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Diagnosis and Management of Sacral Spine Fractures

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Determining the optimal treatment of sacral fractures is a challenge for spine surgeons and traumatologists alike. Because of the relative rarity and heterogeneous nature of sacral fractures, individual surgeons have limited exposure to these injuries and studies of sacral fractures have been largely retrospective in nature and have involved nonhomogeneous or small treatment groups. Few scientifically based insights can be gathered from the current literature in this field.

The sacrum is the mechanical nucleus of the axial skeleton, serving as the base for the spinal column as well as the keystone for the pelvic ring. Despite its mechanical importance, the transitional location of the sacrum between the spine and the pelvis has resulted in its being relatively neglected by both spine surgeons and traumatologists and in both specialties having incomplete experience with treatment of this spinal region.

Biomechanical testing of the sacrum has proven difficult because of the complexities of load transfer from the mobile lumbar spine to the hips and the added variables of regional ligamentous and muscle support[1]. Because of the traumatic comorbidities in patients with a sacral fracture, any attempt to formulate standardized treatment approaches is challenging, if not impossible.

In a large retrospective study of sacral fractures, Denis et al. reported that the chance of identifying a sacral fracture was increased by the presence of an associated neurological injury[2]. An existing sacral fracture was correctly identified in 76% of patients presenting with a neurological deficit but in only 51% of neurologically intact patients.

Unrecognized and inadequately treated sacral fractures may lead to painful deformity and progressive loss of neurological function[3]. Delayed surgery for posttraumatic sacral deformity is complex, and the results are often less favorable than those of early surgery[4]. Therefore, determination of an integrated diagnostic and therapeutic approach to sacral fractures should be a goal.

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Sacral Anatomy

The sacrum provides the foundation for lumbar as well as pelvic ring alignment. A combination of intact osseous and ligamentous components is necessary to provide a sound weight-bearing platform as well as protection for the lumbosacral (L4-S1) and sacral (S2-S4) plexuses and iliac vessels. Transmission of load on the trunk is distributed by the first sacral segment through the iliac wings to the acetabulum on either side[1]. Strong posterior lumbosacral and lumboiliac ligaments stabilize the osseous components of this transition zone, which is characterized by nonconstrained articulations. The sacrum is a kyphotic structure with a sagittal angulation ranging from 0° to 90°. This contributes to the sacral inclination angle of the superior end plate of S1, which then determines the compensatory lordosis of the lumbar spine. The thin posterior soft-tissue coverage of the sacrum, consisting of a thin layer of multifidus muscle and the lumbosacral fascia, has implications in terms of the ability of this area to withstand blunt trauma and tolerate bulky implant systems.

The sacral spinal canal is capacious and provides more than adequate space for the cauda equina. Of the anteriorly exiting sacral roots, S1 has proportionally the least foraminal exit area, occupying up to one-third of the foramen. The lower sacral roots have progressively more relative space, with the S4 root occupying only one-sixth of the available anterior foraminal area[5]. The anterior rami of the S2 through S5 roots contribute to sexual function as well as bowel and bladder control by providing parasympathetic innervation to the bladder and rectum. The sympathetic ganglia of the inferior hypogastric plexus extend from the anterolateral L5 and S1 vertebral bodies caudally to the anterior surface of the sacrum along the medial margin of the anterior foramina of S2, S3, and S4[5]. The posterior rami of the sacral roots consist of small sensory fibers, with contributions to the cluneal nerves.

Evaluation

Physical Examination

Approximately 30% of sacral fractures are identified late[6]. Delayed diagnosis of these injuries can have a negative impact on long-term outcome and can be avoided by a targeted clinical evaluation. Sacral injury should be suspected in any patient reporting peripelvic pain. Inspection and palpation of the entire body is necessary following high-energy blunt trauma, especially in the presence of an altered sensorium. Lacerations, bruising, tenderness, swelling, and crepitus are clear signs of a potential underlying injury. More specific signs suggesting possible sacral injury include a posterior sacral osseous prominence or a palpable subcutaneous fluid mass consistent with lumbosacral fascial degloving (Morel-Lavelle lesion)[7].

Although rectal examination is a standard component of the evaluation of a patient who has sustained traumatic injury, patients with a suspected sacral fracture should also undergo functional assessment of the lower sacral roots, including determination of spontaneous and maximum voluntary rectal sphincter contraction, checking for the presence of light touch and pinprick sensation along the perianal concentric dermatomes of S2 through S5, and elicitation of specific reflexes including perianal wink and the bulbocavernosus and cremasteric reflexes[5]. Female patients should undergo a vaginal examination so that an occult open pelvic fracture is not missed.

