14 Spinopelvic Fixation After Sacrectomy

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14.1 Introduction

Obtaining solid arthrodesis of the lumbosacral region of the spine continues to be a challenge for spine surgeons. Various spinal pathologies require a spinopelvic fixation including adult deformities with coronal or sagittal malalignment, neuromuscular scoliosis with pelvic obliquity, high-grade spondylolisthesis, and lumbosacral tumors (primary or secondary) [1–3]. The latter represents actually the most challenging indication for a spinopelvic fixation, due to the special anatomical (large vessels, bladder, bowel) and biomechanical characteristics of the lumbosacral region. From a biomechanical point, the sacrum–sacroiliac joint–ilium complex cannot be discussed separately, as the vertical load from the axial skeleton is transferred to the lower limbs via this area; thereby, an intact sacropelvic region is one of the key points of the human upright posture and walking ability. Tumors in this region alone as well as their surgical resection can significantly influence the biomechanics of the sacropelvic complex resulting in failure of axial load transmission. Therefore, to perform an oncologically and functionally optimal surgery, both the anatomical and biomechanical consequences must be carefully considered during preoperative planning [4].

En bloc resection of tumors in the lumbosacral region with procedures such as total sacrectomy or L5 spondylectomy is typically indicated for patients with locally invasive primary sacral tumors such as chordomas, sarcomas, chondrosarcomas, or giant cell tumors. In contrast, this strategy has been applied in limited cases to metastatic diseases, mainly due to recent advances in adjuvant treatment in surgical oncology [5]. Additionally, treatment of metastatic tumors in the lumbar spine near the lumbosacral junction often requires pelvic fixation even with separation surgery procedures to allow for adequate stabilization of the lumbosacral junction, as these patients often have poor bone quality [5].

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Therefore, standardizing universal surgical procedures and techniques is a copious attempt for spinal and orthopedic surgeons.

14.2 Indications

Total sacrectomy is indicated for primary sacral malignancies. More rarely, sacrectomy is indicated for patients with primary or recurrent pelvic visceral tumors (most commonly colorectal carcinoma with sacral involvement by direct extension) and no evidence of metastatic or nodal disease. The techniques hereby described may also be adapted to intralesional treatment of benign tumors such as osteoblastoma and aneurysmal bone cyst. Last, some carefully selected benign aggressive sacral tumors may also be considered for en bloc resection, particularly if small or recurrent [6].

A surgical procedure of a much larger scale is the amputative sacral resection that extends into the pelvis and may be necessary in the following instances: tumor epicenter within the ilium but disease extends across the sacroiliac joint, or tumor epicenter in the sacrum but removal requires resection of the femoral nerve as well as the lumbosacral trunk or the lumbosacral trunk and the hip joint articulation. In these cases, the ultimate function of the limb is so poor that external hemipelvectomy in conjunction with sacral resection allows the maximal oncologic margin to be obtained and provides for healthy and robust flap coverage from the limb [6].

On the other side, the presence of disseminated malignancy is a strong relative contraindication for sacrectomy. The procedure is of such magnitude and generally entails deliberate neurological defects with frequent loss of bowel, bladder, sexual, and potentially lower extremity function that it is usually inappropriate to pursue without curative intent. Patients with tumor thrombus in the iliac veins or vena cava by sarcoma predictably have a rapid development of metastatic disease and demise [6]; evidence of the above on preoperative imaging can prompt catheter-directed biopsy, while its finding at time of surgery prompts abortion of resection [6]. The inability to obtain a tumor-free margin of resection is similarly a relative contraindication. The medical status of the patients also is important; patients receiving chemotherapy frequently require alterations in their chemotherapy schedules to allow for surgery of this magnitude. All patients are subject to an intense preoperative medical evaluation including a dobutamine stress echocardiogram for (a) anyone with known cardiovascular disease; (b) men above age of 40 years; or (c) women above age of 50 years [6].

Special consideration has been made regarding the use of spinopelvic fixation with dual iliac screws. These constructs are necessary mostly if (a) total sacrectomy is performed where the whole sacroiliac joint is removed on both sides [7], (b) partial sacrectomy is performed involving more than 50% of sacroiliac joint on each side, or partial sacrectomy involving less than one half of the sacrum but with one-side sacroiliac joint resection [8], and (c) in palliative fixation cases for unstable destructive lumbosacral metastatic lesions where pedicle screw anchorage in the sacrum is extremely poor [1, 9].

