Chapter 4

Sacropelvic and Pelvic Instrumentation in Spinal Surgery Complications and Their Management, From Recent Literature

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Abstract

Sacropelvic and pelvic fixation constitute the distal foundation of long spinal constructs in adult spinal deformity (ASD), multilevel degenerative disease, high-grade spondylolisthesis, spinopelvic trauma, and complex revision surgery, with the lumbosacral junction exposed to high shear and cantilever forces that make failure at this level a major driver of reoperation and disability . This chapter presents a complication-focused overview of sacropelvic and pelvic instrumentation, addressing indications, mechanisms of failure, prevention, perioperative management, discharge criteria, and structured follow-up, based on a narrative review of biomechanical, clinical, and radiological studies, including recent systematic reviews and large cohort analyses. Modern sacropelvic fixation, particularly S2-alar-iliac (S2AI) –based constructs, has reduced distal junctional failure and rod fracture, yet mechanical complications such as pseudarthrosis, rod fracture, screw loosening, and sacral or pelvic fractures still occur in 5–20% of complex ASD cohorts. S2AI screws show lower rates of hardware prominence and wound problems than conventional iliac screws, with similar or better radiologic correction and reoperation rates . Sacral and pelvic insufficiency fractures, sacroiliac (SI) joint pain, and sacroiliitis are increasingly recognized late complications after long lumbosacral fusion, particularly in older or osteoporotic patients, and pelvic fixation, although associated with greater operative time and blood loss, does not consistently increase systemic perioperative morbidity when enhanced

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perioperative pathways are applied. Complication-conscious sacropelvic fixation therefore requires meticulous preoperative risk stratification, judicious selection of distal anchors (often favoring S2AI in deformity and degenerative indications), robust lumbosacral fusion strategies (interbody support, multi-rod constructs, adequate graft), and structured postoperative surveillance, with early recognition of characteristic failure patterns and timely, principle-based revision surgery essential to preserving correction and function.

1. INTRODUCTION

Extensive posterior spinal fusions extending to the sacrum and pelvis have become a standard approach in the treatment of adult spinal deformity (ASD), multilevel degenerative lumbar disease, revision surgeries, and complex spinopelvic trauma [1–3]. The lumbosacral junction serves as a biomechanical fulcrum subjected to significant shear forces and cantilever moments, especially when long thoracolumbar constructs terminate at S1 [1,2]. Historically, distal failure and lumbosacral pseudarthrosis have been among the most prevalent causes of construct failure and subsequent reoperation [2,4,5].

Advancements in sacropelvic fixation methods, such as the implementation of iliac screws, S2AI screws, sacroiliac buttress screws, and various combinations of pelvic anchors, in conjunction with multi-rod constructs, have significantly bolstered the stability of fusion at the lumbosacral junction [1,3,7,10–13]. Despite these technological improvements, recent systematic reviews indicate that spinopelvic fixation failure rates persist, ranging from approximately 4.5% to 38%, with nearly half of these cases necessitating subsequent surgical intervention [4]. Contributing factors to morbidity in this high-risk group include mechanical failure, pseudarthrosis, sacral or pelvic fractures, degeneration of the SI joint, and both wound-related and systemic complications [1,3–5,11,15–18,20–23].

This chapter examines the complications associated with sacropelvic and pelvic fixation, along with their respective management strategies. The technical aspects and indications are discussed solely in relation to their direct relevance to the prevention and treatment of complications. The focus is placed on:

- Indications and patient selection for sacropelvic fixation
- Biomechanical principles and commonly used techniques (particularly iliac vs S2AI screws, multi-rod constructs)
- Intraoperative complications and their immediate management

- Early (0–30 days) and late (>30 days) mechanical and biological complications
- Discharge criteria, structured follow-up, and imaging algorithms
- Practical checklists summarizing key points for each major complication type

2. INDICATIONS AND PATIENT SELECTION

Sacropelvic fixation represents a significant advancement in spinal reconstructive surgery, offering robust distal anchoring in complex cases where standard lumbosacral fusion is inadequate. Its use encompasses a wide array of pathologies, ranging from extensive degenerative and deformity corrections to traumatic injuries and oncological resections. Careful patient selection is crucial, as it involves balancing substantial biomechanical benefits with potential increases in surgical morbidity. This section outlines the primary indications and key patient selection criteria for sacropelvic fixation in various clinical scenarios. Essentially, sacropelvic fixation aims to extend the lever arm of spinal instrumentation into the pelvis, thereby enhancing stability, distributing load, and reducing stress concentration at the lumbosacral junction, which is particularly vulnerable in long-segment constructs or in compromised bone. Although sacropelvic fixation is highly effective, it is not without challenges. Relative contraindications include severe pelvic bone fragility that precludes adequate screw purchase, active pelvic infection, or specific anatomical variations that significantly hinder safe implant placement. Patient comorbidities must also be carefully considered against the benefits of these procedures, given the increased operative time and blood loss associated with them.

2.1. Adult Spinal Deformity and Multilevel Degenerative Disease

The most frequent contemporary indication for sacropelvic fixation is long posterior fusion for ASD or multilevel degenerative disease extending to the sacrum [1,3,6,19]. Harris and Kebaish highlight that constructs spanning ≥4 levels or crossing the thoracolumbar junction with inclusion of S1 are at particular risk for distal junctional failure if the pelvis is not incorporated [1]. For such constructs, additional pelvic fixation reduces the cantilever load across the lumbosacral junction and improves fusion rates [1–3,6].

Meta-analysis of fusion to S1 with or without sacropelvic fixation in ASD patients demonstrates that adding pelvic fixation improves radiographic deformity correction and reduces rates of pseudarthrosis and distal mechanical failure, particularly in cases with severe sagittal malalignment [6]. However, pelvic fixation increases operative time and blood loss, requiring careful patient selection and perioperative planning [3,6,11].

