

Review

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Review

Surgical Management of Spinal Chordomas: A Narrative Review

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Abstract

Background: Chordomas are rare malignant tumors derived from notochordal remnants, accounting for 1–4% of skeletal malignancies. These slow-growing tumors most commonly affect the sacrum, skull base, and spine, posing significant challenges due to their anatomical location near critical neural structures. Despite their low metastatic potential, chordomas have a high local recurrence rate, necessitating aggressive surgical intervention. **Methods:** A narrative review of the literature was conducted, analyzing studies on the surgical management and adjuvant radiotherapy (RT) of spinal chordomas. Electronic databases, including MEDLINE, Scopus, ProQuest, and Google Scholar, were searched using relevant keywords. The retrieved studies were reviewed to assess surgical approaches, complications, outcomes, and the role of RT in treatment. **Results:** En-bloc resection with negative margins remains the primary treatment approach for cervical spinal chordomas, though achieving complete excision is challenging due to anatomical constraints. Sacrectomy and en bloc spondylectomy have been considered for sacral and thoracolumbar chordomas, respectively. Advances in RT, including proton beam and carbon ion therapy, have shown promise as adjunct treatments, especially when gross total resection is not possible. However, the benefit of adjuvant radiation remains debated. Postoperative complications, such as infections, neurological deficits, and mechanical instability, highlight the need for a multidisciplinary approach in patient management. **Conclusion:** The management of spinal chordomas requires an individualized treatment approach, balancing surgical feasibility, functional preservation, and disease control. While en bloc resection remains the gold standard, newer RT techniques may improve outcomes in select cases. A multidisciplinary team is essential to optimize prognosis and quality of life for affected patients.

Keywords: spinal tumors; chordomas; spinal chordoma

Introduction

Chordoma is a primary bone sarcoma that is locally aggressive and originates from notochordal remains in the vertebral bodies along the spinal axis [1]. Virchow first characterized chordoma in 1846; it is an uncommon primary tumor with malignancy that makes up 1 to 4% of skeletal malignancies and develops from the embryonic remains of the notochord [2,3]. In the adult group, all forms of chordomas are more common in men [4]. Chordoma makes up 40% of primary spinal tumors and 2%–4% of all spinal column tumors. The sacrum (50%), skull base (30%), and mobile spine (20%) are the locations of chordomas [5]. In mobile spine, they are mostly seen in the cervical spine. Patients with chordoma typically have a life expectancy of 6 years. Survival rates are 70–80% after five years and 40–60% after ten. Metastasis affects 30–40% of patients in advanced stages [5,6]. While spinal and sacral chordomas were most common in the Caucasian population, cranial

chordomas were more common in Asian/Pacific people [4]. Chordomas may also have an impact on young adults and children. In contrast to the craniocervical and sacrococcygeal prevalence in the adult populations, there is a female preponderance in the pediatric group, and it is more frequently appearing at the craniocervical junction with declining incidence caudally along the spine [7]. Given their placement along the midline of the axial skeleton and their close connection to the brainstem, cranial nerves, and spinal cord, chordomas have a poor natural course that is significantly accompanied by morbidity and death [8]. Chordoma makes up 4% of cancerous bone tumors, with an incidence of around 1 per one million individuals [2,9]. Chordomas are slow-growing tumors that have a low initial tendency for metastasis but a high probability of local relapse [2].

In radiographic examinations, chordomas commonly show up as a degenerative lesion that damages the axial skeleton and is connected to a sizable soft tissue mass at the tumor's core within the vertebral body [10]. In contrast to osteosarcoma and chondrosarcoma of the vertebral body, which are more frequently detected in the appendicular bone, chordomas are malignancies of the soft tissue [10]. Chordomas are frequently present on computed tomography (CT) scans as an osteolytic, mixed osteolytic, and osteosclerotic bone lesion that typically contains a myxoid component [10]. Intravenous infusion of contrast mediates the visualization of chordomas [10]. Due to the more widespread use of MRI (Magnetic Resonance Imaging), chordomas are now more frequently found in patients in their 30s than in the past [11]. Chordomas exhibit hyperintense on MRI but can vary from isointense to hypointense on T1-weighted images [10]. Gadolinium contrast may be utilized as well to see improved images of the chordoma [10].