14.3 Classification

There is no standard classification of these procedures. Mayo Clinic has proposed the following classification, where resections could be divided into five types based on the extent of the lumbosacral resection and the need for an associated external hemipelvectomy [10, 11]. They are as follows: Type IA resection—total sacrectomy; Type IB resection—subtotal sacrectomy above the S1 foramen; Type IC resection—subtotal sacrectomy below the S1 foramen (the SI joints are not disrupted here, and a reconstruction is not typically performed); Type II resection—hemisacrectomy with or without partial lumbar excision, and iliac wing resection; Type III resection—external hemipelvectomy with hemisacrectomy with or without partial lumbar excision; Type IV resection—external hemipelvectomy with total sacrectomy with or without lumbar excision; and Type V resection—hemicorporectomy-type procedures (Fig. 14.1).

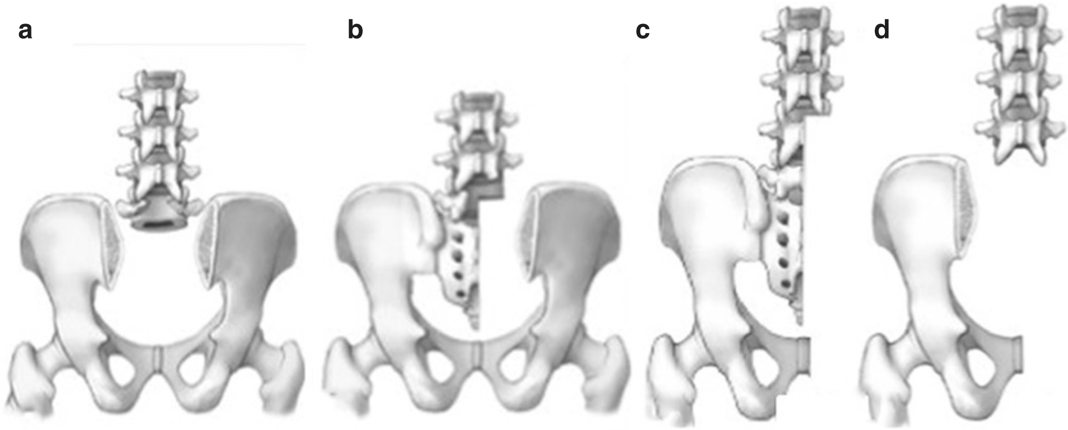

Fig. 14.1 Mayo classification of spinopelvic resections: (**a**) total sacral resection (total sacrectomy), (**b**) hemisacral resection (partial sacrectomy), (**c**) hemisacral and lower lumbar spine resection (partial sacrectomy and extended external hemipelvectomy), and (**d**) total sacral and lower lumbar spine resection (total sacrectomy and [extended] external hemipelvectomy)

14.4 Techniques and Implants

Generally, there are three components in spinopelvic surgery, spinopelvic fixation, posterior pelvic ring fixation, and anterior spinal column support [5]. The infrequency of these procedures does not allow for an established gold-standard technique, as the various instrumentation techniques are scattered across the literature in case reports and small case series; however, it was implied 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 including blood loss [12].

14.4.1 Spinopelvic Fixation

The goal of the surgical stabilization after an extended oncological procedure such as sacrectomy is to restore the load-bearing structures from the lumbar spine to the remaining pelvis. There are several techniques for spinopelvic instrumentation that were originally described for spinal deformity or trauma surgery. These include sacral sublaminar wires and hooks, S1 tricortical screws, Galveston rod technique (direct implantation of L rods into the iliac crests), intrasacral rods, transiliac bars, iliac screws, and S2-alar-iliac screws [5]. Some of the earliest reported techniques used Harrington rods [13, 14], or hooks and CD rods connected to transiliac bars [15]. The Galveston technique for spinopelvic fixation was initially described by Allen and Ferguson for use in scoliosis surgery in 1982 [16]. It was later modified for use in spinopelvic reconstruction after sacrectomy [17, 18]. Since then, various modifications have been proposed and the direct implantation of rods into iliac crests has been practically abandoned. In the modified Galveston technique, the rods are fixed to the pelvis with iliac screws in the caudal part of the system. Further modifications include the multiple rod–screw techniques such as the four-rod reconstruction or double-rod double iliac screw reconstruction [19]. The use of one single U-shaped rod anchored with iliac screws—the closed-loop technique—was published in 2009 providing a more harmonic stress distribution along the whole construct [20].