Pelvic ring stability can be tested manually by gently applied internal and external rotation of the iliac wings[8]. Lower-extremity push-and-pull tests with supplemental radiographic documentation of pelvic shifting have been described but are not commonly performed[9]. In patients who can walk, the presence of mechanically related low-back or buttock pain may indicate a sacral insufficiency fracture.

Imaging

The ATLS (Advanced Trauma Life Support) protocol for imaging in the setting of a suspected sacral fracture includes an anteroposterior radiograph of the pelvis[10]. Because of the inclination angle of the sacrum, however, only limited visualization is possible with this view. Pelvic inlet and outlet radiographs are recommended as additional studies to improve visualization of the sacrum in any patient with a suspected pelvic ring injury[6]. The sacral spinal canal and a superior view of S1 are seen clearly on the pelvic inlet radiograph. The pelvic outlet radiograph can usually provide true anteroposterior visualization of the sacrum. The Ferguson view is a centrally coned-down modification of a pelvic outlet view directed perpendicular to the sacral inclination to allow en face visualization of the entire sacrum. The lateral sacrum view is a simple yet effective radiographic study for screening and assessing sacral injuries, even in obese patients[11]. It should be kept in mind that radiographic landmarks may be obscured in a patient with osteopenia or lumbosacral dysmorphism, and the diagnosis may be delayed or missed altogether.

Nork et al. identified several radiographic indicators of potential sacral fractures, including a fractured L5 transverse process (found in 61% of patients with a sacral fracture), a paradoxical pelvic inlet view found on supine anteroposterior radiographic projections (92% of patients), and a stepladder sign indicative of anterior sacral foraminal disruption[12].

Computed tomography is the preferred modality for diagnosing suspected or known posterior injury of the pelvic ring. A dedicated sacral computed tomography scan with 2-mm or thinner cuts as well as sagittal and coronal reformatted views offers superior visualization of a disrupted sacrum and is especially useful for complex sacral fractures[10]. Because of termination of the thecal sac at the S1-S2 interspace, computed tomography myelography is of limited usefulness. Sacral magnetic resonance imaging may be helpful for patients presenting with unexplained sacral neurological deficits after trauma. In an elective setting, magnetic resonance imaging can reveal sacral stress fractures or provide visualization of the lumbosacral plexus. Technetium bone scans enhanced with single-photon emission computed tomography is an effective imaging modality for identifying posttraumatic arthritis as well as insufficiency fractures.

Electrophysiological Assessment

Patients who have a sacral fracture and a neurological deficit or a cognitive impairment can be effectively evaluated with a variety of electrodiagnostic tests. Perineal somatosensory evoked potentials and anal sphincter electromyography are useful for assessing patients with a possible neurological deficit related to sacral injury or as a monitoring tool during surgical intervention. Electrodiagnostic evaluation can also be used to differentiate upper motor neuron lesions from spinal cord injury concurrent with sacral trauma or for patients with an injury to the lower part of the urinary tract, for whom neurological evaluation may be difficult[5]. Cystometrography performed with sphincter electromyography and postvoiding residual measurements can be used as a follow-up test for patients with a neurogenic bladder. However, electromyography is not as useful in the acute setting, as abnormalities may take several weeks to emerge.

Classification

A perplexing number of classification

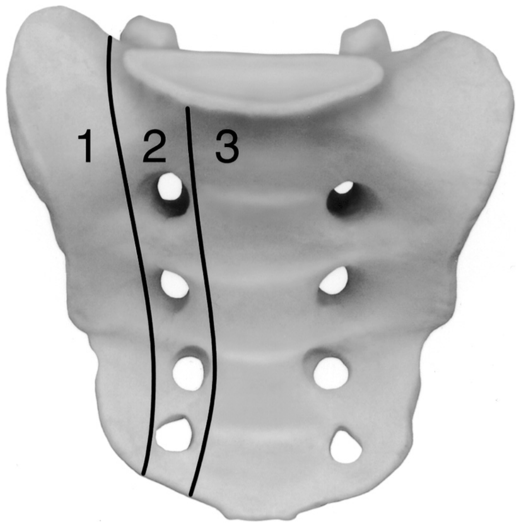

Fig. 1-A

Figs. 1-A through 1-D Systems for classification of sacral fractures. **Fig. 1-A** The three-zone system of Denis et al.[2]. Zone-I injuries are entirely lateral to the neuroforamina, zone-II fractures involve the neuroforamina but do not involve the spinal canal, and zone-III injuries extend into the spinal canal with primary or associated fracture lines.

systems have emerged to describe sacral injuries over the last decade (Figs. 1-A through 1-D)[8,13-15]. A systematic conceptual approach, rather than an extensive review of the various classification concepts, will be discussed. Five basic principles must be followed when assessing a sacral injury.

