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Journal

European Spine Journal, 23(2)

ISSN

0940-6719

Authors

Bederman, S Samuel
Shah, Kalpit N
Hassan, Jeffrey M
[et al.](#)

Publication Date

2014-02-01

DOI

10.1007/s00586-013-3075-z

Peer reviewed

Surgical techniques for spinopelvic reconstruction following total sacrectomy: a systematic review

S. Samuel Bederman · Kalpit N. Shah ·
Jeffrey M. Hassan · Bang H. Hoang ·
P. Douglas Kiester · Nitin N. Bhatia

Received: 17 June 2013/Revised: 12 October 2013/Accepted: 13 October 2013/Published online: 23 October 2013
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Abstract

Purpose To identify all available reconstruction methods for a total sacrectomy. Secondly, we aimed to evaluate outcomes based on different interventions.

Methods We searched PubMed to identify sacral resections for tumors requiring internal fixation for stabilization. Demographic information, fixation techniques and postoperative outcomes were abstracted.

Results Twenty-three publications (43 patients) met inclusion criteria from an initial search of 856 (κ 0.93). Mean age was 37 years and follow-up was 33 months. Fixation methods included a combination of spinopelvic fixation (SPF), posterior pelvic ring fixation (PPRF), and/or anterior spinal column fixation (ASCF). For the purposes of analysis, patients were segregated based on whether they received ASCF. Postoperative complications including wound/instrument infections, GI or vascular complications were reported at a higher rate in the non-ASCF group (1.63

complications/patient vs. 0.7 complications/patient). Instrument failure was seen in 5 (16.1 %) out of the 31 patients with reported outcomes. Specifically, 1 out of 8 patients (12.5 %) with ASCF compared with 4 out of 23 patients (17.4 %) without ASCF had hardware failure. At final follow-up, 35 of 39 patients were ambulating.

Conclusion While surgical treatment of primary sacral tumors remains a challenge, there have been advances in reconstruction techniques following total sacrectomy. SPF has shifted from intrapelvic rod and hook constructs to pedicle and iliac screw–rod systems for improved rigidity. PPRF and ASCF have adapted for deficiencies in the posterior ring and anterior column. A trend toward a lower rate of hardware failure emerged in the group utilizing anterior spinal column support. Despite a more involved reconstruction with ASCF, surgical complications such as infection rates and blood loss were lower compared to the group without ASCF. While we cannot definitively say one system is superior to the other, based on the data gleaned from this systematic review, it is our opinion that incorporation of ASCF in reconstructing the spinopelvic junction may lead to improved outcomes. However, most importantly, we recommend that the treating surgeon operate on patients requiring a total sacrectomy based on his or her level of comfort, as these cases can be extremely challenging even among experts.

Keywords Total sacrectomy · Spinopelvic fixation · Posterior pelvic ring fixation · Anterior spinal column fixation · Systematic review

Introduction

Primary sacral tumors represent a rare entity, accounting for <7 % of all spinal tumors [1]. Chordomas, which are the

S. S. Bederman (✉) · K. N. Shah · J. M. Hassan ·
B. H. Hoang · P. D. Kiester · N. N. Bhatia
Department of Orthopaedic Surgery, University of California at
Irvine, 101 The City Drive South, Pavilion III, Orange,
CA 92868, USA
e-mail: sbederma@uci.edu

K. N. Shah
e-mail: knshah@uci.edu

J. M. Hassan
e-mail: hassanj@uci.edu

B. H. Hoang
e-mail: bhhoang@uci.edu

P. D. Kiester
e-mail: pkiester@uci.edu

N. N. Bhatia
e-mail: bhatian@uci.edu

most common primary malignant sacral neoplasm, along with chondrosarcomas and giant cell tumors are relatively resistant to radiotherapy and chemotherapy [2, 3]. Given the relatively mild symptoms initially, patients with sacral malignancies often present with large, advanced neoplastic disease. Intralesional resection without adequate margins may lead to higher local recurrence [1, 4–6]. Hence, en bloc resection has been demonstrated to increase the disease-free survival period in patients harboring various primary sacral neoplasms that are unresponsive to chemotherapy and radiotherapy [4–6]. Despite the obvious advantages for disease-free survival, en bloc resection and spinopelvic reconstruction for sacral tumors pose a unique challenge for the surgeon given the complex anatomical and biomechanical relationships that govern the spinopelvic junction. Although partial sacrectomy operations are usually well tolerated without the requirement of stabilization, in patients with extensive expansion of the tumor requiring total sacrectomy, the vertical and rotational instability created necessitates stabilization between the lumbar spine and the pelvis to allow for mobilization and improved function [7–9].

With advances in surgical techniques, a variety of interventions for reconstruction following total sacrectomy have been reported. However, the rarity of this unique intervention has limited these accounts to individual case reports and small case series [2, 8, 10–30]. There are no published systematic reviews that provide the surgeon with a comprehensive summary of current and past surgical reconstructive techniques with associated outcomes. The primary aim of this systematic review was to provide the treating surgeon with a comprehensive overview of available options for reconstructing the spinopelvic junction following total sacrectomy. Secondly, we examined outcomes and complications between the various treatment techniques, identifying differences between the methods of instrumentation.

Materials and methods

A search strategy was developed with the assistance of a medical librarian to identify relevant articles in the PubMed database that reported on en bloc sacral resections for tumors requiring internal fixation for stabilization. All relevant articles in English up to March 17, 2011 were included. Conceptually, the search was constructed by combining keywords that focused on (1) sacral tumors, (2) sacral resection and (3) reconstruction (Appendix). We additionally performed hand searches of bibliographies of relevant articles as well as archives from meeting proceedings of the American Academy of Orthopaedic Surgeons (2010–2011), Musculoskeletal Tumor Society

(2010–2011), Scoliosis Research Society (2009–2011), American Academy of Neurological Surgeons (archives), and Congress of Neurological Surgeons (2005–2012).

We included all studies that contained details of surgical instrumentation and fixation methods for patients who underwent en bloc resection of the tumor requiring a total sacrectomy. We excluded studies that reported on patients with partial sacrectomy, those who underwent intralesional resection, tumors without sacral involvement, those who did not report on reconstruction details, studies without rigid internal fixation, animal models, finite element modeling, and biomechanical studies.