The main course of treatment is still en bloc resection; however, some patients cannot have it because of the location and possible consequences [1]. Understanding chordomas has advanced; immunohistology markers like brachyury help make a positive diagnosis [1]. Although radical excision at initial presentation has been advised for many years, it is not practical in many cervical spine cases; sacral tumors can grow to enormous sizes prior to diagnosis, and tumor-free margins are sometimes unattainable [12]. Some centers have started using proton therapy as the main treatment for chordomas because they are resistant to traditional radiotherapy (RT) [13–15]. Thus, to discuss this contemplative topic further on, the authors aimed to review the literature regarding principles of surgical management, efficacy, survival rates, and complications of spinal chordoma surgery. Additionally, we also reviewed studies concerning the adjuvant RT given to chordoma patients.

Methods

To find articles about patients with spinal chordomas who underwent surgical intervention as well as RT, the authors searched electronic literature. MEDLINE, Scopus, ProQuest, and Google Scholar were among the databases used. Keywords used were, “chordoma” [OR] “chordomas” [AND] “spine” [OR] “spinal” [OR] “sacrum” [OR] “lumbosacral” [OR] “lumbar” [OR] “thoracic” [OR] “cervical” [AND] “surgery” [OR] “radiosurgery” [OR] “radiotherapy” [OR] “radiation therapy” [OR] “proton” [OR] “photon” [OR] “carbon ion” [OR] “adjuvant therapy” [OR] “chemotherapy”, were utilized as search phrases to conduct a literature search. Additionally, the retrieved papers' references were checked for other articles.

Management

Principles of Surgery

The Enneking classification was first used in 1980 to categorize people who had primary tumors that were malignant of the appendicular bone [16]. These patients' local control was improved, and their survival rate went up, thanks to this theory [17]. As a result, primary malignancies of the axial skeleton are now treated according to the Enneking classification [18]. The main objective of surgery was to obtain negative margins verified by the musculoskeletal pathology department because numerous studies have indicated that local recurrence rates dropped, and rates of survival improved following spinal tumor excision with negative margins [17,19–25]. For the best local management, a

surgical margin has been suggested based on the tumor grade, tumor area, and the presence or absence of metastases [26].

When applying the Enneking classification standards, these tumors should all receive a large resection due to the aggressive nature of chordoma [16,17,26]. The spine, where marginal resection is most frequent, may make the wide-margin notion less useful [18]. Enneking appropriate (EA) refers to resections that produce marginal or wide margins; Enneking inappropriate (EI) refers to resections that produce intralesional or infected margins [17,23,26]. But as was already indicated, published material demonstrates that micro skip metastases, which are invisible by modern imaging techniques, can happen as far as 20 mm (about 0.79 in) from the primary tumor [27]. It is important to note that just 1 study, including the sacrum, has looked at skip metastases [18]. If the movable spine falls under this definition, it is not clear [18]. Therefore, until improved long-term outcomes from other types of therapy are available, evidence-based oncologic guidelines should be followed [18]. Achieving these margins, however, comes at higher morbidity and greater cost to neurologic function [18]. To effectively treat these individuals, patient interest should always be a primary consideration [18].

Surgical Efficacy

The preferred treatment for cervical chordoma is total spondylectomy [28]. The conventional anterior reconstruction technique, which uses large autologous bone or titanium mesh bone graft in conjunction with titanium plate fixation, has good clinical results, but it also has drawbacks, including a limited supply of large autologous bone, a lengthy bone fusion time, and more frequent complications like internal plant displacement and titanium mesh sinking [29]. Additionally, it is challenging to locate an appropriate titanium mesh to reconstruct the stability of the cervical spine after vertebral excision of several segments, particularly tumors involving more than three segments. Furthermore, it is challenging to achieve dependable stability right away when reconstructing the cervical spine using titanium mesh because the anatomical morphology of the cervical spine is unique, particularly the upper cervical spine, and the morphology of the titanium mesh differs greatly from that of the vertebral body [30].

