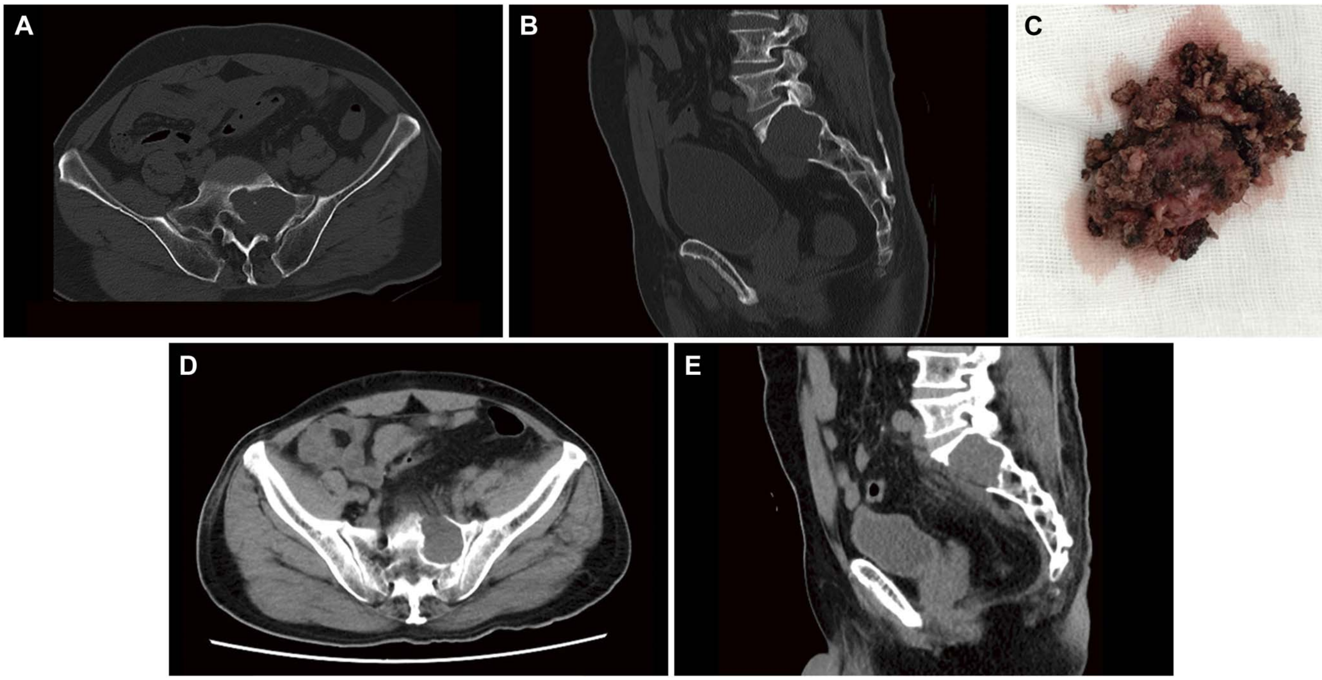

FIGURE 5. *A 71-year-old man diagnosed with schwannoma (case 11 from Table).* **A** *and* **B***, The tumor was classified as type III according to preoperative computed tomography.* **C***, Gross view of the tumor after an intralesional partial resection.* **D** *and* **E***, No progression was observed during a 15.1-month follow-up.*

invade the sacrum could be resected via a robotic-assisted anterior approach, so they were classified as type I (Figure 3). The tumor diameters of type I patients in our series were smaller than 9 cm. Case 5 from Table, whose tumor (diameter: 8.1 cm) was one of the largest tumors in type I patients, had longer operation time and more blood loss than other type I patients, because the relatively large diameter made it difficult to dissect presacral vessels around the basal part to tumor. After effective hemostasis, robotic-assisted neurogenic sacral tumor resection of this patient was completed without conversion to laparotomy.

In terms of type II (Figure 4), the tumors involved the sacrum (narrow base) and were relatively small, which allowed robotic system to perform en bloc resection after ultrasonic osteotomy. For the type III patient (case 11 from Table) whose tumor involved the sacrum with a broad base, although a bony window could be enlarged by the ultrasonic osteotomy surgical system, the tumor invaded the sacrum deeply and the boundary between tumor and sacral nerve roots was unclear. To preserve neurological function, a partial resection was performed (Figure 5).