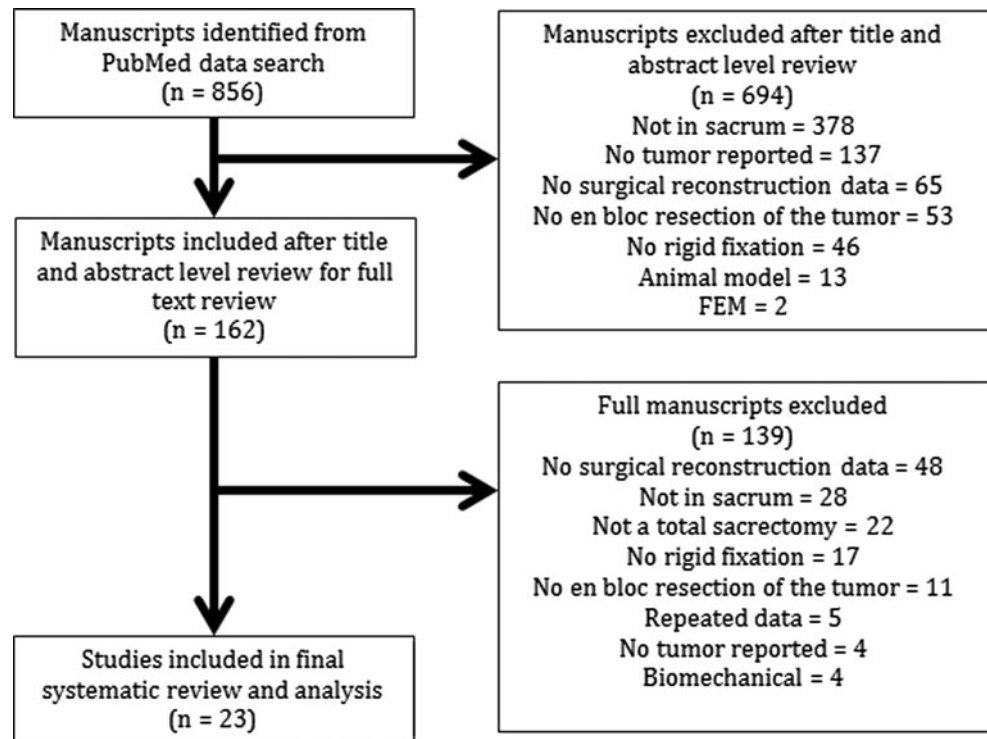
Titles and abstracts were reviewed by two investigators to include potentially eligible articles. Full manuscripts identified were retrieved in a blinded manner. Disagreements were resolved by a third investigator. Cohen's Kappa was used to quantify overall agreement. For all included studies, demographic information, fixation techniques and instrumentation details, as well as postoperative outcomes were abstracted using a standardized form. We considered surgical constructs that connected the lumbar spine to the ilium as 'spinopelvic fixation' (SPF) while constructs that connected only the ilia together without fixation to the lumbar spine were identified as 'posterior pelvic ring fixation' (PPRF). Constructs that aimed to strengthen the anterior spinal column were recognized as 'anterior spinal column fixation' (ASCF). These designations were used either individually or in combination.

All authors were contacted to inquire about any changes in patient outcomes since publication as they relate to tumor recurrence, ambulation, and the need for revision surgery. Authors of the studies were contacted in cases where patient data were presented only as an aggregate, making it difficult to tease apart the relevant data. If further clarification could not be provided, we maintained the aggregate data and noted this in the tables.

Results

Search results

The initial search of the PubMed database located 856 publications based on our search strategy. After a title and abstract level review, 162 articles were found to be potentially eligible (κ 0.93). Of those, 139 studies did not meet our inclusion criteria—48 did not provide surgical technique or instrumentation detail, 28 were based on non-sacral tumors, 22 did not describe a total sacrectomy, 17 did not use rigid fixation for the treatment of sacral tumors, 11 reported intralesional tumor resections, 5 included repeated patient data or no patient data, 4 reported biomechanical data, and 4 did not include tumors (Fig. 1).

Fig. 1 Outline of the review process

23 Articles representing 43 patients met our inclusion criteria and were included in our final analysis. 15 studies of the 23 included were single case reports and 8 studies were case series. Eight studies reported on multiple patients, where only a portion of the patients met our inclusion criteria. Patients not meeting our criteria in those studies were excluded and the eligible patient data were isolated.

A total of 107 abstracts were identified as relevant from the annual meeting archives of relevant academic organization using the search terms “sacrum”, “sacral”, and “sacrectomy”. Of these, 23 studies were identified as potentially relevant; however, all were excluded. 16 abstracts did not provide sufficient reconstruction technique or instrumentation details, 5 studies presented data on partial sacrectomy, and 2 studies reported on patients who were presented in studies included from our original search.

Study characteristics

For the 43 patients included in our review, the mean age of patients was 37 years (range 13–61), with 25 being male and 18 female. The tumor types are displayed in Fig. 2. 32 patients were reported to have neurological deficits pre-operatively, while no data were reported for the other 11 patients (Table 1).

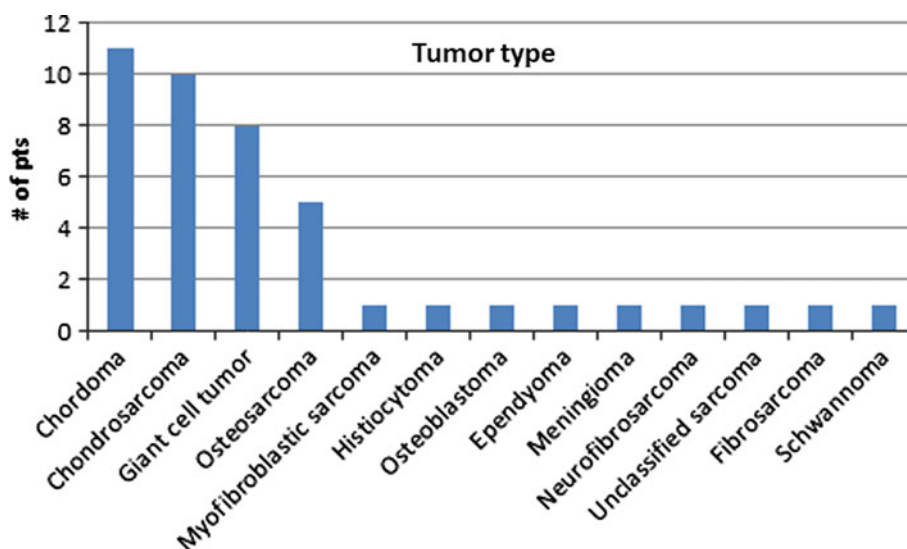
Reconstruction methods

Fixation methods were stratified by the techniques of reconstruction (SPF, PPRF, and ASCF). All patients received SPF along with some form of additional fixation: 1 patient (2.3 %) had additional ASCF (Fig. 3), 34 (79.1 %) received additional PPRF (Fig. 4), and 8 (18.6 %) received both ASCF and PPRF in conjunction with SPF (Fig. 5). For the purpose of our evaluation, we separated those who received ASCF (9 patients, 20.9 %) from those that did not (34 patients, 79.1 %).