Iliac screws represent a modified version of the Galveston technique having three times more biomechanical strength than the Galveston technique, and at the same time, they are applicable in every case, unless a hemi- or partial pelvectomy is required [5]. In fact, one of the main indications for the use of dual iliac screws is the need to perform partial or total sacrectomy in order to have a solid basis at the bottom of the spinopelvic construct. In addition, the dual iliac screw techniques may be used in palliative fixation of metastatic lumbosacral lesions with extremely poor sacral bone quality [1]. Several biomechanical cadaveric studies have evaluated theses fixation techniques. In the setting of total sacrectomy, Mindea et al. [7] showed that the double-rod double iliac screw technique provided the most rigid fixation, followed by the single-rod double iliac screw fixation, in comparison with single-rod single iliac screw or modified Galveston technique. Yu et al. [21] showed that dual iliac screws, when all inserted in the lower iliac column, exhibited higher compressive and torsional stiffness not only when compared to single iliac screws (short and long) but also to dual iliac screws where two screws are inserted in the lower iliac column and two screws in the upper iliac column.

In terms of selecting iliac screw length, according to the biomechanical study of Zheng et al. [22], short iliac screws (7 mm in diameter and 70 mm in length) are susceptible to loosening after cyclic loading. Bone cement augmentation of short screws has shown a significant increase in the fixation strength of short screws to an extent similar to that of long iliac screws (7 mm in diameter and 120 mm in length). Therefore, given the potential complications of long screw breach, short iliac screw fixation with augmentation with bone cement may be a viable option for lumbopelvic reconstruction, although much larger screw diameters are currently available and more commonly used [5]. According to biomechanical analyses, it cannot be argued that a stronger construct with multiple rods and screws increases the rigidity of the construct. However, it should be also kept in mind that more metal implants increase the risk of wound healing problems; therefore, increased caution is required [23].

14.4.2 Posterior Pelvic Ring Fixation

Techniques for posterior pelvic ring reconstruction include allografts (femur or tibia) with screw fixation to bilateral iliac, transiliac bars, and cages [5]. With the triangular frame reconstruction, the pulled down L5 vertebral body is affixed to the bilateral ilium with sacral rods. The pelvis is also connected to the spinal rods with a second sacral rod [4]. Murakami et al. [24] showed in their in vitro and in silico biomechanical analyses that there was less stress concentration on the implants with this technique; however, excessive stress occurred in the iliac bones that could be associated with loosening of the sacral rods. Gallia et al. [25] published a challenging technique known as the Johns Hopkins University (JHU) technique; a modified Galveston technique was used, where a transiliac bar was inserted through the iliac crests, and single iliac screws were implanted and linked with a horizontal rod. The spinal rods were attached to the transiliac bar with L connectors, and the transiliac bar, the horizontal rod, and a horizontal connector between the vertical spinal rods were connected with one other using vertical connectors. Last, a femoral allograft was placed horizontally, between the two iliac crests bridging the defect.

14.4.3 Anterior Spinal Column Support

The importance of anterior spinal column support in lumbopelvic reconstruction after total sacrectomy has been discussed extensively. In 2005, Dickey et al. [26] published the use of bilateral fibular grafts. The fibular grafts are placed between the L5 vertebra and the bilateral iliopectineal area, and this technique can be combined with the posterior stabilization techniques. In vitro and in silico biomechanical study showed that with the help of these combined systems, greater rigidity can be achieved; however, the increase of the morbidity from the extension of the surgery has to be also considered [4]. A cadaveric biomechanical study by Cheng et al. [27] evaluated the following four constructs: sacral rod reconstruction; bilateral fibular flap reconstruction; four-rod reconstruction; and improved compound reconstruction (a combination of the previous methods). Among these, improved compound reconstruction that utilized the sacral rod and the fibular triangular construct in the anterior approach produced optimal structural stability after total sacrectomy. Similarly, Clark et al. [28] examined the biomechanical strength of three constructs: femoral strut allograft reconstruction, where a femoral allograft was placed between iliac and secured with bone screws; L5–iliac cage strut reconstruction, where two titanium cages were placed obliquely, each wedged between the inferior L5 endplate and the iliac bone; and S1 body replacement with expandable cage reconstruction, in which a rod was placed from the inferior L5 endplate and fixed to a transiliac bar and a 22-mm expandable cage was placed between the L5 endplate and the transiliac bar. They concluded that the latter technique provided the most biomechanically stable structure.