Presence of active bleeding: Sacral fractures may be associated with life-threatening injuries to the iliac vessels, anterior perisacral venous plexus, or superior gluteal artery. Determination of hemodynamic stability is crucial.

Presence of an open fracture: The presence of an open sacral fracture substantially affects treatment and prognosis. The majority of open sacral fractures fall into the Type III-A category according to the Gustilo-Anderson system[16]. More substantial open injuries include those with violation of the rectal or vaginal vault or fracture contamination from an accompanying urogenital injury. A variant of a true open fracture is an extensive lumbosacral fascial degloving injury similar to that described in Morel-Lavelle syndrome[14]. Technically, these injuries are closed, but it is a substantial challenge to treat them because of the severity of the soft-tissue trauma. Grading of closed soft-tissue injuries has been well described in the four-stage system of Tscherne[17], and this system can be extrapolated to closed sacral soft-tissue injuries.

Neurological injury: A neurological deficit is a major determinant of a patient's ultimate quality of life. Potential neurological injuries in patients with a sacral fracture include those involving the cauda equina, the lumbosacral plexus, the sacral plexus, and the sympathetic and parasympathetic chains. All neurological injuries can be subclassified as complete or incomplete with the American Spinal Injury Association (ASIA) classification system.

Pattern and stability of skeletal injury: Determination of structural stability is a crucial component of the description of a sacral fracture. Unfortunately, the issue of defining stability with respect to the pelvic ring remains largely unresolved. Because of the pelvic ring's strong dependence on ligamentous support, any posterior ligamentous disruption of the pelvic ring is likely to be unstable. By convention, any sacral or posterior pelvic fracture-displacement of ≥1 cm is considered to be unstable. A three-stage system of stability classification has been proposed for sacral injuries. With this system, stage A indicates an osseoligamentous injury with retention of structural function; stage B, an occult osseoligamentous disruption; and stage C, an obvious complete osseoligamentous disruption. Differentiation between stage-A and B injuries can be very difficult and may require provocative tests, such as weight-bearing and traction studies, or repeated imaging over time. Descriptive systems for classification of pelvic-sacral trauma have been put forth by several investigators including Tile[8], Denis et al.[2], Roy-Camille et al.[18], Strange-Vognsen and Lebech[19], and Isler[20].

Systemic injury load: The cumulative injury load or degree of force impact sustained by the patient has considerable short and long-term implications for treatment and outcome. Certain patients or fractures may not be amenable to surgical intervention. Also,

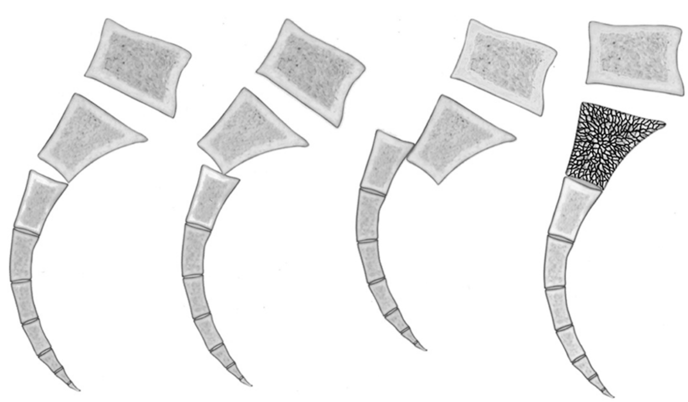

Fig. 1-B

Subclassification of Denis zone-III fractures as suggested by Roy-Camille et al.[18] and modified by Strange-Vognsen and Lebech[19] . From left to right: Type-1 injuries are angulated but not translated, type-2 injuries are angulated and translated, type-3 injuries show complete translational displacement of the cephalad and caudad parts of the sacrum, and type-4 injuries are segmentally comminuted as a result of axial impaction.