Key indications for sacropelvic fixation in ASD and degenerative disease include [1–3,6,19]:

- Long fusion constructs (≥4 levels or constructs extending to the thoracolumbar junction or above) including S1
- Marked preoperative sagittal imbalance, particularly large pelvic incidence–lumbar lordosis (PI–LL) mismatch and high pelvic tilt
- High-grade lumbosacral spondylolisthesis or severe L5–S1 degeneration
- Prior distal junctional failure or pseudarthrosis at L5–S1
- Poor bone quality (osteoporosis) requiring multiple distal anchor points

2.2. High-grade Spondylolisthesis and Flat-back Deformity

High-grade lumbosacral spondylolisthesis and iatrogenic flat-back deformity requiring osteotomy are classic indications for sacropelvic fixation [1,2]. The combination of anterior column deficiency, large slip angles, and corrective maneuvers (reduction and osteotomy) imposes substantial loads on the lumbosacral junction. Sacropelvic constructs—often with S2AI screws and anterior L5–S1 support—are recommended to prevent postoperative loss of reduction or nonunion [1–3].

2.3. Trauma and Spinopelvic Dissociation

In high-energy sacral fractures and spinopelvic dissociation, lumbopelvic fixation provides simultaneous stabilization of the spine and posterior pelvic ring and facilitates early mobilization [1–3,16,17]. Techniques include lumbopelvic or triangular osteosynthesis with iliac or S2AI screws connected to lumbar pedicle screws [16,17]. Neurologic compromise is common in this setting, and fixation must be planned together with decompression when indicated [16,17].

2.4. Tumor, Infection, and Complex Revision

Primary or metastatic sacral tumors, chronic infection, and extensive revision surgery for prior failed lumbosacral fusion often require sacropelvic reconstructions to restore load-bearing across the lumbosacral junction [1–

3]. In these cases, the mechanical demands and compromised biology dictate the use of robust distal anchors and generous grafting, often with multi-rod constructs to protect long lumbosacral reconstructions [1–3,12,13].

In summary, as explored in the preceding subsections, the decision to employ sacropelvic fixation is multifaceted, requiring careful consideration of the patient's underlying pathology, extent of spinal involvement, biomechanical demands, and individual patient risk factors. Thus, proper patient selection is crucial for optimizing outcomes and minimizing complications associated with these complex reconstructive procedures.

3. BIOMECHANICAL PRINCIPLES AND SURGICAL TECHNIQUES

3.1. Anatomy and Biomechanics

The sacrum consists of cancellous bone with a thin cortical shell and relatively small pedicles, limiting screw length and purchase [1,2]. The lumbosacral junction acts as a pivot point between the mobile lumbar spine and the rigid pelvis, experiencing high shear stresses, particularly in long constructs [1,2]. Classical concepts such as McCord's lumbosacral pivot point and O'Brien's sacropelvic zones emphasize that more caudal fixation (into the ilium) increases resistance to flexion moments and cantilever forces [1,2,3].

Pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) determine the spinopelvic alignment. Achieving a postoperative PI–LL mismatch within about 10° is a key target; residual mismatch is associated with mechanical failure, rod fracture, and pseudarthrosis at the lumbosacral junction [1,3,4,12,13].

3.2. Iliac Screws

Traditional iliac screws originate near the posterior superior iliac spine and traverse the ilium toward the sciatic notch [1,2]. They offer strong purchase in the ilium and, when combined with S1 pedicle screws, form a "triangulated" distal construct [2,5]. However, iliac screws require lateral and distal exposure, often necessitating offset connectors, and their heads sit relatively superficially, predisposing to prominence and soft-tissue irritation [1,2,7–10].

3.3. S2-alar-iliac (S2AI) Screws

S2AI screws were introduced to address limitations of conventional iliac screws [1,3,7,8]. They start at the dorsal S2 foramen region and traverse the sacral ala into the ilium in line with S1 pedicle screws, allowing direct rod connection without offset connectors and placing the screw head deeper under soft tissue [1,3,7]. Comparative studies and meta-analyses consistently show that S2AI screws achieve similar or better deformity correction with lower rates of screw prominence, wound complications, and implant failure than iliac screws [7–10,24].

Turkish series and regional experiences (e.g., Arslan et al.) confirm that S2AI fixation in long segment fusions provides favorable radiological and clinical outcomes, with reduced prominence and comparable fusion rates compared with conventional iliac screws [10].

3.4. Multi-rod Constructs and Multiple Pelvic Anchors

Fatigue failure at the lumbosacral junction is common when only two rods span high-stress segments, especially when three-column osteotomies are performed or PI–LL mismatch remains [12–14]. Multi-rod constructs—defined as more than two rods across the lumbosacral junction—distribute forces across additional rods, reducing bending stresses and protecting the main rods from fatigue failure [12,13].

Retrospective cohort studies and meta-analyses demonstrate that multi-rod constructs across the lumbosacral junction are associated with lower rates of rod fracture and pseudarthrosis than standard dual-rod constructs, particularly in high-demand ASD cases with pelvic fixation [12,13]. However, increased construct stiffness may shift stress proximally, potentially increasing the risk of proximal junctional complications [12–14].

Finite element analyses and clinical series support the use of multiple pelvic screws (e.g., bilateral dual S2AI screws) combined with multi-rod constructs in very high-risk reconstructions [12,13,21].

4. PERI-OPERATIVE MANAGEMENT AND PREVENTION STRATEGIES

4.1. Preoperative Risk Stratification

Patients requiring sacropelvic fixation typically have advanced age, multiple comorbidities, and complex deformity or degenerative pathology [1–3,11]. Preoperative assessment must address the following:

- Frailty indices and cardiopulmonary reserve
- Bone quality (DEXA, opportunistic CT Hounsfield units)
- Nutritional status and anemia
- Metabolic risk factors (diabetes, smoking, obesity)

Optimizing modifiable factors (smoking cessation, glycemic control, vitamin D and calcium repletion, treatment of osteoporosis) is critical to reducing pseudarthrosis, infection, and fracture risk [1–3,11,15–18].

4.2. Intraoperative Strategies

Key strategies to reduce complications include the following:

- Accurate alignment correction: targeting PI–LL mismatch ≤10° and appropriate global sagittal alignment [1,3,4,12].
- Robust distal fixation: combining S1 pedicle screws with S2AI or iliac screws when long constructs include S1 [1–3,6–10,19].
- Anterior column support: L5–S1 interbody fusion or cages in most long constructs to improve load sharing and fusion [1–3,12,13].
- Navigation and neuromonitoring: particularly for S2AI and iliac screw placement and osteotomy maneuvers [1–3,7,8,24].
- Blood conservation: cell salvage, antifibrinolytics (e.g., tranexamic acid), and staged procedures to reduce transfusion-related complications [11].