- *Type 1 and 2 resections*
- Resections at or below the level of the S2 neuroforamen are generally resected through a posterior approach unless there is involvement of pelvic visceral or vascular structures. Given the need to obtain an oncologic margin, this generally implies lesions at or below the S2/3 vestigial disk [6].
- Lesions cephalad to this level or involving pelvic structures are treated first with anterior mobilization of pelvic structures, vessel ligation, and unicortical anterior sacral osteotomy. The use of pedicle flaps is encouraged for facilitating wound healing. A pedicled myocutaneous rectus abdominis flap can be harvested in this stage and tucked into the abdomen with the anterior procedure. Tumor resection is then completed through a posterior approach, and the rectus flap is pulled through the abdomen and rotated to assist in wound closure and reconstruction of the posterior abdominal wall. The posterior approach can be performed 48 h later, unless the rectum is devascularized and requires resection with the tumor specimen [6].
- Resections cephalad to the S1 neuroforamen require spinopelvic reconstruction. Fibula autografts or allografts can be used additionally to posterior spinal instrumentation. Pedicle screw instrumentation is performed in usually the remaining three to four vertebral body sites (Fig. 14.2a, b). Prior instrumentation, appropriate changes to the surgical table should be made to restore lumbar lordosis. Pedicle screws are placed aggressively to extend to the anterior cortex or even bicortically. Usually, after the sacrum is removed, a hand can be placed ventral to the spine to feel the pedicle screws as they come through to allow for safe bicortical placement. Screws are placed in the remaining ilium, ideally with the double iliac screw techniques. "Docking sites" are placed for fibula strut grafts in the supra-acetabular region. A burr is used to place these from behind. If the level of iliac resection prohibits this, the ischium is usually an appropriate site for docking stations as well. Once this is done, fibula strut grafts are placed as described by Dickey et al. [26], in a "cathedral fashion"; struts are placed in the supra-acetabular region and then end in the last remaining vertebral segment. Appropriate rods are placed after the strut grafts are positioned, and compression is achieved across these to lock the fibula grafts in. If the patient has undergone prior pelvic radiation, consideration is given to using vascularized fibular grafts. This significantly extends the operative time and may require staging to a further day [6, 11].
- *Type 3 and 4 resections*
- Partial and total sacrectomies in conjunction with external hemipelvectomy represent the amputative sacrectomies. These procedures are performed in one stage. Patients undergoing Type 3 resections are considered for an instrumented spinopelvic arthrodesis to the remaining limb if more than 50% of the lumbosacral articulation is resected. The instrumentation can be performed 48 h after the amputation to allow time for final margins to be ascertained and to minimize the physiologic impact on the patient. In Type 4 resections, the resection is performed in a single stage, and the spinopelvic instrumentation between the remaining lumbar spine and

