

# Surgical Management of Sacral Schwannomas: A 21-Year Mayo Clinic Experience and Comparative Literature Analysis

**William Mualem**

Mayo Clinic Minnesota

**Abdul-Karim Ghaith**

Mayo Clinic Minnesota

**Deja Rush**

Howard University College of Medicine

**Ryan Jarrah**

Mayo Clinic Minnesota

**Yohan Alexander**

Mayo Clinic Minnesota

**Cameron Zamanian**

Mayo Clinic Minnesota

**John L. D. Atkinson**

Mayo Clinic Minnesota

**Michael J. Yaszemski**

Mayo Clinic Minnesota

**William E. Krauss**

Mayo Clinic Minnesota

**Robert J. Spinner**

Mayo Clinic Minnesota

**Mohamad Bydon** (✉ [Bydon.Mohamad@mayo.edu](mailto:Bydon.Mohamad@mayo.edu))

Mayo Clinic Minnesota <https://orcid.org/0000-0002-0543-396X>


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## Research Article

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## Abstract

**Introduction:** Sacral and presacral schwannomas are rare and account for a minority of spinal schwannomas. We aim to present our institution's experience surgically treating sacral schwannomas over twenty-one years. Additionally, we assess the literature for surgical cases of sacral schwannomas to compare tumor characteristics and outcomes following resection.

**Methods:** Data on demographics, presenting symptoms, lesion characteristics, surgical management, and outcomes were collected for 27 patients treated surgically for sacral or presacral schwannoma between 1997 and 2018 at all Mayo Clinic locations and compared to those of patients found in the literature.

**Results:** We identified 31 studies in the literature containing 93 patients with sacral schwannoma treated surgically. Our patients and those in the literature experienced similar symptoms, with the most common symptom being pain and the least common being sexual dysfunction, and age at diagnosis. Most of our patients (59.3%) reported full recovery from preoperative symptoms, while a minority reported a partial recovery (33.3%) and no recovery (11.1%). A smaller percentage of patients found in the literature experienced full recovery (31.9%) and partial recovery (29.8%) but also no recovery (1.1%). Our patients experienced fewer complications (14.8% versus 25.5%).

**Conclusion:** Outcomes of patients with sacral or presacral schwannomas vary based on patient demographics, tumor characteristics, symptoms, and surgical treatment. Among the range of symptoms experienced by these patients, the most common is pain. Prognosis improves and overall survival rate is high when the surgical approach towards sacral schwannomas is prepared and executed appropriately.

## Introduction

Schwannomas are benign, slow-growing neoplasms of the peripheral nerve sheath, often arising from the dorsal rootlets of the spine. These are the most common tumors of peripheral nerves and present in the spine as intradural, extramedullary tumors. While spinal schwannomas typically present in the thoracic region, 1%-5% originate in the sacrum [1]. Schwannomas may develop sporadically or be associated with inheritance. For instance, neurofibromatosis 2 is associated with the development of various benign tumors throughout the central nervous system, spine, and periphery, and up to 75% of patients with schwannomatosis develop spinal schwannomas [2].

The clinical presentation of sacral and presacral schwannomas (tumors contained within the presacral space or extending into it from the sacrum or foramina) may involve local pain and weakness, changes to sensory innervation of the bowel and bladder, or sexual dysfunction. Due to the reality that these tumors may remain asymptomatic for extended periods of time, patients may present with large lesions later discovered in the fourth and fifth decades of life often following the development of neurologic symptoms [3–4]. Except for patients with a history of neurofibromatosis type 2, sacral schwannomas often follow an indolent course postoperatively with low rates of recurrence or malignant transformation [5]. While total resection has the potential to relieve symptoms and recurrence, surgical intervention is often complicated by tumor size, and consequently, complex distortion of normal anatomy [4].

In this study, we aim to detail and provide an update on our institution's experience with the surgical management of both sacral and presacral schwannomas [6]. A comprehensive literature review was conducted to characterize surgical sacral schwannomas and their post-operative outcomes.

## Methods

### Patient Cases

We retrospectively reviewed the records of patients who underwent surgery for the removal of sacral or presacral schwannoma at our institution—Mayo Clinic (Minnesota, Arizona, and Florida)—between 1997 and 2018 following Institutional Review Board (IRB) approval (IRB number 21-000125). We abstracted the following information: demographics, presenting symptoms, lesion characteristics, surgical management, and outcomes. Patient demographic data were defined under the scopes of both age and gender. Lesion characteristics included size, need for lumbosacral laminectomy, nerves involved and laterality. Surgical outcomes included progression, improvement, follow-up, and surgical complications. Surgical management details included operative approach taken to remove the lesion (anterior, posterior, or combined), nerve sacrifice, how extensive the surgical resection was, and whether a revision surgery was necessary. Patient outcomes were characterized by tumor progression, range of recovery (full, partial or none), follow-up time, survival, and post-operative complications.

### Study Selection

We conducted a systematic literature review of peer-reviewed articles published from inception to December 2020 using relevant word searches performed electronically on PubMed, EMBASE, Web of Science, Scopus, Medline, and Cochrane Library databases. To maximize search results, specific keywords were used as Medical Subject Headings (MeSH) terms in all logical permutations to identify relevant studies: “spinal OR spine,” “schwannoma,” “sacral,” “presacral” and “surgical treatment.” The results of the search were then screened by two authors to determine eligibility for inclusion in the final review. Eligibility criteria included original research studies written in English and only involving human subjects. Narrative reviews, abstracts, book chapters, and cadaveric studies were excluded. Studies involving non-sacral schwannomas or patients who had not undergone surgery for their schwannomas, and studies that were not full-length articles, were also excluded.