4.3. Enhanced Recovery Pathways

Enhanced recovery after surgery (ERAS) concepts, including multimodal analgesia, early mobilization, standardized thromboembolism prophylaxis, early feeding, and aggressive pulmonary care, are effective in reducing systemic complications and length of stay in complex deformity surgery with pelvic fixation [3,11].

5. INTRAOPERATIVE COMPLICATIONS AND THEIR MANAGEMENT

5.1. Screw Malposition and Neurologic or Vascular Injury

Misplacement of S1, iliac, or S2AI screws can injure lumbosacral nerve roots, the lumbosacral plexus, or pelvic vascular structures such as the internal iliac artery and its branches, superior gluteal vessels, or the iliolumbar vein [1–3,7,8,24]. Risk is higher in obese patients, in those with sacral dysmorphism or prior surgery, and whenever free-hand techniques are used without reliable fluoroscopic or navigation guidance [1–3,7,24]. Neurologic injury typically results from medial or caudal breach into the sacral canal or foramen (S1) or into the neuroforamen and plexus anterior to the sacrum (S2AI), whereas vascular injury is more often related to anterior or lateral cortical perforation of the sacrum or ilium with screw tips abutting or lacerating internal iliac or gluteal branches [7,8,24].

Neurologic compromise may manifest as abrupt triggered EMG threshold changes, loss or significant reduction in motor-evoked potentials (MEPs) or somatosensory-evoked potentials (SSEPs) during screw advancement, particularly when a single screw is being inserted [1–3,7]. Vascular injury presents with sudden, unexplained hypotension and tachycardia, rapid blood accumulation in the operative field or retroperitoneum, difficulty maintaining visualization despite suction, and, occasionally, a pulsatile hematoma deep to the sacrum or ilium [7,8,24]. When screws are placed percutaneously, major bleeding may be initially occult and only apparent as a sudden drop in blood pressure and hemoglobin.

For S1 pedicle screws, an AP view ensuring the screw path remains medial to the sacral ala and lateral to the sacral canal, combined with a true lateral view confirming that the screw tip remains within the sacral body without breaching the anterior cortex, is essential [1–3,7]. For S2AI screws, a true lateral view with overlapping sciatic notches and clear visualization of the sacral ala and iliac wing is critical; the screw trajectory should be directed approximately 30° caudally and 40° laterally, aiming toward the anterior inferior iliac spine, with the tip maintained within the bone corridor on inlet and outlet views [7,8,24]. Iliac screws require careful use of inlet, outlet, and oblique views to confirm that the screw is centered within the ilium and does not perforate the inner or outer tables or enter the acetabulum [1–3,7].

When neuromonitoring shows a significant drop in MEP/SSEP amplitudes or low triggered EMG thresholds during screw insertion, the immediate response should be to stop further advancement, back the screw out to a safer level, and obtain fluoroscopic or 3D imaging to verify the trajectory [1–3,7]. If imaging confirms malposition with potential root compression, the screw should be removed and redirected or replaced at an alternative level (e.g., converting a malpositioned S2AI screw to a safer S1 pedicle trajectory).

In the presence of major vascular injury (sudden hypotension, brisk bleeding), priorities are: (1) immediate packing and local tamponade around the suspected breach site, (2) rapid communication with anesthesia for volume resuscitation and activation of massive transfusion protocol, and (3) early involvement of vascular or interventional radiology teams for definitive control (open repair or endovascular embolization) [7,8,24]. Screws suspected of causing a major vascular tear should not be repeatedly advanced and withdrawn; rather, the screw is usually left in place until proximal and distal vascular control is achieved, to avoid enlarging the tear [7,24].

Preventive anatomical strategies for mitigating complications:

- For S1 screws, clearly identify the sacral ala and foramen; keep the starting point slightly medial to the SI joint and lateral to the sacral canal, and avoid excessive medial angulation that would direct the screw toward the canal or foramina [1–3]
- For S2AI screws, use a consistent bony landmark triad: the dorsal S1 foramen, S2 foramen, and posterior superior iliac spine. The entry point is typically just lateral to the S1–S2 foramen line and caudal to the S1 dorsal foramen; preoperative CT templating helps define the individualized corridor [7,8].
- On the true lateral view, ensure that the screw path remains within the silhouette of the sacrum and ilium; any perception that the tip is approaching or crossing the anterior cortex should prompt correction before full-length insertion [7,8,24].
- In revision cases with distorted anatomy, navigation or intraoperative CT/O-arm should be strongly preferred, and screw diameters should be chosen conservatively to reduce the risk of cortical blowout.

Checklist – Screw malposition and neurovascular injury

- Use neuromonitoring (MEPs/SSEPs, triggered EMG) for all sacropelvic screws, especially in high-risk anatomies.
- For each screw: verify trajectory on at least two orthogonal C-arm views (AP + lateral for S1; lateral + inlet/outlet for S2AI/iliac) before final seating.
- Sudden neuromonitoring change → stop, back out partially, image, and redirect or reposition.
- Sudden hypotension with deep bleeding → pack, call for vascular help, avoid manipulating the suspect screw until proximal vascular control is secured.

5.2. Dural Tears and Cerebrospinal Fluid (CSF) Leakage

Dural tears are relatively common during decompressions, foraminal releases, and osteotomies in rigid deformity, particularly near the lumbosacral junction where thickened ligamentum flavum, adhesions from prior surgeries, and distorted anatomy increase the risk [1–3]. Sacropelvic instrumentation itself rarely causes dural tears, but the extended exposure required for spinopelvic fixation and concomitant decompression increases the overall risk.

Clear CSF egress, visible dural defects, or arachnoid herniation into the wound are classic findings. In revision surgery, small tears can be hidden beneath scar; a sudden "wet" field obscure to bloodless suction or an unanticipated collapse of the dural sac after decompression should raise suspicion. Occasionally, neuromonitoring changes occur if a large tear leads to acute root or cord manipulation [1–3].