Advancements in surgical methods have also been achieved through artificial vertebral reconstruction. In contrast to conventional titanium mesh, 3D printing allows for the customization of artificial vertebral bodies according to the angle of the adjacent vertebral endplates and the segments of the tumor. The use of 3D printed prosthetic vertebral bodies for repair following surgery for cervical spine tumors was primarily documented in case reports due to the brief clinical application of these structures [31,32]. A retrospective analysis of 24 patients with cervical chordoma who had total vertebral resection at Peking University Third Hospital between March 2005 and September 2019 included 15 patients undergoing titanium mesh reconstruction and 9 patients receiving artificial vertebral reconstruction using 3D printing [33]. Compared to titanium mesh reconstruction, 3D printed artificial vertebral bodies offered dependable immediate and medium-to-long-term cervical stability in total spondylectomy for cervical chordoma, lowering the risk of postoperative endoprosthetic subsidence [33].

In the evidence retrieved from the last 5 years, it was observed that surgical intervention plays a crucial part in enhancing survival rates [5,34]. Subtotal resection (STR) and gross total resection (GTR) patients had considerably lower hazard ratios [34]. Although malfunctions were also associated with anterior column repair and hardware malfunctions after en bloc removal of upper cervical chordoma [35]. For sacral and thoracolumbar chordomas, the best results were yielded with sacrectomy and en bloc spondylectomy [12]. The same study also found complications in mobile spine surgery [12]. Surgical procedure of 360° four-level en bloc showed good bone fusion with no recurrence, but there was a high rate of structural failure suspected [36]. Wang et al. studied that for lateral multilevel cervical chordoma, parasagittal osteotomy was a good alternative for en bloc spondylectomy [37]. One vertebral artery was preserved with the en bloc resection [37]. Yet, patients' nerve roots and vertebral arteries were sacrificed (see Table 1).

Table 1. Surgical efficacy for spinal chordoma.

Authors	Approach description	Efficacy	Complications
Agner and Larkins [34]	GTS (315 patients) STR: (308 patients)	The study verified that surgical intervention plays a crucial part in enhancing survival rates. STR and GTR patients had considerably lower hazard ratios than non-surgical patients ($p<0.001$).	Poor outcomes were seen with increased age, disease histology, severe disease stage, chordoma of the sacrum/pelvis compared to chordoma of the vertebrae, and lack of surgical treatment.
Patel et al [5]	Partial resection (499 patients) Radical resection (550 patients)	Higher overall survival rate was noted after surgical excision.	A lower overall survival rate was linked to older age, larger tumors, and metastases.
Pinter et al. [35]	Reconstruction using a free vascularized fibular graft after en bloc removal of a high cervical chordoma (C1-C3).	There are reported negative margins and limited long-term oncologic results.	Hardware malfunctions and complications associated with anterior column repair
Zileli M and Karakoç [12]	C2 chordoma: Anterolateral retropharyngeal excision, combined anterior-posterior approach, posterior excision, and fixation (9 patients) Subaxial cervical chordomas: Anterolateral corpectomy, graft, plate, posterolateral excision and fixation, combined approach (4 patients) Thoracolumbar chordomas: Total spondylectomy, intralesional excision, combined surgery (7 patients) Sacral chordomas:	For sacral chordomas, sacrectomy at S2 and lower yields the best results. For thoracolumbar chordomas, en bloc spondylectomy yields the greatest results.	Compared to sacral procedures, mobile spine surgeries had a higher prevalence of complications. While mobile spine procedures entailed a higher risk of neurological and vascular complications, sacral surgery frequently featured wound problems and rectal/urinary tract damage.

	Sacrectomy, posterior intralesional surgery (28 patients)		
Aoun et al. [36]	360° four-level en bloc (C3–C6).	Imaging follow-up revealed good bone fusion and no tumor recurrence.	High rate of structural failure; reoperations are required
Wang et al. [37]	Four patients had two-stage en bloc excision of multilayer cervical chordomas using parasagittal osteotomy, expandable cage repair, and posterior instrumentation.	When treating lateralized multilevel cervical chordoma, parasagittal osteotomy is a helpful substitute for en bloc spondylectomy since it preserves one vertebral artery while still accomplishing an en bloc resection.	Two patients had their nerve roots sacrificed, while three had their vertebral arteries ligated.
GTS: Gross total resection, STR: Subtotal resection			

Reconstruction After Removal of Chordoma

A case investigation revealed a lobulated extradural mass that spanned from C3 to C6, severely compressing the spinal cord and damaging the vertebral body [38]. The procedure was carried out using a sequential circumferential approach. Anterior corpectomy and tumor removal with reconstruction utilizing an anterior plate and titanium cage comprised the first step; posterior instrumentation for stabilization made up the second. A histopathological analysis verified the presence of brachyury expression in typical chordoma. After two months, the patient had a significant neurological recovery and was recommended for adjuvant RT [38]. The case report by Pinter et al. documented reconstruction using a free vascularized fibular graft after an en bloc removal of a chordoma affecting C1-3 [35]. This report was the first to show satisfactory long-term oncological results following true margin-negative excision of a high cervical chordoma. It also showed the construct's sustainability at a 10-year follow-up [30].