### Data Collection and Analysis

Data were extracted from relevant studies including patients with sacral schwannoma treated surgically. Data were also tabulated regarding patient age and gender, presenting symptoms, size and location of tumor, and surgical management and outcome including complications and/or recurrence. Comparative

analysis was conducted to determine whether there were any statistically significant factors related to the development of sacral schwannomas, prognosis after surgical resection, and propensity for recurrence.

## Results

### Demographics

We identified 27 patients with sacral schwannomas at our institution. Average age of was 49.9 years, and 44.4% identified as female (Table 1). In the literature, 93 patients were identified with an average age of 43.4 years and 60.6% identifying as female [5, 7–36]. None of our patients were known to have schwannomatosis or neurofibromatosis type 2. Only one of the 93 patients found in the literature review, the patient in the case report by Braley et al., had a history of schwannomatosis while no patients had any known history of neurofibromatosis type 2.

### Presenting Symptoms

Most patients treated at our institution (88.9%) and in the literature (78.7%) experienced pain related to their sacral schwannomas (Tables 1 and 2). Sexual dysfunction was the least common symptom experienced by both our patients and those in the literature (3.7% and 3.2%, respectively). Other symptoms including weakness, sensory changes, and bowel/bladder incontinence had more variable distributions amongst the two patient populations. Intraoperative monitoring was included for 15 (55.6%) of our patients (including anal sphincter monitoring for six patients). At our institution, 29.6% of patients experienced weakness, 33.3% experienced sensory changes and 37% experienced bowel/bladder incontinence. In the literature, 12.8% of patients experienced weakness, 20.2% experienced sensory changes and 26.6% experienced bowel/bladder incontinence.

### Lesion Characteristics

The dimensions for the largest lesion surgically treated at our institution were 11.5 x 7 x 3.5 cm (Figure 1). The largest lesion found in the literature was considerably greater, measuring 12.1 x 11 x 10.7 cm. Laminectomies were performed more often for patients treated at our institution (44.4% at S1-S2 level and 33.3% at L5-S1) than for patients in the literature (10.6% at S1-S2 level and 9.6% at L5-S1). Involvement of the S1 nerve was the most frequent for our patients (70.3%). However, only 26.6% of cases in the literature demonstrated S1 nerve involvement. While less common, the L5 nerve showed a similar trend, with involvement in 22.2% of our cases but only 8.5% of cases in the literature. Tumor predilection for right, left or combined laterality was well-dispersed. At our institution, 48.1% of tumors were right-sided, 37% left-sided, and 11.1% bilateral. In the literature, 14.9% of tumors were right-sided, 17.0% left-sided, and 10.6% bilateral. In our cohort, patients with sacral tumors without extension into the presacral space outnumbered those extending into it (15 versus 8) while there was an equal number of patients with presacral tumors either limited to or extending into the foramina or sacrum (2 patients in both). Six of our patients had schwannomas that were intradural.

### Surgical Management

Most surgeries performed on our patients (59.3%) and in those in the literature (51.1%) were through a posterior approach, while an anterior approach was used for 22.2% of our patients and 28.7% of patients in the literature (Tables 3 and 4). The least common technique used in both patient populations was a combined anterior and posterior surgery (14.8% of our patients and 18.1% of patients in the literature). Most patients had a gross total removal of their lesion (63% of ours and 72.3% in the literature). Subtotal resections were performed on 40.7% of our patients and 26.6% of those in the literature. With regards to sacrificing of the nerves involved and revision surgery, 33.3% of patients treated at our institution had a nerve sacrificed and 40.7% of patients required a revision surgery. In the literature, however, only 4.3% of patients treated had a nerve sacrificed, and 8.5% underwent revision surgery.

#### *Outcomes*

The average follow-up time for patients at our institution was 3 years, compared to 5 years for patients in the literature (Table 3 and 4). Moreover, 59.3% of our patients reported full recovery from preoperative symptoms while only 31.9% of those in the literature recovered fully. However, fewer patients in the literature reported no recovery of symptoms (1.1%) compared to our patient cohort (11.1%). An approximately even number of patients in both populations reported a partial recovery (33.3% at our institution and 29.8% in the literature).

More patients treated at our institution experienced lesion progression (37% versus 14.9%). Furthermore, our patients demonstrated a lower complication rate (14.8%) compared with patients in the literature (25.5%). Complications at our institution were only neurological in origin and specifically included neuropathic pain, dysesthesia, paraplegia, and incontinence. The overall survival rate was 92.6% for our patients and 93.6% for patients in the literature. Our progression analysis showed a decrease to zero in the probability of tumor progression over time (**Supplemental Figure 1**).

## Discussion

### Epidemiology and Clinical Presentation

The fourth and fifth decades of life are the typical age range when schwannomas are diagnosed, which is consistent with patients at our institution and those in our literature search. The literature also indicates that Black and American Indian/Alaska Native races were associated with lower incidence rates of spinal schwannomas when compared to Whites and Asians [37]. While schwannomas may occur in the sacral region of the spinal canal, they comprise only a small percentage of the variety of neoplasms that may arise in this location; other tumors found to occur in this region include chordomas, chondrosarcomas, neurofibromas, malignant peripheral nerve sheath tumors (MPNSTs), giant cell tumors, plasmacytomas, lymphomas, aneurysmal bone cysts, inflammatory and congenital lesions. The most consistent presenting symptom for most patients (88.9% of our patients versus 78.7% in the literature) was local pain.

Sexual dysfunction appeared to be relatively uncommon with only 3.7% and 3.2% of patients experiencing it both at our institution and in the literature, respectively.