The tumor of case 12 from Table was 10.3 cm in diameter and involved 2 sacral nerve roots. Large tumors (maximum diameter >10 cm) restrict the visual field and operative space, increasing the risk of injuring important tissues, such as ureters and branches of internal iliac vessels. Moreover, involving sacral nerve roots ≥2 levels makes it difficult to perform a safe total resection and preserve neurological function via a robotic anterior approach. In such situations, the combined anterior-posterior approach was preferred, and the robotic system could be used in vessel dissection and ligation as an adjuvant method. Therefore, case 12 was classified as type IV (Figure 6).

The median operation time and blood loss of type I, type II, and type III patients treated by robotic system were less than those of the patients treated by laparoscopy or laparotomy.[17,18] Moreover, the median operation time, blood loss, and postoperative hospital stay of type I and II patients were much less than those of type IV patients, which suggested that our surgical strategy provided guidance on estimating operation time, intraoperative blood loss, and recovery.

En bloc resection of sacral tumors is surgically challenging and associated with significant perioperative complications.[19] Total resections were achieved in 11 patients (92%). During follow-up, only 5 patients developed mild complications. The relatively high total resection rate, low complication rate, and low recurrence rate proved the effectiveness and safety of robotic system and our surgical strategy.

The surgical strategy was helpful to determine surgery types (robotic-assisted anterior approach vs combined anterior–posterior approach) and the application of ultrasonic osteotomy, and to evaluate surgical difficulty based on tumor diameter and the extent of tumor invasion. It has been applied to subsequent cases treated at our hospital.

Application of the Ultrasonic Osteotomy Surgical System in Robotic Surgery

Traditional osteotomy devices, including high-speed drills, threadwire saws, and rotating burrs, could easily damage surrounding soft tissues and cause notable osseous bleeding.[20,21] And