Following sacral chordoma excision, patients have four dependable options: free flaps, transpelvic vertical rectus abdominis myocutaneous flaps, bilateral gluteal advancement flaps, and direct closure [39]. Rajagopalan et al. conducted a retrospective analysis of patients who had reconstruction following the excision of lumbar or sacral chordomas at a single facility between 2012 and 2023 [40]. The majority of the patients received gluteus muscle (GM) flaps. The second most frequent flaps were those of the paraspinous muscle (PSM) and vertical rectus abdominus myocutaneous (VRAM). Hardware placement was more frequently linked to VRAM and PSM flap reconstruction ($p<0.01$). The median follow-up period was 34 months. The incidence of postoperative surgical complications was not correlated with the method of reconstruction or the location of the hardware [40]. Two cases of significant deformities after total sacrectomy for chordoma were reported by Xu et al [41]. A modified lumbar artery perforator flap was used to treat Case 1, a 65-year-old woman with a deep three-dimensional cavity, after the initial standard vacuum sealing drainage (VSD) was unable to eliminate the dead space. In Case 2, a 45-year-old man with a significant surface defect had conservative treatment using a modified VSD technique in conjunction with silver ion dressings. In Case 1, full and long-lasting wound healing resulted from the perforator flap's solid, vascularized covering. In Case 2, a silver dressing regimen and improved VSD effectively prevented possible infection and encouraged strong granulation, leading to full wound closure by secondary intention. Both patients had well-healed wounds during follow-up, showing no signs of

serious consequences or recurrence [41]. For post-sacrectomy deformities, the aforementioned report emphasizes that a single reconstructive technique is not always appropriate. From expert conservative care with modified VSD and antimicrobial dressings to intricate perforator flap restoration, a graduated and customized strategy is crucial. However, for patients with partial sacrectomy, intact gluteal vessels, and no preoperative RT, bilateral gluteal advancement flaps or gluteal perforator flaps are the first option [39]. For patients with near-total sacrectomy and preoperative RT, transpelvic vertical rectus abdominis myocutaneous flaps or free flaps are the next options [39].

Complications

Cervical Chordomas

Many researchers contend that an aggressive surgical approach is constrained by the potential of neurovascular damage since cervical spine chordomas typically include important anatomy like the vertebral arteries and cervical nerve roots [42–45]. Because of the diversity of the radiculomedullary branches, vertebral artery sacrifice can result in spinal cord ischemia and stroke, especially if the tumor involves the dominant vertebral artery [45,46]. In order to assess the viability of vascular sacrifice for en bloc excision, a number of investigators have suggested that patients with chordomas involving the vertebrae undergo a cerebral angiography and a transient balloon occlusion test as part of the preoperative workup [45]. Since doing so results in a neurological deficit (loss of function in the upper limb muscles), which is crippling and lowers quality of life, scholars have been hesitant to sacrifice nerve roots in subsequent experiments [45]. En bloc advocates suggest that if long-term survival or a possible cure are enhanced, neurological deficits would be tolerable [45]. It is interesting to note that no notable neurological impairments were observed in patients who had the C1–6 cervical nerve root(s) excised [44,45,47].

Sacral Chordomas

An early scar disunion following surgery necessitates surgical revision and ongoing antimicrobial therapy [11]. Additionally, it's possible that it is a late infection [11]. When compared to laparotomy, the anterior technique requires less blood loss [48,49]. Nevertheless, the primary source of bleeding is the posterior approach with the sacral osteotomy [11]. Even without RT, sacrectomy above the S2 carries a risk of pathological fracture; hence, prophylactic internal fixation should be used [11]. When compared to laparotomy, the anterior technique requires less blood loss [48,49]. Nevertheless, the primary source of bleeding is the posterior approach with the sacral osteotomy [11]. Following a sacrectomy for chordoma, many additional problems have been documented, including sacroiliac instability [50], non-union [51], digestive fistula [11], osteomyelitis [11], ureter wound [11], CSF leaking [11], and pseudo-meningocele [51]. To improve their quality of life, they need specialist interdisciplinary management [11].