Whenever technically feasible, primary repair with fine, non-absorbable sutures (e.g., 6-0 or 7-0) in an interrupted or running fashion should be attempted. When the dural edges are friable or inaccessible (e.g., far lateral), a combination of onlay graft (autologous fascia, muscle, or synthetic patch) and sealant may be used [1–3]. After repair, the surgical field should be dried and gently Valsalva-tested to confirm watertightness. Drains, if used, should not be placed directly over the dural repair and should be set to low suction or gravity to minimize CSF siphoning. Prophylactic antibiotics and careful sterile handling are mandatory because persistent CSF leakage increases the risk of wound dehiscence and infection.

Fluoroscopy does not directly diagnose dural tears, but minimising unnecessary bony resection guided by preoperative MRI and intraoperative imaging reduces the risk of inadvertent dural violation. A limited laminectomy tailored to pre-existing stenosis and decompression planned away from prior laminectomy margins (where adhesions are dense) are the prudent strategies [1–3].

Preventive anatomical strategies for mitigating complications:

- During decompression near the lumbosacral junction, work subperiosteally along the medial facet to define the dorsal lamina safely before entering the canal.
- In revision cases, identify the plane between scar and dura using sharp dissection; use microdissectors rather than blunt instruments to avoid traction tears.

- When osteotomies are performed near the canal, protect the dura with malleable retractors and avoid aggressive curettage against the ventral dura.

Checklist – Dural tears

- Maintain high suspicion in revision surgery, rigid deformity, and multilevel laminectomy.
- If a tear is seen: repair primarily when possible, reinforce with graft/sealant, and avoid placing high-suction drains over the repair.
- Perform a gentle Valsalva test to confirm watertight closure before closure.
- In the postoperative period, monitor for orthostatic headache, pseudomeningocele, and wound drainage; low threshold for imaging and re-exploration if leak is suspected.

5.3. Intraoperative Sacral or Pelvic Fracture

Intraoperative sacral or pelvic fractures can occur during aggressive deformity correction, when over-sized screws are used in osteoporotic bone, or when screw trajectories violate cortical boundaries of the sacrum or ilium [1–3,15,18]. Sacral ala fractures may initially present as hairline cortical breaches, but can propagate under continued correctional forces or cantilevering of the rod. Pelvic fractures may result from misdirected iliac screws perforating the cortical tables.

Surgeons may feel a sudden "give" or loss of resistance while tapping or inserting screws, especially in the sacral ala or ilium of osteoporotic patients. During rod reduction, an unexpected audible crack or sudden change in deformity behavior (e.g., excessive lordosing at the lumbosacral junction) may signal bony failure. Fluoroscopically, new lucent lines in the sacral ala, changes in the contour of the sacral endplate, or step-offs in the pelvic ring may be seen. Bleeding from newly opened cancellous bone, not corresponding to planned osteotomy sites, is another indirect sign [1–3,15,18].

Before final seating of screws, AP and lateral views should be examined for any cortical breach or unusual angulation. For S2AI screws, the screw should remain within the ilium on oblique, inlet, and outlet views; if the tip appears to exit near the sciatic notch or acetabulum, the screw should be redirected [7,8,23,24]. During rod reduction, serial lateral images can detect excessive hinging at the lumbosacral junction that may predispose to sacral fracture.

If a sacral ala fracture or cortical breach is recognized intraoperatively, correction maneuvers should be immediately relaxed to remove excessive stress on the fracture. The compromised screw should be removed or redirected, and additional fixation (e.g., supplementary S2AI screws, bilateral pelvic screws, or longer sacral screws) placed to span and neutralize the fracture zone [1–3,15,18]. Multi-rod constructs should be considered across the lumbosacral junction to distribute loads. In case of an unstable fracture pattern involving the entire sacrum or pelvic ring, intraoperative consultation with a trauma or pelvic surgeon and conversion to a formal lumbopelvic or triangular fixation construct may be required [15,18].

Preventive anatomical strategies for mitigating complications:

- Preoperatively, assess sacral morphology and bone stock on CT; recognize sacral dysmorphism and narrow ala corridors that are at higher risk for fracture.
- Avoid over-tapping or using screws that are too large in diameter for osteoporotic sacral ala; when in doubt, prefer multiple standard-diameter screws over a single over-sized screw.
- During rod cantilevering and deformity correction, apply correction gradually and symmetrically, avoiding aggressive "one-shot" reduction maneuvers at the lumbosacral junction.
- In severely osteoporotic patients, consider cement augmentation of sacral screws or using alternative strategies (e.g., multiple smaller-diameter screws, vertebral body tethering) to reduce the risk of intraoperative fracture [15,18].

Checklist – Intraoperative sacral/pelvic fracture

- If you feel a sudden "give" during screw insertion: stop, obtain fluoroscopic images, and reassess screw trajectory.
- If fracture is confirmed: relax correction, add supplemental fixation (additional pelvic screws/multi-rod construct), and avoid concentrating stress on the fractured area.
- Do not ignore subtle lucent lines or step-offs on intraoperative imaging; small fractures can progress to catastrophic failure if untreated.

5.4. Visceral (Bowel and Urologic) Injury

Visceral injury during sacropelvic fixation is rare but potentially catastrophic. Misplaced sacral, iliac, or S2AI screws that perforate the anterior cortex of the sacrum or ilium can enter the pelvic cavity and injure small or large bowel, bladder, ureter, or gynecologic organs [1–3,7,8,24]. While most of the literature consists of case reports and small series, these events are associated with a high risk of sepsis, peritonitis, and need for emergency laparotomy if not recognized promptly.

Anterior over-penetration of sacral screws, especially when trajectories are aimed too steeply anteriorly or directed medially toward the pelvic cavity, can contact pelvic viscera or urologic structures. Long iliac screws that perforate the inner table and project into the true pelvis can injure bowel loops or the bladder. Risk is increased in patients with prior pelvic surgery (adhesions), distorted anatomy, or when fluoroscopic views are suboptimal due to body habitus or positioning [1–3,7,8,24].Unlike vascular injuries, visceral injuries may not immediately present with dramatic bleeding. Early signs can be subtle: unexpected air bubbles in the wound (if bowel is perforated), foul odor, the presence of enteric contents, or bleeding that appears bright red but mixed with non-arterial flow. If the bladder is injured, brisk hematuria may be noted in the Foley catheter intraoperatively after screw placement or during trial reduction. In cases where bowel or bladder is perforated but not recognized, the first signs may be postoperative: abdominal distension, peritonitis, fever, leukocytosis, ileus, or sepsis within 24–72 hours.