Accurately diagnosing the cause of low back pain and the appropriate treatment thereafter is important both in improving patient prognosis but also reducing costs, as low back pain affects most people at least once in their lifetime. Kim et al. reported a case in which a sacral schwannoma was discovered with MRI of the sacrolumbar region following a lumbar epidural block performed for low back pain of a few years' duration. Imaging was ordered only when the patient presented with transient cauda equina syndrome—perineal numbness, lower extremity weakness, and decreased deep-tendon reflexes—that completely resolved over the following nine hours before discharge home [38]. This was triggered by the lumbar epidural block meant to relieve the refractory back and leg pain the patient had been experiencing for years.

## Treatment Algorithm

Various surgical approaches in treating spinal schwannomas have been developed. Gross total resection was seen more often in the literature (72.3%) compared to the retrospective data at our institution (63%) and likely explains the difference in need for revision surgery (40.7% versus 8.51% in the literature) and subsequent tumor progression (37% versus 14.9% in the literature). However, most patients at our institution fully recovered (59.3%) as opposed to those in the literature (31.9%). Still, overall survival was high for both patient populations (92.6% versus 93.6% in the literature). While total resection is often pursued as a surgical treatment in the literature, it is not always successful given the variable sizes of the tumors. The risk of developing neurologic deficits from total resection exists alongside the benefit of preventing recurrence [39–41].

During surgical removal of schwannoma, care must be taken to avoid damaging the surrounding neurovascular organs. Importantly, of the nine patients at our institution presenting with bowel/bladder incontinence, five (55.6%) were diagnosed with schwannomas involving the S2 nerve, thus increasing the risk of dysfunction of the pudendal nerve. Four of the nine patients presenting with incontinence had schwannomas involving the S1 nerve but none of the lower sacral nerves; three of them presented with incontinence due to mechanical displacement i.e., tumor putting pressure on either the bladder or colon, while one had longstanding incontinence due to a history of transverse myelitis. None of our patients suffered from bowel or bladder incontinence as a postoperative complication. The most frequent operative approach employed was from the posterior (59.3% versus 51.1% in the literature), which is reasonable as it avoids the need to dissect through the abdomen and is optimal for cases in which the tumor extends into the spinal canal or sacrum with a small presacral component. However, the treatment plan of surgical approaches varies depending on the intrasacral and retroperitoneal extension of the mass [42]. An anterior transabdominal or retroperitoneal approach may be employed to protect the vascular plexus and intrapelvic organs while liberating the tumor. When the tumor is limited to the front of the sacrum, an anterior approach may be preferred, otherwise these tumors may be removed via the posterior approach alone. Moreover, a posterior approach with proper fenestration may be used to remove sacral schwannomas with large presacral components. A combined approach may be worth considering to allow for complete resection when a schwannoma consists of an extraspinal portion larger than the intraspinal and vertebral body portions or erosion of the lumbar vertebral body [43].

Because local recurrence and malignant transformation are very rare, subtotal resection or simple enucleation is frequently the preferred treatment of choice. The risk that it can grow again still exists though, and if removed inadequately, the reoperations have higher complication risks. A postoperative CT scan may be ordered to aid in planning the reconstruction of bone structures depending on the destruction of the sacral bone and the invasion of the sacroiliac joint.

## Patient Outcomes

Patients with sacral or presacral schwannomas at our institution had a shorter average follow-up time and a lower complication rate than those in the literature. More of our patients also reported full recovery from preoperative symptoms. However, it is also true that more of our patients reported no recovery of symptoms. Notably, more patients at our institution experienced lesion progression, which may be due to a higher rate of postoperative MRI with our patients relative to those treated at other institutions.

Clinical outcomes of patient studies following sacral schwannoma resection have been characterized for significance. One study by Pan et al. assessed ten patients between the ages of 31 and 63 years old. A single patient underwent an anterior approach, eight patients followed a posterior approach, and two patients underwent a combined approach. The results found the average surgical blood loss at 980 mL, with three patients suffering from postoperative complications such as bladder/bowel dysfunction and CSF leakage with secondary intracranial infection. Six patients underwent biopsies with no subsequent complications afterwards, with the overall average follow-up time being 22.7 months [43].

Another study by Pongstorm et al. treated six cases of giant sacral schwannoma. The average patient age was 47.8 years old, with all patients having the same clinical presentation of lumbosacral pain. The surgical method was posterior in two patients, anterior in one patient, and a combination in three patients. The mean surgical time was 7.8 hours with an average blood loss of 2562 g, with only one patient requiring a second surgery. One patient had postoperative complications of erectile dysfunction and motor weakness, while another had causalgia in the right leg. In the final follow-up, no patients presented with pain or neurological deficits with the surgical treatment with a piecemeal subtotal excision was found to have positive outcomes [31].

A study by Chandhanayingyon et al. further assessed sacral schwannoma removal using intralesional curettage and adjuvant radiation therapy. The study involved four cases, three females and one male, with an average age of 45.5 years. The main symptoms were lumbosacral pain, with each patient undergoing a posterior approach. The final follow-up found lumbosacral relief in all patients with no neurological deficits or recurrent symptoms. Radiographic imaging did find marginal sclerosis at the lesion site for one patient. However, it was still found that intralesional curettage and adjuvant radiation therapy effectively relieved sacral schwannoma symptoms [13].

Sowash et al. conducted a retrospective review on thirty-two patients with giant sacral schwannomas. Sixteen cases used the posterior approach and three underwent the combined approach, with instrumentation being placed in 10 cases. Gross tumor recession was achieved in 19 patients, with 12 patients showing enhancement in MRI imaging following surgery. Five patients had complications following surgery, including chemical meningitis, wound infections,

gastrointestinal obstruction, and Guillain Barre Syndrome. Long-term follow-up showed all 32 patients improved with regards to nonradicular pain, sensory deficits, bowel and bladder function, and sensory deficits. Three patients showed tumor recurrence, yet the surgical resection of sacral schwannoma was found to have overall benefits in improving clinical outcomes [44]. In a case series by Handa et al., eleven patients with giant schwannomas were treated surgically. Four patients were treated posteriorly, three patients were treated anteriorly, and four underwent a combinative approach. The average surgical blood loss was calculated at 3740 g with three patients having complications. The complications included massive bleeding, causalgia, and motor weakness. Surgical recurrence occurred in two cases, with one patient requiring a second surgery [45]. The outcomes of these studies all indicate positive clinical outcomes in improving symptom presentation without manifesting neurological deficits or complications. The posterior approach was the most widely used approach, with surgical blood loss varying between studies. While the occurrence of complications and tumor recurrence is not impossible, most surgical treatments are found to treat sacral schwannoma effectively.