Comprehensive Treatments

Radiotherapy

RT is frequently thought to have a negligible effect on chordomas [18]. However, the majority of historical data indicate that in the salvage context, relatively low radiation doses (less than 50 Gy) were employed [18]. The application of radiation appeared to have been kept for situations where it was impossible to treat a recurring chordoma under ideal conditions [18]. Additionally, it is acknowledged that chordoma cannot be treated with lower radiation doses [18]. The radiation dose, however, has been increased thanks to improvements in radiation administration. Some, such as Massachusetts General Hospital (MGH), have called for doses of more than 70 Gy [18]. With time came experience at MGH employing elevated levels of radiation as an adjunct to surgery, and the results compared well to earlier studies [52]. At MGH, radiation is delivered using protons, which

have advantageous distribution patterns that include a high concentration of dose at the tumor and no exit dose [18]. These elements lessen radiation's effect off-target, enabling one to raise the dose.

RT can be divided into three basic categories:

1. Fractionated RT
2. Gamma knife and Cyberknife
3. Hadron therapy (proton and carbon ion) [1].

According to reports, proton treatment is safe and helpful for chordoma patients [53]. RT is required because:

- (a) Cervical malignancies frequently fail locally
- (b) Sacral tumors frequently fail distantly.

To improve the prognosis, proton therapy refinement is necessary, such as using intensity-modulated PT for cervical cancers [53]. However, compared to surgery, radical definitive particle therapy provides a comparable result [13,54]. A prospective, randomized multinational research comparing definitive high-dose RT and surgery has been started by a Chordoma Global Consensus Group [54]. One possibility to reduce the morbidity and consequences of en bloc resection is the use of RT as the main treatment. This might be especially true for cutting-edge techniques like stereotactic RT, proton beam therapy, and carbon ion RT [1].

Chemotherapy

Chordomas are essentially unaffected by classical chemotherapy [1]. On the other hand, targeted chemotherapy is currently popular. The most crucial factors at the cell surface are the tyrosine kinase receptors (RTKs). RTKs are triggered by numerous ligands, principally growth factors, including platelet-derived growth factor (PDGF), Epidermal growth factor (EGF), and transforming growth factor [1]. Cetuximab, an anti-EGFR antibody, has been proposed as an immunotherapy for chordomas [55]. This is a type of cell-mediated natural killer.

PDGF receptor inhibitors (imatinib), EGF receptor inhibitors (cetuximab, gefitinib, erlotinib), and mTOR inhibitors (sirolimus) are the most often utilized inhibitors for targeted chemotherapy [1]. Regrettably, the series is limited, and there is no solid proof of their advantages at this time [56]. It is widely believed that the development of effective targeted chemotherapies and a deeper comprehension of the molecular biology and oncogenesis of chordomas will be crucial to the future of medical care.

Complications

Following RT, a pathologic condition known as fatigue fracture affects almost half of the patients [57,58], varying in duration from 1 to 62 months (about 5 years) in the case of Bostel et al. [57]. Contrary to the previous findings, Osleret et al. found that fractures occurred more frequently in surgery combined with RT than only in RT [57,58]. In sacral chordoma patients treated with carbon ion RT, 211 (96%) of whom were treated without surgery, Demiz et al. [59] reported grade 3 complications in 5.9% of patients at a mean of 56 months, with 2.7% skin complications, 1.4% myositis, 0.9% pathologic fracture, and 1.4% chronic pain.

Outcomes of Chordoma Surgery

Metastasis, Recurrence, and Survival

After broad excision, there is a 40% to 20% local recurrence rate of sacral chordoma and a 20% to 40% metastatic recurrence rate [60]. Difficulty in performing successful wide resection or GTR of the spinal chordomas is demonstrated by high rates of recurrence and metastasis, which emphasizes the significance of cautious surgical management of these patients [61]. Because infection in the resection margins can increase the risk of recurrence and mortality, as shown in a meta-analysis, it is crucial to achieve a wide excision [62]. A database analysis has shown not much benefit in cases where

GTR has been achieved [63]. Promising developments have been made in more accurate RT techniques, such as stereotactic RT, carbon ion treatment, and proton beam therapy [61].