A trend was recognized with regard to the evolution of SPF systems—‘older’ systems (reported up to 2005) included intrapelvic Galveston rods and hook–rod constructs connected to transiliac bars (21 patients), while ‘newer’ systems (reported starting in 2001) included pedicle screw–rod constructs connected to iliac screws, transiliac rods, or custom plates (22 patients) (Fig. 6).

The PPRF systems connecting ilium to the contralateral ilium included transiliac rod or plate fixation (35 patients), structural allografts (12 patients), and prosthetic cages (2 patients). ASCF systems that connected the pelvis to the anterior spinal column included iliolumbar screws (1 patient), fibular grafts (6 patients), titanium mesh and expandable cages (2 patients), and a vertical rod through the lumbar vertebral bodies (1 patient) (Table 2).

Fig. 2 Tumor diagnoses for patients included in this review



Instrumentation complications

Revision surgery or instrument failure was seen in 5 (16.1 %) out of the 31 patients with reported outcomes (Table 3). The need for revision surgery was not reported for 12 (27.9 %) of the 43 patients included in this review. Instrumentation failure was reported in 1 out of 8 patients (12.5 %) who received ASCF compared with 4 out of 23 patients (17.4 %) in the group without ASCF (Table 4).

General surgical complications

Soft tissue flaps were used in the operation for 31 patients (72.1 %) to cover the void left by the en bloc sacral resection. Blood loss was reported for 24 patients (55.8 %) with an average of 9,276 mL per patient (range 1,500–21,700 mL). Postoperative complications were reported for 23 patients and included wound/instrument infections (7 patients, 30.4 %), wound dehiscence (4 patients, 17.4 %), gastrointestinal complications (hemorrhage, perforation, *C. difficile* infection and ileus) (7 patients, 30.4 %), urinary tract infections (4 patients, 17.4 %), vascular complications (7 patients, 30.4 %), seizures (1 patient, 4.3 %), decubitus ulcer (1 patient, 4.3 %), and none in 4 patients (Table 2).

General surgical complications were reported at a higher rate in the group without ASCF than in the group that did receive ASCF (1.63 complications per patient vs. 0.7 complications per patient). Average blood loss for the group without ASCF was 9,535 mL for 16 patients, while in the group with ASCF an average blood loss of 6,650 mL was reported in 2 patients (Table 4).

Long-term outcomes

Mean follow-up was 33 months (range 5–83 months) as reported in 22 out of the 23 articles for 42 patients (Table 3). Since all patients had S1–S5 nerve transection (4 with additional L5 transection), bowel and bladder dysfunction was common in all 32 patients with reported outcomes (25—complete, 7—partial).

The incidence of tumor recurrence was reported for 25 patients, of whom 14 (56 %) had no recurrence at an average of 37 months, 6 (24 %) had local recurrence at an average of 40 months, and 5 (20 %) had metastatic disease at an average of 22 months. The tumors that recurred or metastasized included chordoma (4), chondrosarcoma (3), osteosarcoma (1), histiocytoma (1), meningioma (1), and fibrosarcoma (1). Changes in pain were reported inconsistently and are presented along with other outcome data in Table 3.

At final follow-up, 35 patients (89.7 %) of the 39 with reported ambulatory status were ambulating. Of the patients who did not receive ASCF, 8 (24 %) were able to ambulate independently, 22 (65 %) with help, and the status was not reported for 4 patients (Table 4). For the group of patients that received ASCF, four (44 %) ambulated independently, one (11 %) with help, and four (37 %) could not ambulate at all.

Discussion

A variety of instrumentation techniques exist to stabilize the lumbosacral junction following total sacrectomy; however, due to the infrequency of these tumors requiring total sacrectomy, the novel instrumentation techniques are scattered across the literature in case reports and small case

Table 1 Patient demographics and tumor type

Author	Year	# of Pts	Age	Sex	Tumor type	Neurological deficit
Humphries et al. [16]	2010	1	15	F	Myofibroblastic sarcoma	Y
Gallia et al. [17]	2010	1	52	F	Malignant fibrous histiocytoma	Y
Varga et al. [10]	2010	1	42	M	Chordoma	Y
Newman et al. [11]	2009	1	35	M	Chondrosarcoma	Y
McLoughlin et al. [12]	2008	1	57	M	Osteoblastoma	Y
Shen et al. [18]	2006	1	44	M	Chordoma	NR
Gallia et al. [21]	2005	1	52	M	Chordoma	Y
Fourney et al. [2]	2005	3	35 ^a	M (3)	Chordoma (2), chondrosarcoma (1)	NR
Dickey et al. [20]	2005	6	40 ^a	M (2), F (4)	Ependymoma, osteosarcoma, chordoma, chondrosarcoma, osteosarcoma, meningioma	Y
Min et al. [29]	2005	1	35	F	Neurofibrosarcoma	Y
Zileli et al. [24]	2003	3	28 ^a	M (1), F (2)	Chondrosarcoma (2), osteosarcoma (1)	Y
Ohata et al. [13]	2004	1	13	M	Unclassified sarcoma	Y
Doita et al. [8]	2003	3	61 ^a	M (2), F (1)	Giant cell tumor, chordoma (2)	NR
Mooney et al. [14]	1999	1	10	M	Fibrosarcoma	Y
Sar et al. [25]	2002	3	18 ^a	M (2), F (1)	Giant cell tumor, chondrosarcoma (2)	NR
Wuisman et al. [19]	2001	1	42	F	Osteosarcoma	Y
Jackson et al. [22]	2000	5	45 ^b	M (8), F (5) ^b	Giant cell tumor (2), chordoma (2), chondrosarcoma (1)	Y
Spiegel et al. [15]	1999	1	16	M	Osteosarcoma	Y
Gokaslan et al. [26]	1997	2	34 ^a	F (2)	Giant cell tumor (2)	Y
Santi et al. [30]	1993	1	48	M	Schwannoma	N
Shikata et al. [23]	1992	1	34	M	Giant cell tumor	Y
Tomita et al. [27]	1990	2	52 ^a	M (1), F (1)	Giant cell tumor (1), Chordoma (1)	NR, Y
Shikata et al. [28]	1988	2	35 ^a	M (1) F (1)	Giant cell tumor (1) Chondrosarcoma (1)	Y