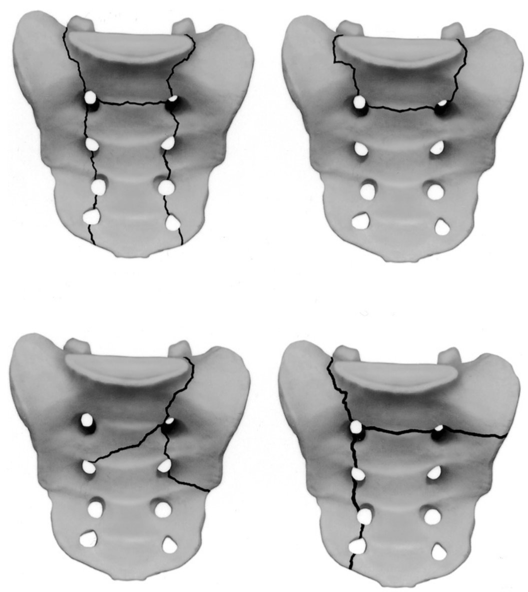

Fig. 1-C
Examples of complex sacral Denis zone-III fractures[2]. The fracture on the top left is frequently referred to as the "H" type, and the one on the top right is the sacral "U" type. The bottom row shows two of many other complex fracture variations. On the left is a sacral "lambda" fracture, and on the right is a sacral "T" fracture.

a metabolically impaired patient with multiple insufficiency fractures may not be amenable to surgical intervention.

These five basic principles of sacral fracture assessment provide the treating physician with a sound fundamental understanding of the nature of the injury and facilitate communication with other care providers.

The Denis three-zone classification system for sacral fractures was introduced in 1988 and is based on fracture anatomy (Fig. 1-A)[2]. Denis et al. performed an eleven-year retrospective review of the cases of 236 patients and determined that medial fracture excursion was closely associated with both injury mechanism and prevalence of neurological injury. Due to its clarity and reproducibility, this remains the standard system for classification of sacral fractures.

Zone-I fractures are the most common, accounting for 50% of the fractures in the series described by Denis et al.[2]. Zone-I fractures mainly involve the sacral ala, with possible extension into the sacroiliac joint. By definition, zone-I fractures occur lateral to the sacral foramina. The fractures can be subdivided into stable and unstable injuries, according to the three-stage severity system discussed above. Neurological injury occurs in approximately 6% of patients and typically involves the L4 and L5 nerve roots.

Zone-II fractures are the second most common pattern, accounting for 34% of the injuries in the study by Denis et al.[2]. These injuries consist of a vertical transforaminal fracture without involvement of the sacral spinal canal. An associated neurological injury is found in 28% of patients, and it most frequently affects the L5, S1, or S2 nerve root. It is important to distinguish between stable and unstable zone-II injuries because malunions in this area are associated with very poor functional outcomes. Vertical shear injuries are considered to be highly unstable zone-II fractures.

Any sacral fracture involving the spinal canal is classified as a zone-III injury. This fracture subtype was encountered the least frequently (in only 16% of the patients in the study by Denis et al.[2]) but was associated with the highest prevalence and severity of neurological injury, which affected 57% of the patients. Bowel and bladder control or sexual function was impaired in 76% of the patients with a neurological injury in this group.

Two additional factors to consider are whether the injury is bilateral and the axial level of the fracture. Patients with a transverse sacral fracture involving the S1, S2, or S3 segment tend to have a higher prevalence of bladder dysfunction than do those with a more caudad sacral fracture affecting the S4 or S5 segment. It should be kept in mind that bilateral zone-I or II injuries are extremely uncommon and, on closer inspection, are usually associated with an unrecognized zone-III injury and an obscure transverse fracture line.