## Limitations

This comparative literature analysis includes studies with low-level evidence and no prospective or randomized control trials, limiting the strength of conclusions that can be made regarding our qualitative and quantitative analysis. We were not able to perform a survival analysis as this type of tumor is benign, and most of the cases were resolved surgically. Furthermore, we could not assess the impact of radiotherapy on the survival of the patients. Another limitation is that our literature search was confined to major databases and English studies. Finally, we could not study the cause-and-effect relationships and assess the rate of this disease because there was no relevant comparative group.

## Conclusion

Sacral schwannomas are uncommon benign tumors of the spine, which may require operative management. Patient experience can vary significantly in terms of demographics, symptoms, tumor qualities, surgical treatment protocol, and outcome. Among the range of symptoms experienced, the most common was pain. Most patients were treated through gross total resection via the posterior approach. The prognosis may be good, with preservation of neurologic function and a high overall survival rate, when the surgical approach is well-planned and well-executed.

## Declarations

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### Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

### Author Contributions

All authors contributed to writing and editing of the manuscript.

### Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### Conflict of interest

We have no conflicts of interest.

### Ethics Approval

Mayo Clinic IRB: 21-000125

### Consent to participate

No consent needed due to retrospective nature of study and use of patient records.

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## Tables

**Table 1:** Patient demographics, presenting symptoms, and tumor characteristics of patients who underwent surgical resection of sacral schwannoma at our institution.

**Table 2:** Demographics and presenting symptoms of patients who underwent resection of sacral schwannoma found in the literature.

Patient	Age	Gender	Pain	Weakness	Sensory Changes	Bowel/bladder incontinence	Sexual dysfunction	Biopsy(yes/no)	Size of the lesion (CCM)	Levels (Laminectomies)	Nerve(s) involved
1	39	F	yes	yes	yes	no	no	yes	11.5 x 7 x 3.5 cm	L5-S2	L5-S2
2	45	F	yes	no	no	no	no	yes	8.3 X 5.2 X 4.8 cm	S2-S3	S2-S3
3	57	F	yes	yes	yes	yes	no	yes	12 x 9 x 3.8 cm	L5-S1	L5-S1
4	70	M	yes	yes	no	no	no	yes	3 x 1.4 x 1.2 cm	L5-S1	L5-S1
5	52	M	yes	no	no	no	no	yes	1.7 x 1.5 x 1.2 cm	S1-S3	S1-S3
6	58	M	yes	yes	no	no	yes	yes	3.5 x 0.5 x 0.5 cm	L5-S1	L5-S1
7	45	M	yes	no	no	no	no	yes	10 x 10 cm	S1-S2	S1-S2
8	45	M	yes	yes	no	yes	no	yes	5 cm	S1-S2	S1-S2
9	33	M	no	no	no	yes	no	yes	4 x 4 x 20 cm	-	-
10	70	M	yes	no	yes	yes	no	yes	6 x 4 x 8 cm	S1-S3	S2
11	69	F	yes	no	no	yes	no	yes	2 x 6 x 1 cm	L4-S1	S1-S2
12	44	M	yes	yes	yes	no	no	yes	-	S1-S2	S1
13	50	F	no	yes	no	no	no	no	9 cm	L5-S1	S1
14	37	F	yes	no	no	no	no	no	-	-	S1
15	35	F	yes	no	no	no	no	no	-	-	S1
16	49	F	yes	no	yes	no	no	no	8 cm	-	S2
17	44	M	no	no	no	no	no	yes	8.2 cm	S1-S3	S2
18	49	M	yes	no	yes	yes	no	no	13.5 x 11.3 cm	L5-S4	S1
19	71	M	yes	no	no	no	no	yes	5 x 6.8 x 4 cm	S1-S3	S1
20	47	M	yes	no	no	yes	no	yes	6 cm	-	S1
21	43	F	yes	no	no	yes	no	yes	15 cm	-	S1
22	58	M	yes	yes	no	no	no	yes	-	L5-S2	S1-S2
23	37	M	yes	no	yes	no	no	yes	-	S1-S3	S1-S2
24	62	F	yes	no	no	no	no	yes	-	S1-S2	S1
25	35	F	no	no	no	yes	no	yes	7 x 7.5 x 8 cm	S1-S4	S2-S4
26	59	F	yes	no	no	no	no	no	2.9 x 4.3 x	L5-S1	L5-S1