On intraoperative fluoroscopy, an excessively long screw tip projecting beyond the anterior sacral or iliac cortex on lateral or inlet views should raise concern. For S2AI and iliac screws, careful assessment of the screw's relationship to the pelvic brim and acetabulum on inlet/outlet and oblique views is essential; if the tip appears within the pelvic cavity rather than contained in the ilium, the screw should be repositioned [7,8,23,24]. Any screw that appears suspiciously long or beyond the bony boundaries on multiple views should be backed out and shortened or redirected.

If visceral injury is suspected intraoperatively—based on direct visualization, hematuria, or strong radiographic concern—prompt general or urologic surgical consultation is mandatory. For suspected bowel perforation, intraoperative exploration through an extended abdominal or retroperitoneal approach may be necessary, with repair or resection of the affected segment and generous irrigation. Bladder injuries are typically repaired in layers with absorbable sutures and protected with prolonged catheter drainage. When an injury is suspected but not definitively confirmed intraoperatively, early postoperative CT with contrast (including CT cystography if bladder injury is suspected) and close clinical monitoring for signs of peritonitis are indicated [1–3].

Preventive anatomical strategies for mitigating complications:

- Preoperative CT planning should include assessment of the relationship of the sacrum and ilium to pelvic organs; in patients with prior pelvic surgery, consider intraoperative navigation to minimize anterior perforation.
- For S1 and S2 screws, avoid excessive anterior angulation that would direct the tip into the pelvic cavity; aim to keep the tip within the sacral body, stopping 2–3 mm short of the anterior cortex as seen on lateral fluoroscopy [1–3]
- For iliac and S2AI screws, use templated lengths based on preoperative CT; resist the temptation to "maximize length" without clear radiographic confirmation of safe containment within bone.
- In high-risk patients (e.g., distorted pelvic anatomy, severe deformity, or prior pelvic surgery), a lower threshold for navigation or intraoperative CT is justified.

Checklist – Visceral injury

- On fluoroscopy, if a screw tip clearly projects beyond the anterior sacral or iliac cortex on more than one view, treat it as unsafe: back out, shorten, or redirect.
- New intraoperative hematuria, air or enteric contents in the wound, or suspicious foul fluid → stop, call general/urologic surgery, and investigate before closing.
- In early postoperative abdominal pain or peritonitis after sacropelvic fixation, consider screw-related visceral injury and obtain urgent CT with contrast.
- Document screw lengths and trajectories carefully to facilitate postoperative assessment if complications arise.

6. EARLY POSTOPERATIVE COMPLICATIONS (0–30 DAYS)

6.1. Catastrophic Acute Failure of Pelvic Fixation

Catastrophic acute failure (CAF) describes early mechanical collapse of the lumbosacral–pelvic construct, typically within the first 6 months, characterized by loss of distal fixation (screw pull-out, rod disengagement, sacral fracture at the implant–bone interface) and sudden loss of correction [4,5]. Systematic review data suggest that CAF occurs in approximately 5% of patients with ASD with long fusions to the pelvis, accounting for a disproportionate share of early revisions [4,5].

The mechanisms include under-dimensioned or insufficient pelvic screws, inadequate anterior column support, residual sagittal imbalance, and high mechanical demands after three-column osteotomies [1–4,12,13]. Clinically, patients report abrupt recurrence or worsening of low back/buttock pain, sometimes with a "giving way" sensation. Radiography demonstrates loss of lordosis or coronal correction, and CT reveals sacral fractures or hardware disengagement [4,5].

CAF is typically a surgical emergency. Revision aims to restore alignment, reinforce distal fixation (larger diameter and/or multiple pelvic screws, often bilateral dual S2AI screws), augment anterior column support (L5–S1 interbody fusion or cage revision), and convert to multi-rod constructs across the lumbosacral junction [4,5,12,13].

Checklist – Catastrophic acute failure

- Suspect CAF in the early postoperative period in any patient with sudden severe pain and radiographic loss of correction [4,5].
- Obtain standing full-spine radiographs and CT to identify fracture lines and hardware disruption.
- Plan revision with stronger distal foundations (multiple pelvic screws) and multi-rod constructs.
- Reassess and, if necessary, optimize sagittal alignment targets to reduce distal mechanical overload [1,3,4].

6.2. Surgical Site Infection and Wound Complications

Long constructs with pelvic fixation require extensive posterior exposure, predisposing patients to wound complications and surgical site infections (SSIs) [2,3,5,7–11]. Pelvic fixation is associated with increased operative time, blood loss, and length of stay, but not necessarily with higher deep infection rates when preventive bundles are applied [3,11]. Comparative studies have shown that S2AI constructs have lower wound complications and reoperation rates than iliac screw constructs, largely due to smaller, more medial incisions and deeper screw heads [7–10,24]. Superficial infections typically present within 2 weeks with erythema and drainage, whereas deep infections may present later with persistent pain, systemic signs, elevated inflammatory markers, and sometimes sinus tract formation.

Management:

- Superficial SSI: Local wound care and oral or short-course intravenous antibiotics.
- Deep SSI: early surgical debridement, intraoperative cultures, and prolonged intravenous and oral antibiotics. Instrumentation can often be retained if the infection is diagnosed early and the construct is stable [2,3].

- Chronic or recurrent deep infections may necessitate staged hardware removal and delayed reconstruction.

Checklist – Wound/SSI

- Recognize pelvic fixation as a risk factor for longer surgeries and higher blood loss; adopt infection-prevention bundles (glycemic control, normothermia, appropriate antibiotic dosing, meticulous closure) [3,11].
- Favor S2AI over traditional iliac screws to reduce distal wound problems when anatomy permits [7–10,24].
- A low threshold for imaging and debridement should be maintained in cases of persistent wound drainage or systemic signs.
- When possible, early deep infection should be treated with debridement, hardware retention, and culture-directed antibiotics.

6.3. Perioperative Systemic and Medical Complications

Pelvic fixation is a marker of surgical complexity. Large database studies show that pelvic fixation increases blood loss, operative time, and length of stay, but does not independently increase mortality or most 30-day complications when adjusted for case mix [3,11]. Common systemic complications include transfusion-related issues, venous thromboembolism, pulmonary complications, urinary tract infections, ileus, and cardiac events.