NR not reported, Y yes

^a Average of patient with total sacrectomy, ^b average of all patients reported in article

series. It is the relative infrequency of these operations that has limited the ability to directly compare the wide array of techniques and instrumentation approaches. Therefore, in this review we identified and summarized the various reconstructive methods available as well as examined trends in treatment outcomes and complication rates to best assist a surgeon who may be required to care for a patient with large sacral tumors.

Although our inclusion criteria of rigid fixation prevented us from including articles that reported on patients treated without reconstruction following a total sacrectomy, we do acknowledge this as a viable option. Given the high rate of major complications, many authors have found this option a better alternative for their patients [31–34]. These authors argue that the muscles and scar between the pelvis and spine form a biologic sling, eventually stabilizing the spine and often allowing ambulation [32, 35].

Through our comprehensive search, we identified 23 articles (42 patients) that reported on operative techniques for reconstruction following total sacrectomy for en bloc

tumor resection. To our knowledge, this is the only systematic review that focuses on spinopelvic reconstruction. The three most common tumor types reported for patients included in this review included chordoma, chondrosarcomas, and giant cell tumors, which are known to be common sacral tumors [36].

We identified three main reconstructive strategies, namely spinopelvic fixation (SPF), posterior pelvic ring fixation (PPRF), and anterior spinal column fixation (ASCF). No single technique was used in isolation; rather, all patients received SPF in association with either one or two other techniques. The vast majority of patients (34 patients; 79.1 %) received PPRF along with SPF, while eight patients (18.6 %) had both ASCF and PPRF in conjunction with SPF. In summary, we observed an overall instrumentation failure rate of 16.1 % (5 out of 31 patients). No instrument-related complications were reported for 26 patients. Blood loss is a significant consideration for these operations, with an average of 9,276 mL reported for 24 patients. Surgical complications

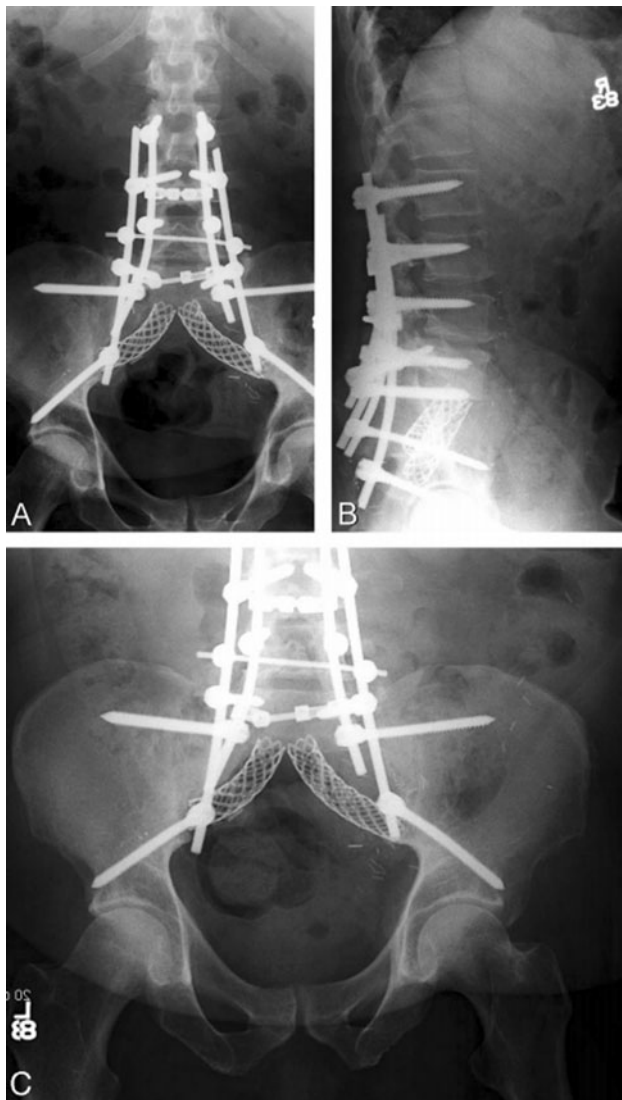


Fig. 3 “Older” SPF methods—pedicle screws connected to ilium via Harrington rods [26]

add significant morbidity to these large operations. 31 instances of complications were reported for 26 patients (1.35 complications per patient). Ambulation was preserved in a majority of the patients reported in literature (35 patients of 39 with reported outcomes; 90 %) with varying degrees of required assistance. However, given that all patients required at least S1–S5 nerve transection, all had some neurological deficits, including bowel and bladder dysfunction.