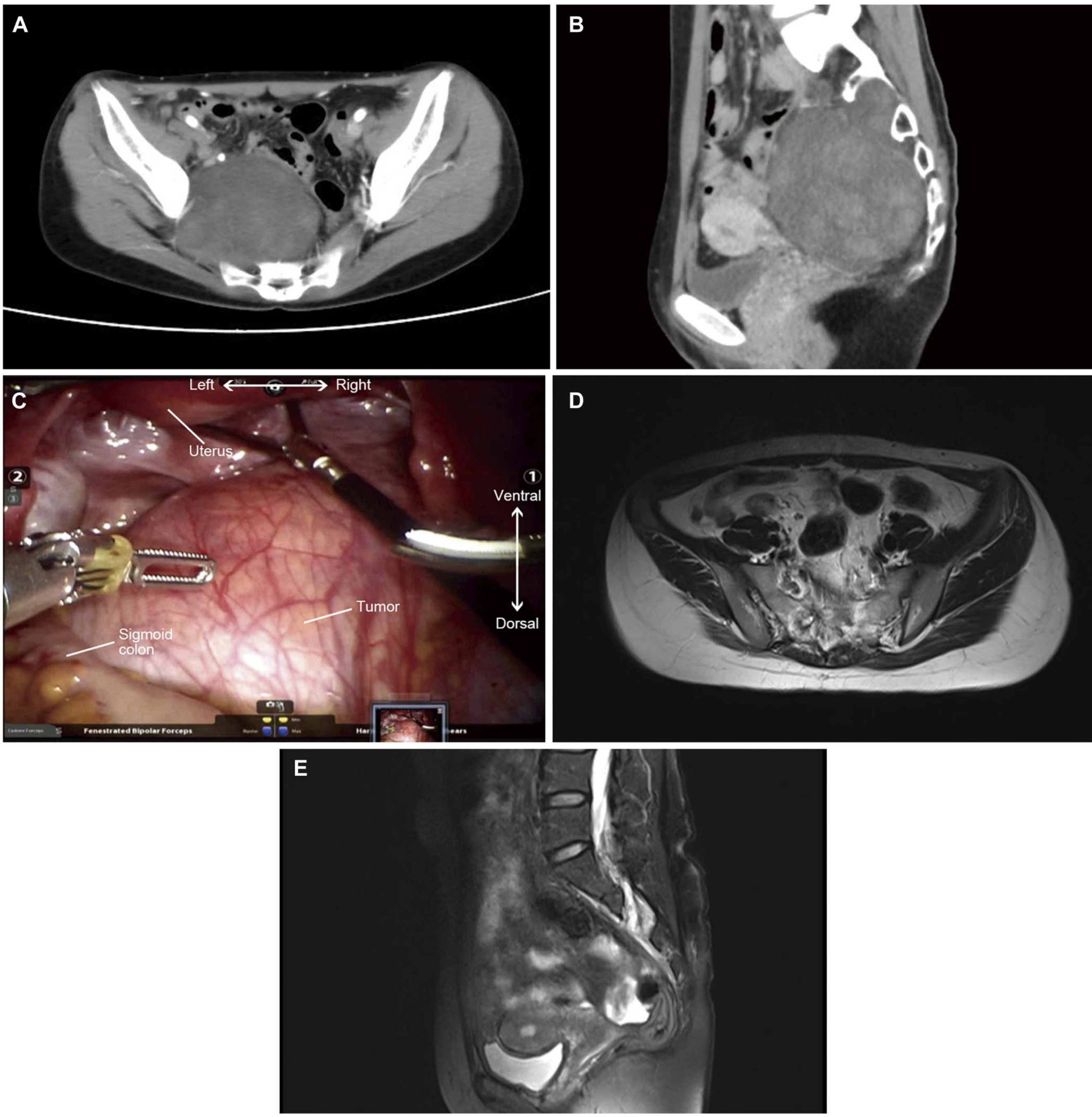

FIGURE 6. *A 22-year-old woman diagnosed with schwannoma (case 12 from Table).* **A** *and* **B**, *The tumor was classified as type IV according to preoperative computed tomography.* **C**, *Robotic system was used to dissect surrounding vessels and other vital tissues.* **D** *and* **E**, *No local recurrence was observed during a 22.8-month follow-up.*

it is difficult to combine traditional osteotomy devices with the robotic system because of poor compatibility.

Comparatively, ultrasonic osteotome is able to protect surrounding soft tissues and reduce bleeding by virtue of a blunt ultrasonic blade while performing precise osteotomy, which improves visibility in the surgical field.[22-24] More importantly, the ultrasonic osteotomy surgical system can be applied in minimally invasive surgery and is compatible with the robotic system.

During the surgery, we found that the ultrasonic osteotomy surgical system helped to create a bony window and to expose the tumor inside the sacrum with minimal osseous bleeding (Figure 2). This system was especially advantageous in the pelvic cavity, an anatomically difficult area. It is important to match the length of the ultrasonic osteotome and robotic arms and to choose proper trocars according to the location and direction of osteotomy.

Although the tumor inside the sacrum was exposed after osteotomy, S1 nerve involvement hindered the total resection. Injuries to S1 nerve root will damage motor function, and injuries to bilateral S2 nerve roots and lower levels will lead to incontinence.[4] As sacral nerve involvement is more common and more extensive in type III patients, we believed that the ultrasonic osteotomy surgical system was more suitable for type II patients than type III patients. Preoperatively, the relationship between tumor and sacral nerve and the level of sacral nerved involved should be carefully evaluated in type II and III patients. To our knowledge, the application of ultrasonic osteotomy surgical system in robotic surgery was not reported before. Despite the small number of cases, the ultrasonic osteotomy surgical system demonstrated its advantage in robotic-assisted neurogenic sacral tumor resection.

Esthetic Advantage and Learning Curve of Robotic Surgery

As a minimally invasive method, the robotic system also meets the esthetic needs of patients by leaving small scars. To avoid leaving more prominent scars on abdominal skin by enlarging trocar incision, we extracted the intact tumor from an additional incision on the mons pubis area, hiding scars in pubic hair.

It was reported that 8 to 25 cases were needed to overcome the initial learning phase in robotic-assisted rectal surgery.[25] According to our experience, a general surgeon experienced in neurogenic sacral tumor resection by laparotomy needs to complete 40 to 50 cases of laparoscopic-assisted general surgery before he/she gains proficiency, and this number decreases to 20 to 30 in terms of robotic-assisted general surgery. For a general surgeon proficient in both laparotomy and laparoscopy, 5 to 10 cases of robotic-assisted general surgery are sufficient.

Limitations

There were several limitations of this study. First, this strategy was derived from our clinical experience and further validation was necessary. Besides, the relatively small sample size and inequality between different groups hampered statistical inference. Third, the follow-up period was relatively short. Finally, this surgical strategy was not suitable for malignant sacral neurogenic tumors where sacrectomy was necessary.

CONCLUSION

This new surgical strategy was helpful in guiding robotic-assisted benign sacral neurogenic tumor resection. The robotic system can be applied to benign sacral neurogenic tumor resection for type I, type II, and type III patients, and used as an adjuvant method for type IV patients. The ultrasonic osteotomy surgical system was an effective tool for type II and III patients, especially type II patients in robotic surgery.

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Supplemental Methods. Details of surgical procedures and ultrasonic osteotomy.

VIDEO. Ultrasonic osteotomy in robotic surgery.

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