Management and prevention:

- Preoperative optimization of comorbidities and anemia.
- Standardized VTE prophylaxis and early mobilization.
- Intensive postoperative monitoring, especially in the first 72 hours, is required for cardiopulmonary and thromboembolic events.

Checklist – Systemic complications

- Anticipate high transfusion needs and consider cell salvage and antifibrinolytics [11].
- Use ERAS protocols (multimodal analgesia, early mobilization, and early oral intake) to reduce ileus and pulmonary complications.
- Monitor carefully for VTE, pneumonia, and cardiac events, especially in elderly and frail patients.

7. LATE MECHANICAL AND BIOLOGICAL COMPLICATIONS (>30 DAYS)

7.1. Screw Loosening and Pull-out at the Sacrum and Pelvis

Screw loosening and pull-out reflect bone–implant interface failure and are among the most common hardware complications [1,2,5–7,12–14,24].

Osteoporosis, long constructs, high PI–LL mismatch, small screw diameters, and S1-only distal fixation all increase the risk [5,6,15,18]. Radiographically, loosening appears as radiolucent halos around the screw threads, changes in screw angulation, and, in severe cases, screw migration or pullout. CT provides more sensitive detection of halo and cortical breach. Clinically, patients may report increasing low back or buttock pain, often with subtle progressive deformity.

Management:

- An asymptomatic halo without migration was observed in the presence of solid fusion.
- Symptomatic loosening, progressive deformity, or impending failure typically requires revision with screw upsizing, cement augmentation in osteoporotic bone, and conversion to robust sacropelvic fixation (often bilateral dual S2AI screws) [5–7,12–14,24].

Checklist – Screw loosening/pull-out

- Monitor high-risk patients (osteoporosis, S1-only constructs) closely with serial radiographs.
- Use CT to confirm loosening and differentiate it from benign lucencies.
- In revision, increase the number and strength of distal anchors and consider cement augmentation.
- Aim to correct or maintain PI–LL mismatch and overall alignment to reduce recurrent mechanical overload [1,3–6].

7.2. Rod Fracture at the Lumbosacral Junction

Rod fracture usually occurs 1–3 years postoperatively and typically reflects underlying pseudarthrosis or excessive cyclic loading at the lumbosacral junction [12–14]. Multi-rod constructs reduce, but do not eliminate, rod fracture risk. Clinically, patients report recurrent low-back pain, sometimes with a palpable or audible "snap." Radiographs reveal broken rods and loss of correction, while CT often confirms L5–S1 nonunion [12–14].

Management:

- Revision involves replacement of broken rods with a multi-rod construct across the lumbosacral junction, reinforcement of anterior column support (e.g., new interbody cage), and aggressive biological augmentation (autograft, allograft, and, when appropriate, osteoinductive agents) [12–14].

Checklist – Rod fracture

- Suspect rod fracture in late recurrent pain with loss of correction.
- Assume underlying pseudarthrosis until proven otherwise by CT.
- Use multi-rod constructs and robust interbody support pre-emptively in high-risk deformity corrections [12,13].
- In revision, both the mechanical (rod number/diameter) and biological (fusion substrate) causes should be corrected.

7.3. Lumbosacral Pseudarthrosis

L5–S1 pseudarthrosis remains a central cause of distal junctional failure even with sacropelvic fixation [2,4,5,6,12–14,19]. Risk factors include S1-only distal fixation, inadequate interbody support, poor bone quality, smoking, and residual sagittal imbalance [1–6,12,13,18,19]. Clinical features include persistent or recurrent pain after initial improvement, often associated with rod fracture or gradual loss of lumbosacral lordosis. CT is the gold standard for diagnosis, demonstrating absent or incomplete bridging bone, clefts, or vacuum changes in the fusion mass [15,16].

Management:

- Symptomatic pseudarthrosis usually requires revision with meticulous decortication, abundant grafting, and reinforcement of both posterior and anterior columns (e.g., L5–S1 interbody fusion or cage revision) [2,4,5,12–14,19].
- Distal fixation is upgraded when necessary (multi-rod constructs, multiple pelvic screws) to maintain the correction during renewed fusion.

Checklist – Lumbosacral pseudarthrosis

- Suspect in persistent pain, rod fracture, or loss of lumbosacral lordosis beyond 6–12 months.
- Use CT routinely in high-risk patients or when symptoms suggest nonunion.
- Prevent by combining sacropelvic fixation with L5–S1 interbody fusion and generous grafting in long constructs [2–4,6,12,13,19].
- Address both mechanical stability and biological environment in revision.

7.4. Sacral and Pelvic Fractures (Including Insufficiency Fractures)

Distal sacral and pelvic fractures after lumbosacral or lumbopelvic fusion include high-energy traumatic fractures and low-energy insufficiency fractures just caudal to the construct [15–18,24]. Older age, osteoporosis, elevated

BMI, long constructs to the sacrum or pelvis, and high postoperative sagittal imbalance are major risk factors [15–18]. Sacral insufficiency fractures are uncommon but likely underdiagnosed; incidence of distal fractures after lumbosacral fusion ranges from about 1% to 6% in contemporary series [15–18]. Patients present with new sacral or buttock pain, often without major trauma. Radiographs may be normal; CT or MRI is frequently required for diagnosis [15–18].

Management:

- Stable, minimally displaced insufficiency fractures may be managed conservatively with protected weight-bearing, analgesia, and rigorous osteoporosis treatment [15–18].
- Unstable fractures, significant deformity, or neurological compromise generally require extension of fixation into the pelvis (if not already present) and formal lumbopelvic stabilization [16–18].

Checklist – Sacral/pelvic fractures

- Maintain high suspicion in elderly osteoporotic patients with new sacral pain after fusion, especially long constructs.
- Utilize CT or MRI early when radiographs are inconclusive.
- Differentiate stable from unstable fracture patterns; unstable patterns often mandate lumbopelvic or triangular fixation [16–18].
- Address underlying osteoporosis and alignment to prevent recurrence

7.5. Sacroiliac Joint Pain and Degeneration

Post-fusion SI joint pain is increasingly recognized as a cause of persistent or new-onset buttock pain after lumbosacral and lumbopelvic fusion [19–23]. Biomechanically, the elimination of lumbar motion and altered load transfer increases stress across the SI joint. Moreover, when instrumentation traverses or buttresses the SI joint (e.g., S2AI screws), local kinematics may be further altered [1,3,19–22]. Retrospective studies and systematic reviews report variable incidence, but SI joint pain may occur in a substantial subset of patients, particularly those with long constructs and higher BMI [19–23]. Imaging may show sclerosis, joint space narrowing, or cysts; however, diagnosis relies heavily on clinical provocation tests and the response to image-guided diagnostic injections [19–23].