When comparing the various methods of reconstruction, a trend toward a lower rate of hardware failure emerged in the group utilizing anterior spinal column support when compared to the patients without ASCF (12.5 vs. 17.4 %). Despite a more involved reconstruction with ASCF, surgical complications, such as infection rates and blood loss were lower compared to the group without ASCF (mean

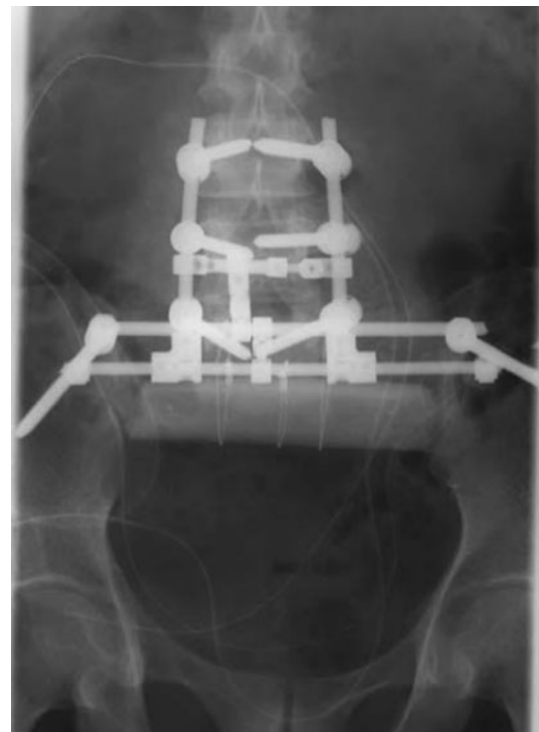


Fig. 4 SPF with ACSF—pedicle screws connected to iliac screws by two lumbar rods on each side; two titanium mesh cages [18]

complications: 0.7 vs. 1.63; infection: 14.3 vs. 37.5 %; blood loss: 6,650 vs. 9,535 mL).

While no obvious differences in the patient demographics were noted between the two groups, it is possible that patient risk factors and other confounders not identified in this review may have led to the counter-intuitive decreased rate of surgical complications in the group with additional ASCF.

Through our review, we identified two authors who have contributed significantly to our understanding of reconstructing the spinopelvic junction following a total sacrectomy. Gokaslan et al. [26] initially reported on the use of modified Galveston L-rods to connect the lumbar spine to the ilia, in addition to the transiliac bar that provided pelvic ring fixation. This represented a significant improvement to the Harrington rod systems of the 1980s which rarely provided the stability necessary to achieve iliolumbar fusion. Many articles included in this review have made use of this technique to establish spinopelvic fixation. Subsequent articles published by Gallia, Fourney, and McLoughlin along with Gokaslan and colleagues have evolved from the use of modified Galveston systems to lumbar pedicle screw systems cross-connecting to intricate arrangements that re-establish connection between contralateral ilia of the pelvic ring [2, 12, 17, 21]. This new spinopelvic system offers safer screw placement in the pedicles of each vertebrae that are independent of the rigid

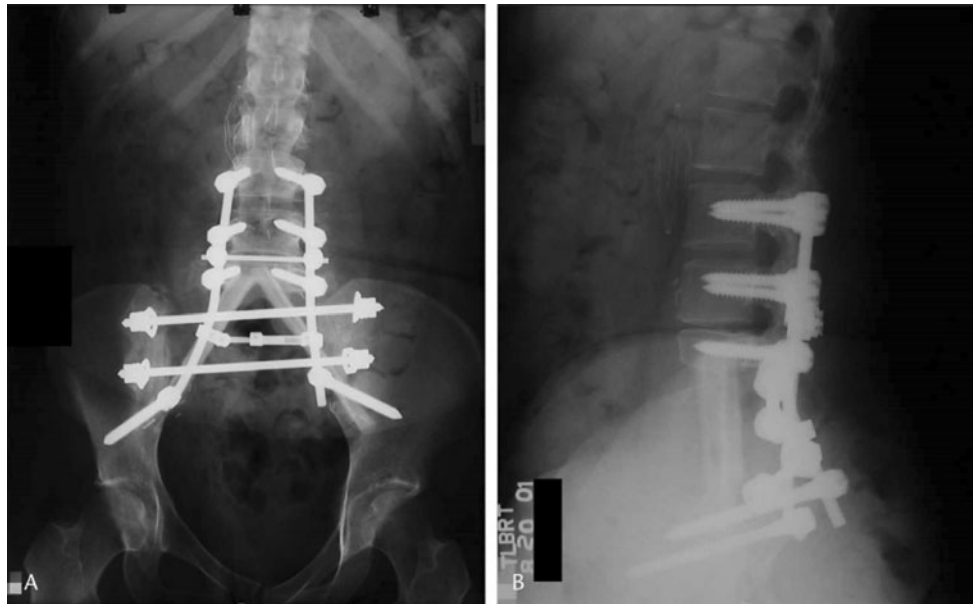


Fig. 5 SPF and PPRF—pedicle screws connected to transiliac bar via lumbar rods and cross connectors; femoral bone graft. **a** Photograph of the final construct, **b** radiograph of the final construct [21]

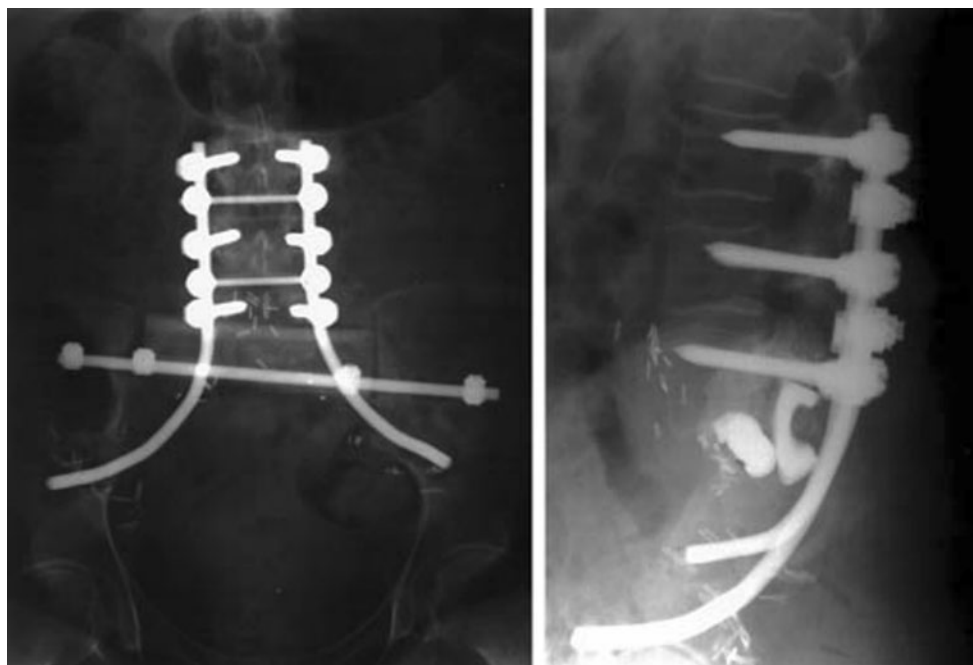


Fig. 6 SPF with PPRF and ASCF—pedicle screws connected to iliac screws via lumbar rods; two transiliac bars (not shown); two oblique fibular grafts from L5 to the anterior ilium [20]

axial bar construct. The posterior pelvic ring has most commonly been reconstructed using transiliac bars, cages, and a variety of bone grafts to promote bony fusion. The fixation they provide is more rigid than previously possible. The most recent article by Gallia made use of an interconnected SPF system, two transiliac bars and femoral

bone graft (PPRF), as well as a vertical cage and rod, through the bodies of lumbar vertebrae (ASCF) [17].