There have been some advances in chordoma survival with recent therapeutic techniques. Surgical margins have little effect on results, despite the fact that numerous earlier studies have supported negative surgical margins, also referred to as Enneking negative surgery [1]. Recent developments in diagnostic and therapeutic approaches, such as improved tumor resection techniques and improved RT methods like proton beam therapy, may have contributed to improvements in the survival times of sacral and mobile spine chordomas [64]. Proton beam therapy is one example of a modern radiation technique that offers longer survival times and fewer complications than surgery [1]. Table 2 displays the outcomes of the discussed interventions in detail.

Usually, metastases develop in the bones, subcutaneous tissues, lymph nodes, and lungs [12]. Following a recurrence, metastases are more commonly seen [12]. Compared to chordomas of the movable spine, sacral chordomas have a higher propensity to spread [12].

Table 2. Literature on survival/ recurrence rate of spinal chordoma in the last 5 years.

Authors	Year	Study type	Intervention	Survival/ recurrence rate
Agner and Larkins [34]	2024	Retrospective study (Surveillance, Epidemiology, and End Results Program); 896 patients	Surgery, Conventional RT, Photon RT, Carbon ion RT	A 5-year overall increase in survival was noticed. STR HR: 0.48 GTR HR: 0.22 RT HR: 0.69
Patel et al [5]	2023	Retrospective study (National Cancer Database); 1548 patients	Surgery, Conventional RT, Photon RT, Carbon ion RT	Mean overall survival: 8.2 years Partial resection HR: 0.43 Radical resection HR: 0.35 RT HR: 0.82
Pennington, Zach et al [64]	2021	Narrative review	Surgery, Conventional RT, Photon RT, Carbon ion RT	High-dose (>50 Gy) neoadjuvant or adjuvant RT is becoming the standard of care because of advancements in radiation modalities (photon therapy, proton beam radiation).
Zileli M and Karakoç [12]	2021	Retrospective clinical series (6-year follow-up); 48 patients	Surgery, Conventional RT	Sacrectomy: Average survival period: 68 months Recurrence rate: 76% Marginal or intralesional resection: Average survival period: 76.5 months Recurrence rate: 83%
Baig Mirza et al [61]	2021	Systematic review; 1531 patients (42 articles)	Surgery, Conventional RT	GTR recurrence rate: 25% STR recurrence rate: 50%

Chehrassan et al [65]	2020	Retrospective study (National population-based study); 122 patients	Not investigated	Mean survival time: 4.5 years. Age-standardized incidence rate (ASIR) of chordoma: 0.28. Sacral chordoma cases: 67.2%
Denaro et al [2]	2020	Systematic review; 1359 patients (58 articles)	Surgery, Conventional RT, Photon RT, Carbon ion RT	Cervical chordomas recurrence rate range: 25% - 60% Sacrococcygeal chordomas recurrence rate range: 18% - 89%
GTS: Gross total resection, STR: Subtotal resection, RT: Radiotherapy, HR: Hazard ratio				

Conclusions

There are significant difficulties in managing spinal chordomas, especially when it comes to metastases and recurrences. Sacral chordomas and movable spine chordomas have similar survival and recurrence rates. Mobile spine chordomas do not typically progress to metastases, while sacral chordomas do. For sacral chordomas at S2 and lower, sacrectomy is effective. Unfortunately, additional marginal excision of cervical chordomas is not feasible without serious impairments and problems. The main treatment for chordoma should be surgical resection. Although drastic surgery is frequently highlighted, the viability should be assessed on an individual basis using a multidisciplinary approach customized to meet the needs of each patient.

The patient should be carefully informed about the surgical process, expected advantages, and any problems. It is difficult to standardize this operation, and the surgeon must know how to modify the surgical process to meet the needs of each patient. As a result, the surgical technique and fixing method must be uniquely tailored to the individual patient. The patient should be psychologically and physically prepared, as well as informed about the difficulties and anticipated aftereffects that may reduce the quality of life. If a colostomy is anticipated, learning how to self-catheterize may be necessary before surgery, along with visiting a stoma therapist. Thus, surgical management requires multidisciplinary skills from the fields of surgery, anesthesia, radiology, etc. Surgery carried out outside of a reference facility is a separate risk factor for fatal results.

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