Management:

- Initial treatment is conservative: physiotherapy, medications, and image-guided injections.

- In refractory cases with confirmed SI-mediated pain and stable spinal fusion, interventional options include SI joint fusion or, in carefully selected cases, modification or removal of crossing hardware [19–23].

Checklist – SI joint pain/degeneration

- Suspect SI-mediated pain in buttock-dominant pain after otherwise solid long fusion.
- Use provocation tests and diagnostic SI joint injections to confirm the pain generator.
- Recognize risk factors: long constructs, sacropelvic fixation, high BMI, pre-existing SI degeneration [19–23].
- Reserve SI joint fusion or selective hardware removal for refractory, well-documented cases.

7.6. Hardware Prominence and Soft-tissue Irritation

Hardware prominence and soft-tissue irritation are particularly problematic with conventional iliac screws because of their lateral and superficial position and the need for bulky offset connectors [1,2,7–10]. Prominence may cause chronic focal pain, difficulty with sitting or lying supine, and, rarely, skin breakdown. Comparative data confirm significantly lower rates of symptomatic hardware prominence with S2AI screws than with iliac screws, due to more medial starting points and deeper screw heads [7–10,24].

Management:

- Once radiographic fusion is confirmed and alignment is stable, isolated removal of prominent pelvic screws (often the iliac screws only) can provide excellent symptom relief with a low risk of loss of correction [2,7–10,24].

Checklist – Hardware prominence

- Anticipate prominence with large, lateral iliac screws in thin patients and discuss potential elective removal preoperatively.
- Prefer S2AI screws when appropriate to minimize prominence and wound issues [7–10,24].
- Confirm solid fusion before elective screw removal.

8. DISCHARGE CRITERIA AND FOLLOW-UP STRATEGY

8.1. Discharge Criteria

Patients with sacropelvic fixation should meet stricter discharge criteria than those undergoing shorter fusions. Common criteria include:

- Hemodynamic stability without ongoing transfusion needs
- Adequate pain control on oral or oral-dominant analgesia
- Ability to mobilize safely with physiotherapy (usually with the aid of a walker)
- Intact and stable neurological examination
- Clean, dry wound with no signs of deep infection
- Established thromboprophylaxis plan and bowel/bladder function

8.2 Follow-Up Schedule

A pragmatic schedule (modified according to local practice and patient status) is:

- 2 weeks: wound check, assessment of early complications
- 6 weeks: clinical review, standing radiographs (AP/lateral) of the whole spine and pelvis
- 3 months: clinical and radiographic evaluation; early assessment of alignment and hardware integrity
- 6 and 12 months: assessment of fusion progression, alignment maintenance, and onset of late complications (rod fatigue, SI pain, sacral fractures)
- Annually thereafter: for high-risk patients (long constructs, osteoporotic, prior complications), with radiographs and CT as indicated

CT is reserved for suspected nonunion, screw loosening, distal fractures, or complex neurologic complaints, to limit radiation exposure [15,16].

8.3. Imaging and Triage Algorithms

- Persistent axial pain without obvious radiographic cause → CT to evaluate fusion and hardware.
- New buttock-dominant pain → consider SI joint pathology; targeted imaging plus diagnostic injections.

- Sudden severe pain with loss of correction → radiographs plus CT to evaluate for CAF, rod fracture, or sacral fracture.

9. PRACTICAL ALGORITHMS AND PEARLS

1. When to include the pelvis:
   - o Long constructs including S1 and/or severe sagittal imbalance, prior distal failure, high-grade lumbosacral pathology, or poor bone quality → strongly consider sacropelvic fixation [1–3,6,19].
2. How to fix the pelvis:
   - o Prefer S2AI screws in deformity and degenerative cases for lower wound and prominence complications, reserving iliac screws for specific anatomic or trauma scenarios [1,3,7–10,24].
3. How to protect the lumbosacral junction:
   - o Combine sacropelvic fixation with L5–S1 interbody fusion and multi-rod constructs in high-risk cases [1–3,12,13].
   - o Target PI–LL mismatch ≤10° and appropriate global sagittal alignment to avoid distal overload [1,3,4,12].
4. How to surveil for complications:
   - o Use structured follow-up with serial standing radiographs and selective CT.
   - o Maintain high suspicion for sacral insufficiency fractures and SI joint pain in elderly, osteoporotic patients or those with new buttock pain [15–18,20–23].
5. When and how to revise:
   - o Early CAF or traumatic fracture → urgent realignment, stronger distal fixation, and enhanced anterior support.
   - o Rod fracture or pseudarthrosis → revise with multi-rod constructs, improved interbody support, and biological augmentation [12–14].
   - o Symptomatic SI joint pain → confirm diagnosis with injections, treat conservatively, and reserve fusion or selective hardware changes for refractory cases [19–23].

10. CONCLUSIONS

Sacropelvic and pelvic fixation are indispensable tools in modern neurosurgical and orthopedic spinal practice, enabling durable correction of complex deformity, stabilization of severe degenerative disease, and reconstruction after trauma, tumor, and infection. Despite technical advances—particularly S2AI fixation, multi-rod constructs, and better understanding of spinopelvic parameters—mechanical and biological complications remain common and clinically significant [1–4,7–13,15–23].

This chapter emphasizes a complication-centric approach: understand the mechanisms of failure; prevent them where possible through sound biomechanics and alignment; detect them early with structured follow-up; and manage them decisively with principle-driven revision strategies. For the neurosurgeon, sacropelvic fixation is not merely a set of techniques but a long-term commitment to preserving lumbosacral stability and function over the patient's lifetime.