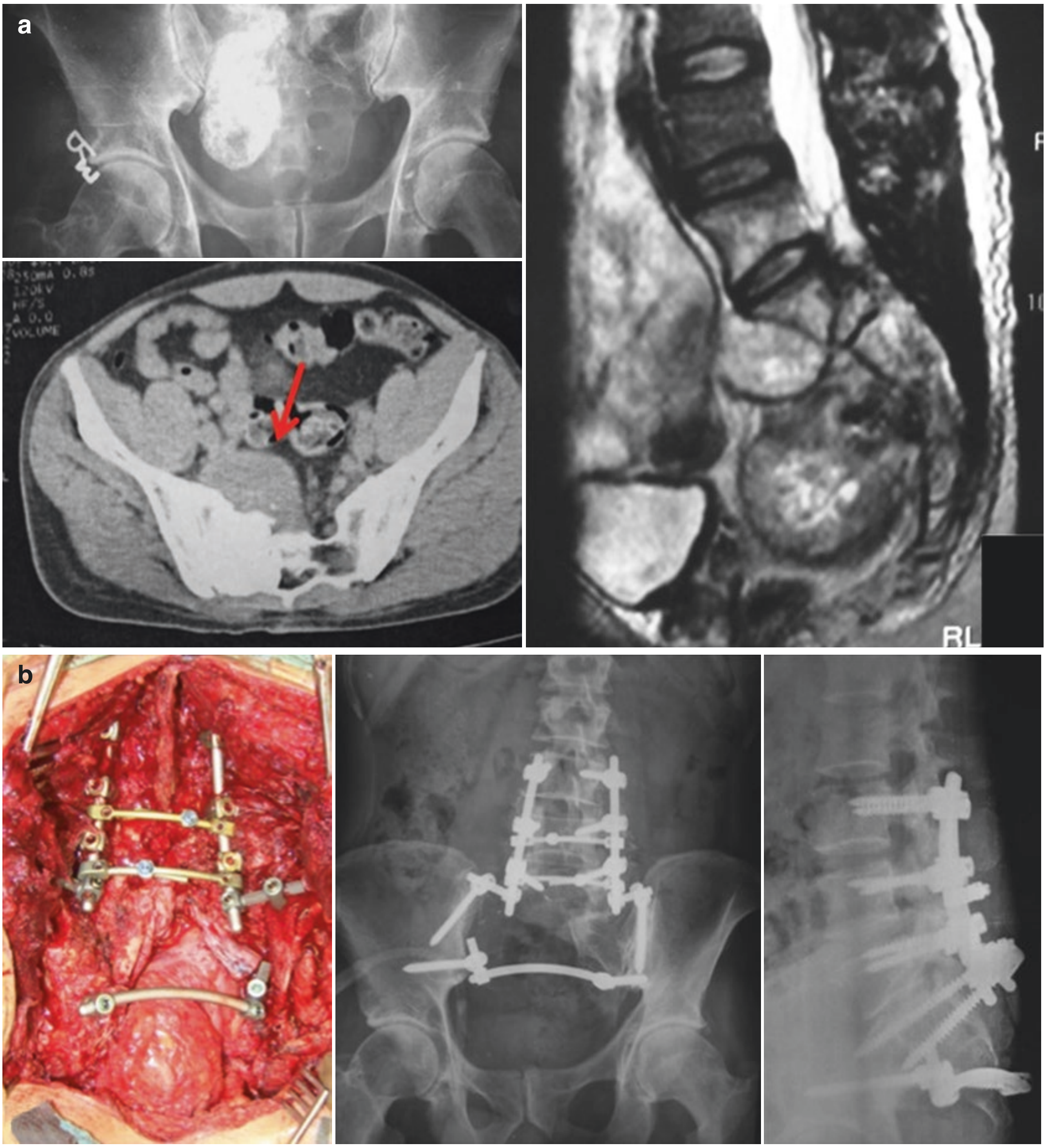

Fig. 14.2 (**a**) A 35-year-old man with a sacropelvic chondrosarcoma. (**b**) Type II resection and spinopelvic reconstruction were done without evidence of local recurrence at 8-year follow-up

remaining limb is in a second stage. Therefore, in Type 4 resections, the tumor-free portion of the amputated femur is ideally stored sterilely in a liquid nitrogen freezer until this second stage of the surgery [29].

- The need for an instrumented spinopelvic reconstruction after a Type 3 resection is controversial. In our experience, if the majority of the lumbosacral articulation is resected, patients likely benefit from instrumented fusion across the spinopelvic junction. This is generally performed in a second stage approximately 48 h after the index surgical procedure. It is usually simple to reopen the wound (and probably advantageous to wash out the inevitable degree of hematoma which develops). Reconstruction is performed using spinopelvic instrumentation from L4 through the ilium on the retained side. There is usually excellent exposure to perform a discectomy of the remaining disk at the L5–S1 segment and provide an anterior interbody graft at this junction. Depending on the vascular mobilization achieved in the index procedure or desired in the secondary procedure, similar anterior lumbar interbody fusion can be performed at the L4–5 level as well [29].

- In the case of a Type 4 resection, it is necessary to provide reconstruction between the remaining lumbar spine and remaining hemipelvis and limb. Because of the very large magnitude of the oncologic resection, these procedures are staged at least 48 h and oftentimes longer after the index procedure, once the patient has physiologically recovered appropriately. Key aspects of the reconstruction of a Type 4 procedure include centralizing the remaining hemipelvis and limb under the lumbar spine as well as providing a robust autograft strut between the lowest remaining vertebral body and the hemipelvis. At the time of the index resection, a portion of the femur of the amputated limb that is largely free of tumor is saved sterilely in a liquid nitrogen freezer. This provides a strut graft to bridge the gap between the remaining lumbar spine and pelvis on the retained side. Pedicle screw instrumentation is performed into at least the lowest three segments of the lumbar spine on the remaining side. Screw fixation is obtained in the bone stock of the remaining ilium avoiding the hip joint. In performing the reconstruction after a Type 4 resection, two key factors are involved. First, the pelvis should be externally rotated centralizing the remaining lumbar spine over the remaining pelvis such that the patient's center of gravity is relatively uniform. Second, a foraminotomy of the lowest one or two lumbar segments remaining should be performed, in order to avoid too much traction on the lumbar nerve roots to the remaining leg from the previous maneuver. Once instrumentation is in place, the femoral autograft from the resected limb is used as a strut graft between the supra-acetabular pelvis and the remaining lumbar spine. Rods and screws allow for fixation and compression across this graft. An alloderm or similar membrane can be prophylactically used to sequester the abdominal contents away from the instrumentation. Similar to the Type 3 resection, the anterior thigh flap is inserted to close the soft tissue defect. As Type 4 resections commonly involve resection of the anus and genital structures, the amount of skin defect may require the full aspect of skin from the quadriceps flap [29].