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27	43	M	yes	no	yes	no	no	yes	5.6 cm	6 x 6 cm	S1-S3	L5
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Study	Sample Size	Study Year	Age	Gender	Pain	Weakness	Sensory Changes	Bowel/bladder incontinence	Sexual dysfunction	Motor dysfunction
Abernathy	13	1986	34	M	Lower back; sciatica	-	-	-	-	-
			31	M	Lower back; sciatica	-	-	-	-	-
			20	F	Lower back; sciatica	-	-	-	-	-
			57	M	Lower back; sciatica	-	-	Urinary hesitancy	-	-
			27	F	Lower back; sciatica	-	-	-	-	-
			31	F	Lower back; sciatica	-	-	-	-	-
			50	M	Sciatica	Lower limb-Bilateral	Hypesthesia-S1	-	-	-
			16	M	Lower back	Lower limb-Bilateral	-	-	-	-
			47	F	Sciatica	-	-	-	-	-
			46	M	Sciatica	-	-	Constipation	-	-
			47	F	Low back; sciatica	-	-	-	-	-
			47	M	-	-	-	-	-	-
			49	F	Low back	-	-	-	-	-
Accicarri	1	1996	19	F	-	-	-	-	-	
Attiah	1	2015	58	F	Low back; Left buttock; Left leg	-	Tingling- Left toes	-	-	
Braley	1	2020	67	F	Left S-1 distribution	Lower limb- Left	Tingling- Left S1	-	-	
Cagli	13	2012	37	F	Lower back	Lower limb-Bilateral	-	-	-	-
			32	M	Lower back	Lower limb-Bilateral	-	Urinary incontinence	-	-
			40	M	Lower back	-	-	Urinary incontinence	Erectile dysfunction	-
			46	M	Lower back; Leg	Lower limb-Bilateral	-	-	-	-
			14	F	Lower back; Leg	-	-	-	-	-
			49	F	Lower back	-	-	Urinary incontinence	-	-
			55	F	Lower back; Leg	-	-	Urinary incontinence	-	-
			52	M	Lower back	-	-	-	-	-
			29	F	Lower back; Leg	-	-	-	-	-
			17	F	Lower back; Leg	-	-	-	-	-
			32	F	Lower back	-	-	-	-	-
			26	F	Lower back	-	-	-	-	-
			54	M	Lower back; Leg	-	-	-	-	-

Camacho	1	2019	58	F	Left perineal and radicular	-	-	-	-	€
Chandhanayingyong	4	2008	62	F	Sacral, radiates to rectal vault	-	-	-	-	€
			29	F	Lumbosacral; Radiculopathy	-	Hypesthesia-Right leg/Left thigh/Perineum	Urinary hesitancy; Constipation	-	€
			39	M	Lumbosacral; Left leg radiculopathy	-	Hypesthesia-Left great toe	-	-	€
			52	F	Lumbosacral; Right leg radiculopathy	-	-	-	-	€
Dominguez	6	1997	38	F	Lower back	-	Dysesthesia-Lower limb	Urinary hesitancy	-	-
			59	F	Lower back	-	-	Urinary hesitancy	-	-
			68	F	Lower back	-	-	Urinary hesitancy	-	-
			23	M	-	-	-	Urinary incontinence	-	-
			17	F	-	-	-	-	-	-
			39	F	Lower back	-	Dysesthesia-Lower limb	-	-	-
Emohare	1	2015	49	M	Lower back	-	-	Difficulty urinating	-	€
Gerhardt	1	2020	49	M	Abdominal	-	-	-	-	€
Higgin	1	2014	71	M	-	-	-	-	-	L
Huang	1	2020	34	M	-	-	-	-	-	-
Kanamori	1	2013	58	F	Left buttock; Left lower limb	Lower limb-Bilateral extensor hallucis longus muscles	Paresthesia-S1-S3	-	-	€
Khan	1	2018	38	M	Abdominal	-	-	Increased urinary frequency; Feeling of incomplete bladder emptying	-	€
Leclerc	6	2020	65	M	-	-	-	Dysuria Constipation	-	€
			34	F	Right S1 radiculopathy	-	-	-	-	€
			69	F	Lumbar	-	-	-	-	€
			32	M	Abdominal; Left L5 radiculopathy	-	-	-	-	€
			57	M	-	-	-	Dysuria	-	€
			55	F	-	-	Paresthesias-Lower limbs	Constipation	-	€
Lee_1	1	2017	40	F	Left buttock	-	Tingling- Left S1 Paresthesia-Left leg	-	-	€
Lee_2	1	2017	47	F	Flank; Iliac fossa	-	Tingling- Left thigh	-	-	€
Lin	1	2016	23	F	Sacrococcygeal region	-	-	Progressive voiding disturbance	-	€
Maccio	1	2019	62	F	Right lower limb (claudication)	-	-	-	-	-
Masanobu	1	2001	45	M	Right buttock; Right leg	Lower limb-Right extensor and flexor	-	-	-	€

						hallucis longus muscles					
Mohanty	9	2018	50	F	Lower back	-	-	-	-	-	§
			38	M	Lower back	-	-	-	-	-	§
			48	F	Lower back	-	-	-	-	-	§
			63	M	Lower back	-	-	-	Urinary retention	-	§
			39	M	Lower back; Right radiculopathy	-	-	-	-	-	§
			40	F	Lower back	-	-	-	-	-	§
			45	F	Lower back	-	-	-	-	-	§
			19	F	Lower back	-	Lower limb-Bilateral	-	-	-	§
			45	F	Lower back; Bilateral radiculopathy	-	-	-	-	§	
Ortolan	1	1996	27	F	Lower back; Right leg	-	Paresthesias- Right perineum	-	-	-	
Oshima	1	2004	54	F	Left buttock	Lower limb- Left	Paresthesia- Left posterolateral thigh	-	-	§	
Pennington_2	7	2019	22	F	-	-	-	-	-	-	
			73	M	-	-	-	Constipation	-	-	
			72	F	Left sided sciatica	-	-	-	-	-	-
			10	M	Lumbosacral	-	-	-	-	-	-
			30	M	Right-sided sciatica	-	-	-	-	-	-
			27	F	-	-	-	Constipation	-	Erectile dysfunction	-
			42	M	Right-sided sciatica	-	-	-	-	-	§
Pongsthorh	6	2009	57	F	Left leg	-	-	-	-	-	
			38	M	Right gluteal region	-	Numbness- Right leg and foot	-	-	§	
			51	F	Right leg	-	Numbness- Right calf	-	-	§	
			43	F	Right leg	-	Numbness- Right leg	-	-	-	
			58	M	Buttock	-	Numbness- Right calf	-	-	-	
			49	F	Right buttock; Right leg	-	-	-	Polyuria	-	
Ragurajprakash	1	2020	56	F	Lower abdomen	Lower limb- Right	Paresthesia- Right thigh	Dysuria; Constipation; Hydroureteronephrosis	-	-	
Silva	1	2018	22	M	Bilateral lumbar; Abdominal	-	-	-	-	-	
Tahta	1	2020	46	M	-	-	-	Difficulty passing urine; constipation	-	§	
Torgal	1	2014	42	M	Left upper quadrant	Lower limb- Bilateral	Paresthesia- S1-S3	-	-	-	
Yang	1	2007	67	M	Lower	-	-	Difficulty with	-	§	