Dickey et al. reported the largest case series with total sacrectomies included in this review. They described their method of using pedicle screws for spinopelvic fixation, dual transiliac bars for reconstructing the pelvic ring and

Table 2 Reconstruction details along with operative complications

Author	Year	# Pts	Extra sacral resection	Nerve sacrifice	Spinopelvic fixation (cephalad level)	Posterior pelvic ring fixation	Anterior spinal column support	Soft tissue flaps	Blood loss (mL)	Operative complications?
Humphries et al. [16]	2010	1	No	S1–S5	PS (L3), connected to transverse rod between IS	(1) TI bar (2) IS with transverse rod (3) Titanium mesh cage between ilia	–	VRAM	NR	<i>S. epidermidis</i> abscess, ischial decubitus ulcer
Gallia et al. [17]	2010	1	(B) ilia, L5	L5–S5	PS (L1), connected to transverse rod between IS	(1) 2 TI bars (2) IS with transverse rod (3) TI femoral graft	(1) Vertical rod through L2–L4 bodies (2) Distractable cage between L4 endplate and TI bar	Paraspinal and partial LD	800 (stage 1), 8,500 (stage 2)	Abdominal hematoma, wound dehiscence, DVT
Varga et al. [10]	2010	1	No	S1–S5	PS (L2), connected to U-shaped rod	(1) Bone graft between ilium and L5	–	GM	NR	NR
Newman et al. [11]	2009	1	(L) ilium	S1–S5	PS (L1), connected to transverse rod between IS	(1) IS with two transverse rods (2) Stacked, carbon-fiber cages	–	RAM + (R) GM	1,500	Flap hematoma
McLoughlin et al. [12]	2008	1	(B) ilia	S1–S5	PS (L3), connected to IS; two vertical rods connected to PS rod and TI bar	(1) TI bar (2) TI femoral graft	–	Alloderm sling	6,000	NR
Shen et al. [18]	2006	1	No	NR	PS (L2), connected to IS–two rods/side	–	(1) Bilateral titanium mesh cages from L5 to SI joint	(R) RAM	1,100 (stage 1), 2,900 (stage 2)	Ileus
Gallia et al. [21]	2005	1	(B) ilia	S1–S5	PS (L3), connected to transverse rod between IS	(1) TI bar (2) IS with transverse rod (3) TI femoral graft	–	RAM	NR	Ileus, vocal cord paralysis, UTI, infection (8 mo)
Fourney et al. [2]	2005	3	No	S1–S5	PS (L3), connected to Galveston rods	(1) TI bar (2) TI tibial graft	–	RAM	NR	SB injury, upper GI hemorrhage and major wound dehiscence
								GM		NR
								RAM		NR

Table 2 continued

Author	Year	# Pts	Extra sacral resection	Nerve sacrifice	Spinopelvic fixation (cephalad level)	Posterior pelvic ring fixation	Anterior spinal column support	Soft tissue flaps	Blood loss (mL)	Operative complications?
Dickey et al. [20]	2005	6	L5 (some cases)	S1–S5	PS (L3 or L4), connected to IS	(1) 2 TI bars	(1) Two oblique, fibular grafts	RAM	NR	None
Min et al. [29]	2005	1	(B) ilia	S1–S4	PS (L4), connected to IS	(1) Two TI tibial grafts	–	RAM	4,300	None
Zileli et al. [24]	2003	1	No	S1–S5	PS (L2 or L3), connected to custom iliac plate	(1) Custom iliac plate	–	Myocutaneous	3,400	Instrument infection
		2			PS (L2 or L3), connected to TI bar	(1) Two TI bars	–	NR	NR	NR
Ohata et al. [13]	2004	1	(B) ilia	(L) L5 and S1–S5	PS (L3), connected to IS	(1) TI bar	–	GM	12,000	UTI, instrument infection
Doita et al. [8]	2003	3	No (B) ilia	S1–S5	PS (L5), connected to TI bar	(1) TI bar	–	NR	9250	NR
			No (R) sciatic, S1–S5		PS (L3), connected to IS; fibular graft between posterolateral spine and ilia	(1) TI bar	–	NR	7,500	NR
Mooney et al. [14]	1999	1	No	S1–S5	PS (L3), connected to Galveston rods	(1) TI bar	(1) Two oblique, ilio lumbar screws	GM	NR	NR
						(2) TI fibular graft				Wound infections (debridement)
Sar et al. [25]	2002	3	NR	S1–S4	PS (L3), connected to Galveston rods or IS	(1) one or two TI fibular graft	–	NR	NR	NR
Wuisman et al. [19]	2001	1	(B) ilia	S1–S5	PS (L2), connected to custom plate	(1) Custom iliac plate	–	GM	8,500	Right lateral wound dehiscence
Jackson et al. [22]	2000	5	NR	NR	PS (L3), connected to Galveston rods	(1) TI bar	–	RAM	NR	None
								RAM	NR	Seizures and UTI
								RAM	NR	Small intestinal perforation, sepsis, coagulopathy, <i>C. difficile</i>
								GM	NR	<i>C. difficile</i>
								RAM	NR	UTI