14.5 Results

Oncologic results are most favorable when complete resection of the tumor is obtained. It is best illustrated by the data of Fuchs et al. [30], reporting the operative management of sacral chordoma. In a series of 52 patients undergoing surgery, complete survival was seen in all patients in whom a wide margin was achieved at the time of surgery. In contrast, the majority of patients with less than a wide margin resection succumb to disease. Results of more aggressive tumors depended heavily upon the response to chemotherapy. Regarding neurologic function after major sacrectomy, preservation of bilateral S2 nerve roots and a unilateral S3 nerve root or unilateral S2, S3, and S4 nerve roots is required for predictable maintenance of bowel and bladder function [31–33]. In those patients undergoing major spinopelvic reconstruction, a study of 45 patients [chondrosarcoma (n = 11); other sarcomas (n = 11); osteosarcoma (n = 9); chordoma (n = 6); locally invasive carcinoma (n = 5); and others (n = 3)] at mean 38-month follow-up has shown that 28 were living and 17 were deceased; 22 of 28 surviving patients were disease-free and 19 of surviving patients were independent in their activities of daily living; 20 patients required early operation for wound healing; and 16 of these 20 patients had a deep infection; in the patients requiring reoperation, a mean of three reoperations was necessary; 4 patients in this cohort have been revised for instrumentation failure [10]. These results pertain to very large resections, which disrupt spinopelvic continuity; much fewer complications and more favorable results are seen with lesser sacral resections provided appropriate margins are obtained [34].

The current literature has not focused on pseudarthrosis in the setting of lumbopelvic reconstruction, and the nonunion rate cannot be assessed. Likewise, there is limited data on the mechanical failure rate. In a systematic review by Bederman et al. [12], it was shown that instrumentation failure was evident in 16.1% of patients (5 of 31 patients). Although there was no statistically significant difference, patients without anterior column support tended to have high mechanical failure rates (17.4% vs. 12.5%). This was also shown recently by Tang et al. [35]; in their study, 63 patients who underwent spinopelvic reconstruction following total sacrectomy were studied. Postoperative mechanical failure of the fixation occurred in 25% of patients, and the factors associated with this failure were: single-rod instrumentation with single or double iliac screws; posterior fixation without anterior augmentation; and female gender.

This evidence is suggestive of the potential benefit of adding anterior column support to spinopelvic reconstruction after total sacrectomy, but since extensive instrumentation both anteriorly and posteriorly requires more operative time and more sophisticated techniques, the potential complications must be thoroughly discussed with the patients [5].

14.6 Future Perspectives

So far, there have not been any methods/implants available for total or partial SI joint replacement; thus, all kinds of stabilization are far from the natural biomechanics. Current stabilization techniques try to ensure a stable fixation between the lumbar spine and the pelvis with metal or combined systems [4]. Recently, investigators from China reported the use of a 3D-printed sacral endoprosthesis after total en bloc sacrectomy [36, 37]. In their series, the authors compared the reconstruction with 3D-printed prosthesis (10 patients) to combined reconstruction, including anterior spinal column fixation (14 patients), and spinopelvic fixation alone (8 patients). Compared to the other two groups, the endoprosthesis group had significantly better spinopelvic stability and implant survival with no greater intraoperative hemorrhage or perioperative complications. Authors found also radiological evidence of implant osseointegration at a mean of 7.2 months. However, the study's retrospective design, the small sample size and short follow-up period (mean 22.1 months), and the fact that some patients from the 3D implant group underwent supplemental reconstruction at the time of surgery led to inevitable selection bias that cannot be ignored. Nevertheless, further research and development of novel materials could be the future answer to the treatment of these extremely complex and challenging cases.

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