					abdomen			defecation			r
Yin	7	2018	45-55	F	-	-	-	-	-	-	-
			40-50	F							
			60-70	F							
			20-30	F							
			50-60	F							
			20-30	F							
			45-55	M							

**Table 3:** Surgical characteristics and postoperative outcomes in patients who underwent sacral schwannoma resection found in the literature.

Study	Surgery	Operative approach	Sacrifice of Nerve	Extent of surgical resection	Revision surgery	Progression	Improvement of symptoms	Follow up Time (Years)	Survival	Cc
Abernathy	Posterior retrorectal transsacral	Posterior	-	Subtotal	No	Yes: 2 No: 11	Full	5	Yes	Ye
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Partial	21	Yes	
	Anterior midline abdominal Combined anterior midline abdominal and posterior retrorectal transsacral	Anterior; Combined (10 months later)		Gross total	Yes		Partial	31	Yes	
	Anterior midline abdominal	Anterior		Subtotal	No		Full	10	Yes	
	Posterior retrorectal transsacral Anterior midline abdominal	Posterior; Anterior (7 months later)		Gross total	Yes		Partial	19	Yes	
	Anterior midline abdominal	Anterior; Anterior (22 months later)		Gross total	Yes		Full	85	Yes	
	Posterior retrorectal transsacral Anterior midline abdominal	Posterior; Anterior (84 months later)		Gross total	Yes		Full	22	Yes	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Partial	193	Yes	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Full	204	Yes	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Full	130	No* (unrelated cause)	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Partial	43	No* (unrelated cause)	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Full	243	Yes	
	Posterior retrorectal transsacral	Posterior		Subtotal	No		Full	399	Yes	
Accicarri	Anterior transabdominal	Anterior	-	Gross total	No	No	Partial	6	Yes	Nc
Attiah	Surgical approach to remove Tarlov cyst	Posterior	Yes	Gross total	No	No	Partial	1	Yes	Nc
Braley	All-posterior transsacral	Posterior	-	Gross total	No	No	Partial	-	Yes	Nc
Cagli	Combined anterior midline abdominal and posterior retrorectal transsacral	Combined	-	Gross total	-	Yes: 2 No: 11	Partial	204	Yes	Ye
	Posterior retrorectal transsacral	Posterior		Gross total	-		Partial	180	Yes	Ye
	Posterior retrorectal	Posterior		Gross total	-		Partial	168	Yes	Nc

	transsacral									
	Combined anterior midline abdominal and posterior retrorectal transsacral	Combined		Gross total	-		Partial	144	Yes	No
	Combined anterior midline abdominal and posterior retrorectal transsacral	Combined		Gross total	-		Partial	120	Yes	Yes
	Posterior retrorectal transsacral	Posterior		Gross total	-		Partial	108	Yes	No
	Combined anterior midline abdominal and posterior retrorectal transsacral	Combined		Gross total	Yes		Partial	108	Yes	Yes
	Anterior midline abdominal	Anterior		Gross total	-		Partial	96	Yes	No
	Anterior midline abdominal	Anterior		Gross total	-		Partial	60	Yes	No
	Posterior retrorectal transsacral	Posterior		Gross total	-		Partial	60	Yes	Yes
	Posterior retrorectal transsacral	Posterior		Gross total	-		Partial	48	Yes	No
	Combined anterior midline abdominal and posterior retrorectal transsacral	Combined		Gross total	-		Partial	48	Yes	No
	Posterior retrorectal transsacral	Posterior		Gross total	-		Partial	24	Yes	No
Camacho	-	Posterior	-	Gross total	No	No	Partial	12	Yes	No
Chandhanayingyong	Intralesional curettage by posterior approach through sacral laminectomy	Posterior	-	Gross total	No	No	Full	27	Yes	No
	Intralesional curettage by posterior approach through sacral laminectomy	Posterior		Subtotal	No	Yes	Partial	21	Yes	Yes
	Intralesional curettage by posterior approach through sacral laminectomy	Posterior		Gross total	No	No	Full	18	Yes	No
	Intralesional curettage by posterior approach through sacral laminectomy	Posterior		Subtotal	No	Yes	Full	7	Yes	No
Dominguez	-	Posterior	-	Gross total	No	No	Full	9.2 (18 months - 21 years)	Yes	-
	-	Combined; Posterior (17 years later)			Yes	Yes	Partial		Yes	
	-	Posterior			No	No	Full		Yes	
	-	Posterior			No	Yes	Full		Yes	