References

1. Harris A, Kebaish KM. Sacropelvic fixation: a comprehensive review. Semin Spine Surg. 2019;31(2):81–86. doi:10.1053/j.semss.2019.03.006.
2. Kebaish KM. Sacropelvic fixation: techniques and complications. Spine (Phila Pa 1976). 2010;35(25):2245–2251. doi:10.1097/BRS.0b013e3181f5cfae
3. Ravinsky R, Lewis S, Fisher C, Polly DW, on behalf of the AO Spine Knowledge Forum Deformity. AO Spine clinical practice recommendations: spinopelvic fixation – what are the key items to understand performance? Global Spine J. 2025;15(6):2855–2861. doi:10.1177/21925682251336746
4. Odland K, Chanbour H, Zuckerman SL, Polly DW Jr. Spinopelvic fixation failure in the adult spinal deformity population: systematic review and meta-analysis. Eur Spine J. 2024;33(7):2751–2762. doi:10.1007/s00586-024-08241-6
5. Guler UO, Cetin E, Yaman O, et al. Sacropelvic fixation in adult spinal deformity (ASD); a very high rate of mechanical failure. Eur Spine J. 2015;24(5):1085–1091. doi:10.1007/s00586-014-3615-1
6. Han B, Yin P, Hai Y, Cheng Y, Guan L, Liu Y. Comparison of spinopelvic parameters, complications, and clinical outcomes after spinal fusion to S1 with or without additional sacropelvic fixation for adult spinal deformity: a systematic review and meta-analysis. Spine (Phila Pa 1976). 2021;46(17):E945–E953. doi:10.1097/BRS.0000000000004003
7. Gao Z, Sun X, Chen C, et al. Comparative radiological outcomes and complications of sacral-2-alar iliac screw versus iliac screw for sacropelvic fixation. Eur Spine J. 2021;30: 2257–2270. doi:10.1007/s00586-021-06864-7
8. Hasan MY, Liu G, Wong HK, Tan JH. Postoperative complications of S2-alar-iliac versus iliac screw in spinopelvic fixation: a meta-analysis and recent trends review. Spine J. 2020;20(6):964–972. doi:10.1016/j.spinee.2019.11.014
9. Rahmani R, Stegelmann SD, Andreshak T. S2 alar-iliac screws are superior to traditional iliac screws for spinopelvic fixation in adult spinal deformity: a systematic review and meta-analysis. Spine Deform. 2024;12(4):829–842 . doi:10.1007/s43390-024-00834-x
10. Arslan A, Olguner SK, Istemen I, Acık V, Gezercan Y. Clinical and radiological comparison of spinopelvic fixation methods: S2-alar-iliac screw versus conventional iliac screw in long segment fusion. J Turk Spinal Surg. 2020;31(2):68–74. doi: 10.4274/jtss.galenos.2020.148
11. Kothari P, Somani S, Lee NJ, et al. Thirty-day morbidity associated with pelvic fixation in adult patients undergoing fusion for spinal deformity: a propensity-matched analysis. Global Spine J. 2016;6(7):665–672. https://doi.org/10.1055/s-0036-1583946

12. Bourghli A, Boissière L, Kieser D, et al. Multiple-rod constructs in adult spinal deformity surgery for pelvic-fixated long instrumentations: an integral matched cohort analysis. European Spine Journal (2020) 29:886–895. doi:10.1007/s00586-020-06311-z
13. Merrill RK, Kim JS, Leven DM, et al. Multi-rod constructs can prevent rod breakage and pseudarthrosis at the lumbosacral junction in adult spinal deformity. Global Spine J. 2017;7(6):514–520. doi:10.1177/2192568217699392
14. Jung JM, Hyun SJ, Kim KJ, et al. Rod fracture after multiple-rod constructs for adult spinal deformity. J Neurosurg Spine.2020;32(3):407–414. doi:10.3171/2019.9.SPINE19913
15. Klineberg E, McHenry T, Bellabarba C, et al. Sacral insufficiency fractures caudal to instrumented posterior lumbosacral arthrodesis. Spine (Phila Pa 1976). 2008;33(16):1806–1811. doi: 10.1097/BRS.0b013e31817b8f23
16. Joaquim AF, Patel AA. Diagnosis, risk factors, and management of sacral and pelvic fractures after instrumented lumbar fusions: a systematic review. Global Spine J. 2019;9(5):540–544. doi:10.1177/2192568218779986
17. Barber LA, Katsuura Y, Qureshi S. Sacral Fractures: A Review. HSS Journal®: The Musculoskeletal Journal of Hospital for Special Surgery. 2022;19(2):234-246. doi: 10.1177/15563316221129607
18. Odate S, Shikata J, Kimura H, et al. Sacral fracture after instrumented lumbosacral fusion: analysis of risk factors from spinopelvic parameters. Spine (Phila Pa 1976). 2013;38(4):E223–E229. doi: 10.1097/BRS.0b013e31827dc000
19. Finger T, Bayerl S, Onken J, et al. Sacropelvic fixation versus fusion to the sacrum for spondylodesis in multilevel degenerative spine disease. Eur Spine J. 2014;23(5):1013–1020. doi: 10.1007/s00586-014-3165-6
20. Finger T, Bayerl S, Bertog M, Czabanka M, Woitzik J, Vajkoczy P. Impact of sacropelvic fixation on the development of postoperative sacroiliac joint pain following multilevel stabilization for degenerative spine disease. Clinical Neurology and Neurosurgery. 2016;150:18–22. doi: 10.1016/j.clineuro.2016.08.009
21. Manzetti M, Ruffilli A, Barile F, Fiore M, Viroli G, Cappello L, Faldini C. Sacroiliac Joint Degeneration and Pain After Spinal Arthrodesis: A Systematic Review. Clinical Spine Surgery 36(4):p 169-182, May 2023. doi: 10.1097/BSD.0000000000001341
22. Colò G, Cavagnaro L, Alessio-Mazzola M et al. Incidence, diagnosis and management of sacroiliitis after spinal surgery: a systematic review of the literature. Musculoskelet Surg 104, 111–123 (2020). doi: 10.1007/s12306-019-00607-0

23. Shen J, Boudier-Reveret M, Majdalani C, Truong VT, Shedid D, Boubez G, et al. Incidence of sacroiliac joint pain after lumbosacral spine fusion: a systematic review. Neurochirurgie. 2023;69(2):101419. doi: 10.1016/j.neuchi.2023.101419
24. Hyun SJ, Kim KJ. Durability and failure types of S2-alar-iliac screws: analysis of consecutive screws. J Korean Soc Spine Surg. 2020;25(1):24–33