Table 2 continued

Author	Year	# Pts	Extra sacral resection	Nerve sacrifice	Spinopelvic fixation (cephalad level)	Posterior pelvic ring fixation	Anterior spinal column support	Soft tissue flaps	Blood loss (mL)	Operative complications?
Spiegel et al. [15]	1999	1	(R) ilia	S1–S5	PS (L3), connected to Galveston rods	(1) Pelvic reconstruction plate	–	NR	NR	NR
Gokaslan et al. [26]	1997	2	No	S1–S5	PS (L3), connected to Galveston rods	(1) TI bar	–	RAM	21,500 21,700	NR
Santi et al. [30]	1993	1	No	S1–S5	Hooks and CD rods, connected to TI bar (L4)	1) Two TI bars	–	NR	6,500	NR
Shikata et al. [23]	1992	1	(B) ilia	L5–S5	Two compression rods, connected to TI bar (L3)	(1) Two TI bars	–	NR	6,300	NR
Tomita et al. [27]	1990	2	No	S1–S5	2 Harrington rods; fibular grafts between L4 pedicles and ipsilateral ilium (NR)	(1) TI bar	–	NR	7,500	NR
			No	(R) L5, S1–S5	CD Instrumentation (T12)	(1) AO 16-hole broad plate (2) AO Reconstruction plate	–	NR	17,000	Torn iliac vein
Shikata et al. [28]	1988	2	(B) ilia	S1–S5	Two Harrington rods (L3); fibular grafts between L3, L4, and ipsilateral ilium	(1) Two TI bars	–	NR	10,000	NR

B bilateral, *L* left, *R* right, *N* no, *N/A* not applicable, *NR* not reported, *PS* pedicle screw, *IS* iliac screw, *TI* transiliac, *CD* Cotrel–Dubousset, *RAM* rectus abdominis myocutaneous, *LD* latissimus dorsi, *GM* gluteus maximus

Table 3 Long-term outcomes to evaluate ambulatory status, neurological deficits, need for revision surgery, pain, and tumor recurrence

Author	Year	SPF	PSF	PPRF	ASF	Follow up (months)	Ambulation	Bowel/bladder deficit	Revision instrumentation	Pain at final follow up	Tumor recurrence
Humphries et al. [16]	2010	N	Y	Y	N	12	Yes (R-AFO)	NR	None	None	None
Gallia et al. [17]	2010	N	Y	Y	Y	5	No	Yes	None	Metastasis	Metastasis
Varga et al. [10]	2010	N	Y	Y	N	NR	Yes (cane)	NR	None ^a	None ^a	None ^a
Newman et al. [11]	2009	N	Y	Y	N	6	Yes (Walker)	Partial	None ^a	NR	NR
McLoughlin et al. [12]	2008	N	Y	Y	N	24	Yes	Yes	None	None	NR
Shen et al. [18]	2006	N	Y	N	Y	9	No	Yes	None	NR	NR
Gallia et al. [21]	2005	N	Y	Y	N	12	Yes	Yes	None	Due to metastasis	Local + Metastasis
Fourney et al. [2]	2005	O	Y	Y	N	83	Yes	Yes	NR	NR	Local
						58	NR		NR	NR	Local + Metastasis
						33	Yes		NR	NR	Local
Dickey et al. [20]	2005	N	Y	Y	Y	8	Yes	Yes	None	Improved	None
						7	Yes		None		None
						38	Yes		Revision instrumentation (6 and 29 months)		None
						42	No		None		Local
						36	Yes		None		None
						14	No		None		Local
Min et al. [29]	2005	N	Y	Y	N	60	Yes (crutches)	Yes	Lumbar rod breakage at 4 months (rods replaced)	Improved ^a	None
Zileli et al. [24]	2003	N	Y	Y	N	Mean 28 (range 18–42)	Yes (crutches)	NR	None		Local + Metastasis
							Yes (crutches)	NR	Revision instrumentation at 7 years		None
							Yes (crutches)	NR	None	None	None
Ohata et al. [13]	2004	N	Y	Y	N	60	Yes (crutches)	Yes	None	NR	None
Doita et al. [8]	2003	N	Y	Y	N	36	Yes (cane)	Partial	None	Improved	NR
						36	Yes (crutches)	Yes	None	NR	Local
						36	Yes (crutches)	Partial	None	NR	NR
Mooney et al. [14]	1999	O	Y	Y	Y	8	Yes (walker + R-AFO)	Yes	NR	NR	Metastasis

Table 3 continued

Author	Year	SPF	PSF	PPRF	ASF	Follow up (months)	Ambulation	Bowel/bladder deficit	Revision instrumentation	Pain at final follow up	Tumor recurrence
Sar et al. [25]	2002	O	Y	Y	N	49	NR	Yes	None	NR	None
						33	NR	Yes	None	NR	Local
						47	NR	Yes	None	NR	None
Wuisman et al. [19]	2001	N	Y	Y	N	36	Yes (cane + AFO)	Yes	None	None	None
Jackson et al. [22]	2000	O	Y	Y	N	50	Yes (walker)	NR	NR	Improved	NR
						47	Yes				
						31	Yes (walker)				
						11	Yes				
						8	Yes (cane)				
Spiegel et al. [15]	1999	O	Y	Y	N	74	Yes (AFO)	Yes	Iliac rod and pelvic plate breakage (no operation—patient asymptomatic)	Occasional	None
Gokaslan et al. [26]	1997	O	Y	Y	N	12	Yes (cane)	Yes	NR	NR	NR
Santi et al. [30]	1993	O	Y	Y	N	33	Yes (AFO)	NR	Hardware removed due to discomfort (7 months)	None	None
Shikata et al. [23]	1992	O	Y	Y	N	72	Yes (cane)	Partial	None	NR	NR
Tomita et al. [27]	1990	O	Y	Y	N	69	Yes	Yes	None	NR	None
Shikata et al. [28]	1988	O	Y	Y	N	24	Yes (brace)	Partial	NR	NR	None
						14	Yes (cane)	Partial	None	NR	NR

NR not reported, AFO ankle foot orthosis

^a Based on email correspondence

Table 4 Complications based on reconstruction method

	Without anterior column support (34 pts)	With anterior column support (9 pts)
Instrumentation failure	4 in 23 pts (NR for 11 pts)	1 in 8 pts (NR for 1 pt)
General surgical complications	26 in 16 pts (NR for 18 pts)	5 in 7 pts (NR for 2 pts)
Surgical site infection	6 (37.5 %)	1 (14.3 %)
Wound dehiscence	3 (18.8 %)	1 (14.3 %)
Gastrointestinal	6 (37.5 %)	1 (14.3 %)
Urinary tract infection	4 (25 %)	0 (0 %)
Vascular	4 (25 %)	2 (28.6 %)
Other	3 (18.8 %)	0 (0 %)
Blood loss	9,535 mL (16 pts; NR for 18 pts)	6,650 mL (2 pts; NR for 7 pts)
Ambulation	8 (24 %) independently 22 (65 %) with help 0 cannot 4 (12 %) NR	4 (44 %) independently 1 (11 %) with help 4 (44 %) cannot 0 NR

two fibular grafts to establish anterior spinal column fixation in a triangular fashion from the caudal end of L5 to the pelvic brim (Fig. 5).