	-	Combined			No	No	Full		Yes	
	-	Posterior			No	No	Full		Yes	
Emohare	Pericoccygeal via minimally invasive	Lateral	No	Gross total	No	No	Full	1	Yes	No
Gerhardt	Computer assisted navigation through abdominal midline	Anterior	No	Gross total	No	No	Full	29	Yes	No
Higgin	Abdominoperineal resection	Anterior	-	Gross total	No	No	-	3	Yes	No
Huang	Midline laparotomy	Anterior	-	Gross total	No	No	-	18	Yes	No
Kanamori	Posterior midline	Posterior	No	Subtotal	No	No	-	36	Yes	-
Khan	Two stage 360 (hemilaminectomy and laparotomy with aid of neuromonitoring)	Combined	No	Gross total	No	No	Full	-	Yes	No
Leclerc	Enucleation	Anterior	No	Subtotal	No	No	Full	25	Yes	No
	Enucleation	Anterior	No	Subtotal	No	No	Full	7	Yes	No
	Enucleation	Anterior	No	Subtotal	No	No	Full	8	Yes	No
	Enucleation	Anterior	No	Subtotal	No	No	Full	100	Yes	No
	Enucleation	Anterior	No	Subtotal	No	No	Full	165	Yes	Yes
	Enucleation	Anterior	No	Gross total	No	No	Full	97	Yes	No
Lee_1	Single state posterior	Posterior	No	Gross total	No	No	Full	24	Yes	No
Lee_2	Anterior retroperitoneal	Anterior	-	Gross total	No	-	-	-	Yes	No
Lin	Posterior resection using image-based customized osteotomy tools	Posterior	No	Gross total	No	No	Partial	24	Yes	-
Maccio	Anterior transperitoneal approach with right adnexectomy and radical tumor excision	Anterior	No	Gross total	No	No	Full	12	Yes	No
Masanobu	High sacral amputation following combined anteroposterior	Combined	No	Gross total	No	No	Partial	18	Yes	Yes
Mohanty	Single state posterior	Posterior	-	Subtotal	-	Yes	-	96	Yes	No
	Single state posterior	Posterior		Gross total		No	-	72	Yes	No
	Single state posterior	Posterior		Subtotal		Yes	-	60	Yes	No
	Single state posterior	Posterior		Gross total		No	-	9	No	No
	Single state posterior	Posterior		Gross total		No	-	48	Yes	No
	Single state posterior	Posterior		Gross total		No	-	48	Yes	No
	Single state posterior	Posterior		Gross total		No	-	36	Yes	No
	Single state posterior	Posterior		Subtotal		Yes	-	4	No	No
	Single state	Posterior		Gross		Yes	-	30	Yes	No



	posterior			total						
Ortolan	Posterior midline incision	Posterior	Yes	Gross total	No	No	Partial	17	Yes	No
Oshima	Resection of tumor and pelvic ring reconstruction	Combined	Yes	Gross total	No	No	Partial	3	Yes	-
Pennington_2	Endoscopic	Anterior	No	Gross total	No	No	-	14	Yes	-
	Posterior	Posterior	No	Gross total	No	No	-	0	-	-
	Posterior	Posterior	No	Gross total	No	No	-	2	Yes	-
	Posterior; Anterior	Posterior; Anterior (months later)	No	Subtotal	Yes	Yes	-	83; 11	Yes	-
	Posterior	Posterior	No	Gross total	No	No	-	21	Yes	-
	Anterior	Anterior	No	Gross total	No	No	-	36	Yes	-
	Anterior	Anterior	No	Gross total	No	No	-	12	Yes	-
Pongsthorn	Enucleation	Posterior	-	Gross total	No	No	-	144	Yes	No
	Anterior and posterior	Combined	-	Subtotal	No	No	-	132	Yes	Yes
	Anterior and posterior	Combined	Yes	Gross total	Yes	Yes	-	84; 180	Yes	Yes
	Anterior and posterior	Combined	-	Subtotal	No	No	-	36	Yes	No
	Posterior	Posterior	-	Gross total	No	No	-	18	Yes	No
	Anterior	Anterior	-	Subtotal	No	No	-	6	Yes	No
Ragurajaprakash	Transabdominal anterior	Anterior	-	Subtotal	No	No	Full	-	Yes	-
Silva	Laparotomy using posterior left paravertebral	Posterior	No	Gross total	No	No	-	24	Yes	-
Tahta	Midline laparotomy; Posterior midline incision and sacral bilateral laminectomy	Combined	No	Gross total	No	No	Full	12	Yes	No
Torgal	Anterior longitudinal midline incision; Posterior sacral cortex	Combined	No	Gross total	No	No	No	12	Yes	Yes
Yang	Endoscopic guided resection	Anterior	No	Gross total	No	No	Full	6	Yes	No
Yin	Robot-assisted sacral tumor resection *2 followed up with posterior	Anterior: 5 Combined: 2	-	Gross total	No	No	-	24-31 months	Yes	No

**Table 4:** Surgical characteristics and postoperative outcomes of patients at our institution.

Patient	Surgery Date	Operative approach	Sacrifice of Nerve(s)	Extent of surgical resection	Revision surgery	Progression	Improvement of symptoms	Follow up Time (Years)	Survival	Complications	Type of Complic
1	3/26/2003	Anterior	Yes	Gross total	No	Yes	Full Recovery	0.75	Yes	No	-
2	4/17/2008	Posterior	Yes	Subtotal	Yes	Yes	Full Recovery	0.50	Yes	No	-
3	1/21/2016	Anterior	No	Gross total	No	No	Full Recovery	0.50	Yes	No	-
4	5/28/2004	-	Yes	Gross total	No	Yes	Full Recovery	0.50	Yes	No	-
5	8/5/2005	-	Yes	Gross total	No	No	Full Recovery	0.25	Yes	No	-
6	1/11/1999	Posterior	No	Gross total	No	Yes	Full Recovery	0.75	Yes	No	-
7	6/5/2018	Combined	Yes	Gross total	No	Yes	Full Recovery	0.50	Yes	No	-
8	4/7/2000	Posterior	Yes	Subtotal	Yes	Yes	Full Recovery	0.50	Yes	No	-
9	5/16/2002	Posterior	Yes	Subtotal	Yes	No	Full Recovery	19.00	Yes	Yes	Neuropain and dysesthe
10	8/24/2001	Posterior	No	Subtotal	No	Yes	Full Recovery	3.50	Yes	No	-
11	8/18/2003	Posterior	No	Subtotal	No	No	Full Recovery	0.08	Yes	No	-
12	2/10/2017	Posterior	No	Subtotal	No	No	Partial Recovery	4.00	Yes	No	-
13	5/5/2010	Posterior	No	Gross total	No	No	Full Recovery	11.00	Yes	No	-
14	5/12/2014	Posterior	Yes	Gross total	Yes	Yes	No recovery	2.00	Yes	No	-
15	2/11/2010	Posterior	Yes	Gross total	No	No	Full Recovery	0.25	Yes	No	-
16	10/28/2008	Anterior	No	Gross total	Yes	Yes	Partial Recovery	0.50	Yes	No	-
17	4/15/2013	Posterior	No	Gross total	No	No	Partial Recovery	1.50	Yes	No	-
18	2/10/2015	Combined	No	Subtotal	No	No	Full Recovery	0.75	Yes	No	-
19	2/16/2004	Combined	No	Subtotal	Yes	Yes	No recovery	17.00	Yes	No	-
20	4/22/1997	Anterior	No	Gross total	Yes	No	Partial Recovery	0.00	Yes	No	-
21	9/22/2015	Anterior	No	Gross total	Yes	No	Partial Recovery	0.50	No	No	-
22	2/9/2006	Posterior	No	Subtotal	Yes	No	Partial Recovery	0.67	Yes	Yes	Neuropain
23	8/12/2013	Posterior	No	Gross total	No	No	Full Recovery	2.00	Yes	No	-
24	1/5/2016	Posterior	No	Gross total	No	No	Partial Recovery	1.00	Yes	No	-
25	3/13/2000	Posterior	No	Subtotal	No	No	Partial Recovery	0.04	No	No	-
26	9/16/2009	Anterior	No	Subtotal	Yes	No	Partial Recovery	11.00	Yes	Yes	Neuropain and Incontin
27	7/17/2008	Combined	No	Gross total	No	No	No recovery	4.50	No	Yes	Parapleg

## Figures

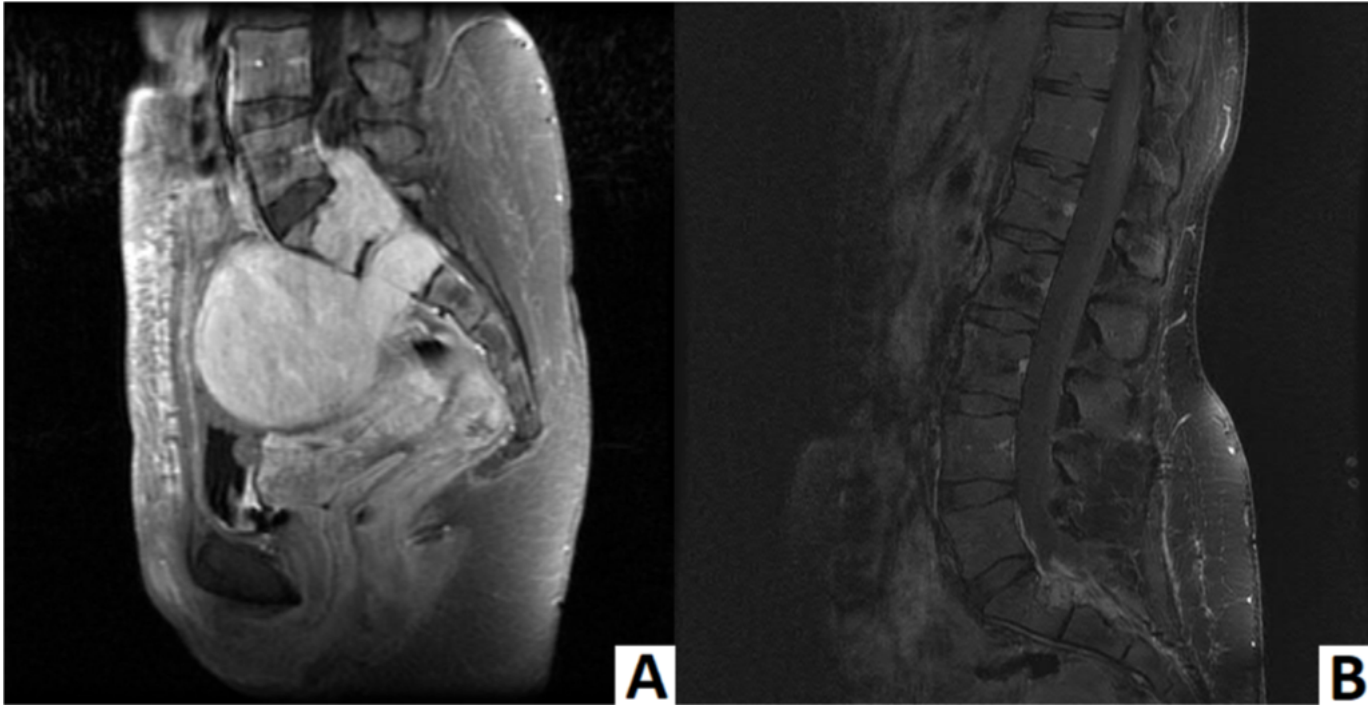


Figure 1

(A) Preoperative T1 MRI for patient 1 at our institution showing a large (11.5 x 7 x 3.5 cm) right-sided sacral schwannoma invading the abdominal cavity. (B) Postoperative T1 MRI following the removal of the tumor via transsacral approach.

## Supplementary Files

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- [SupplementalFigure1.png](#)