Like all systematic reviews, this study possesses inherent limitations. Our systematic search only utilized the PubMed database and may have missed articles captured in other databases. However, to expand our search, bibliographies were manually scanned and abstracts were searched from the archives of various professional society meetings. Additionally, the assistance of a medical librarian in the development of our search strategy strengthened our ability to locate all relevant articles. Another limitation to our review was that several publications had patient and outcome data aggregated with patients receiving partial sacrectomy and other surgical treatments that did not meet our inclusion criteria of total sacrectomy followed by instrumented reconstruction. If the specific data could not be separated from the aggregated data, authors were contacted in an effort to obtain the individual data. An additional limitation was that many surgical techniques identified were from earlier articles utilizing techniques that have subsequently fallen out of favor or have been improved upon. This publication data bias may have resulted in a more guarded prognosis for recovery following treatment. It is worth acknowledging that this article lacks significant statistical pooling, which may have strengthened our arguments. However, statistical analysis was thought not to be of great value for our review given the small number of patients identified, as well as the inconsistently reported objective data. The primary aim of this article was to summarize techniques of reconstruction.

Finally, the value of any systematic review depends on the quality of the individual articles. Because total

sacrectomies followed by reconstruction are uncommon, most publications were limited to retrospective small case series or case reports, representing a much lower level of evidence compared to prospective series. Nonetheless, this review remains the best available evidence we have to evaluate the surgical techniques and outcomes for this rare indication.

Conclusion

While surgical treatment of primary sacral tumors remains a challenge, there has been an evolution in techniques for reconstruction of the spinopelvic junction following total sacrectomy. SPF has evolved from intrapelvic rods and hook constructs to segmental pedicle screw and iliac screw–rod systems. PPRF and ASCF have adapted for deficiencies in the posterior ring and anterior column with the use of structural allografts and/or prosthetic cages. While biomechanical and finite element analysis studies support this improved stability in the newer constructs using PPRF and ASCF [37–39], the functional outcomes and complication rates identified in this review between fixation systems identifies a lack of substantial improvement between theorized structural benefit and actual patient outcomes. While we cannot definitively say one system is superior to the other, based on the data gleaned from this systematic review, it is our opinion that incorporation of anterior spinal column fixation in reconstructing the spinopelvic junction may lead to improved outcomes with lower rates of hardware failure and other surgical complications. However, most importantly, we recommend that the treating surgeon operate on patients requiring a total sacrectomy based on his or her level of

comfort, as these cases can be extremely challenging even among experts. Further investigation with larger case series and large-scale patient registries should be pursued in an effort to better distinguish differences in functional outcomes and complication rates between the instrumentation techniques.

Conflict of interest None.

Appendix: search strategy to capture all relevant articles in the Pubmed database

General scheme

[("tumor terminology" AND "sacral area terminology") OR ("sacral resection terminology")] AND [{"reconstruction terminology"}]

Search terms

Tumor terminology

(Metastasis OR (metastatic AND (tumor OR tumour OR disease OR neoplasm)) OR primary tumor OR: "neoplasm"[Mesh] OR neoplasm OR "Neoplasm metastasis"[Mesh] OR bone neoplasms OR "bone neoplasms"[mesh] OR "pelvic neoplasms"[Mesh] OR pelvic neoplasms OR "Chondrosarcoma"[Mesh] OR chondrosarcoma OR "Giant cell tumor"[Mesh] OR giant cell tumor OR "Lymphoma"[Mesh] OR lymphoma OR "Multiple Myeloma"[Mesh] OR myeloma OR "Plasmacytoma"[Mesh] OR plasmacytoma OR Ewing Sarcoma OR "Chordoma"[Mesh] OR chordoma OR "Osteosarcoma"[Mesh] OR osteosarcoma OR osteogenic sarcoma OR "Spinal Neoplasms"[Mesh] OR spinal neoplasms OR "Bone Cysts, Aneurysmal"[Mesh] OR Aneurysmal bone cysts)

Sacral area terminology

(sacrum OR sacral OR "Sacrum"[Mesh] OR "Lumbosacral Region"[Mesh] OR lumbosacral OR lumbo-sacral OR spinal pelvic OR spinal-pelvic OR spino-pelvic OR spinopelvic OR sacroiliac OR sacro-iliac OR iliosacral OR ilio-sacral OR lumbo-pelvic OR lumbopelvic OR lumbo-iliac OR lumbo-iliac OR lumbosacropelvic)

Sacral resection terminology

(total sacrectomy OR (en bloc resection) OR (enbloc resection) OR ((sacral OR sacrum) AND (resection)))

Reconstruction terminology

((Galveston OR galveston L-rod OR galveston rod OR L-rod) AND (instrumentation OR technique OR fixation)) OR ((sacrum OR sacral OR "Sacrum"[Mesh] OR "Lumbosacral Region"[Mesh] OR lumbosacral OR lumbo-sacral OR spinal pelvic OR spinal-pelvic OR spino-pelvic OR spinopelvic OR sacroiliac OR sacro-iliac OR iliosacral OR ilio-sacral OR lumbo-pelvic OR lumbopelvic OR lumbo-iliac OR lumbo-iliac OR lumbosacropelvic) AND (stabiliz* OR stabilis* OR stable OR stability OR fixation OR reconstruction OR screw)) OR ("fracture fixation"[mesh]) OR (fixation) OR ("Internal Fixators"[Mesh] OR internal fixators) OR ("Bone Screws"[Mesh] OR bone screws) OR ((transiliac OR trans-iliac) AND (bar OR rod OR screw)) OR ("Orthopedic Procedures"[Mesh] OR orthopedic procedures OR orthopaedic procedures OR "Reconstructive Surgical Procedures"[Mesh] OR reconstructive surgical procedures))

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