The zone-III sacral fractures de-

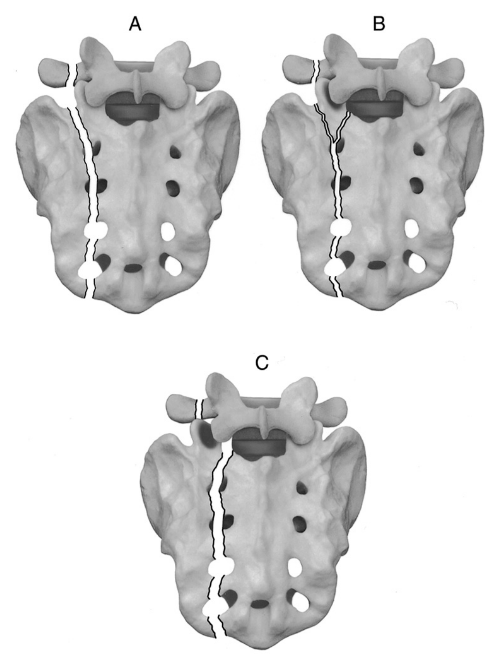

Fig. 1-D
Classification of injuries at the lumbosacral junction, as suggested by Isler[20]. Type-A injuries are lateral to the L5-S1 facet joint and may affect pelvic ring stability but not lumbosacral stability. Type-B injuries extend through the L5-S1 facet joint and are associated with a variety of displacements and neurological injuries. Type-C injuries violate the spinal canal, are invariably unstable, and usually are complex.

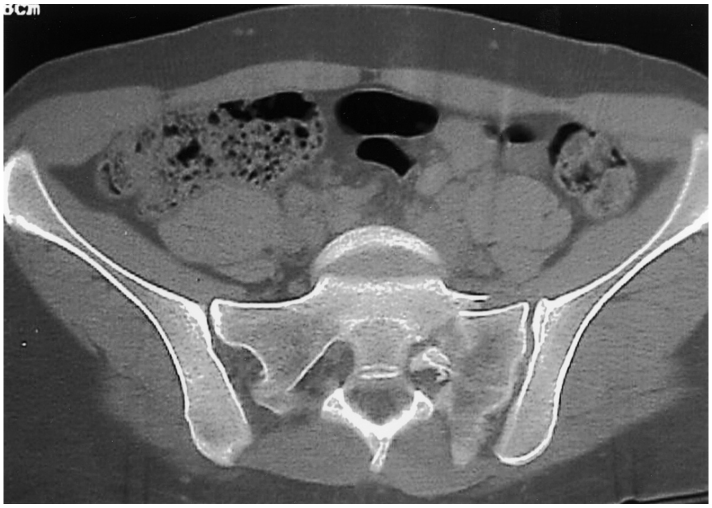

Fig. 2-A

Figs. 2-A, 2-B, and 2-C Sacroiliac fixation and foraminotomy. **Fig. 2-A** A pelvic computed tomography scan demonstrating a Denis zone-II transforaminal sacral fracture in a twenty-four-year-old woman who was injured in a motor-vehicle collision. The patient was found to have a dense S1 radiculopathy on the side of the fractured ala. The computed tomography scan shows a large cortical fragment obstructing the S1 foramen.

scribed by Denis et al. have been subclassified by Roy-Camille et al.[18], with further modification by Strange-Vognsen and Lebech[19]. With use of that system, injury severity, likelihood of neurological injury, and therapeutic implications are directly related to increasingly severe injury types (1 through 4) (Fig. 1-B). Type-1 fractures are the least severe and demonstrate a simple flexion deformity of the sacrum. Type-2 injuries are partially translated as well as hyperkyphotic. Type-3 injuries display complete translation with no fracture overlap, and type-4 injuries, as described by Strange-Vognsen and Lebech, consist of segmental comminution of the S1 vertebral body caused by axial loading of the lumbar spine into the cephalad part of the sacrum.

Injury at the Lumbosacral Junction

Injury at the lumbosacral junction is an important, albeit incompletely understood, category of sacral injury. The lumbosacral ligaments are quite strong, so patients presenting with an injury in this transitional zone have usually sustained very high-energy trauma.

Like cervical spine injuries, lumbosacral injuries can be viewed conceptually as unilateral or bilateral dislocations, with or without accompanying fractures. Displacement can vary from lumbosacral subluxation to complete lumbopelvic dissociation. Isler proposed a system for assessing lumbosacral injury on the basis of the location of the pelvic ring fracture relative to the L5-S1 facet joint (Fig. 1-D)[20]. A vertical sacral fracture lateral to the L5-S1 facet joint is unlikely to have an impact on lumbosacral stability but may affect pelvic ring stability. Fractures crossing through the L5-S1 facet joint can be differentiated as extra-articular fractures of the lumbosacral junction and articular dislocations with various stages of displacement of the L5 and S1 articular processes. Fractures crossing into the neural arch medial to the L5-S1 joint are

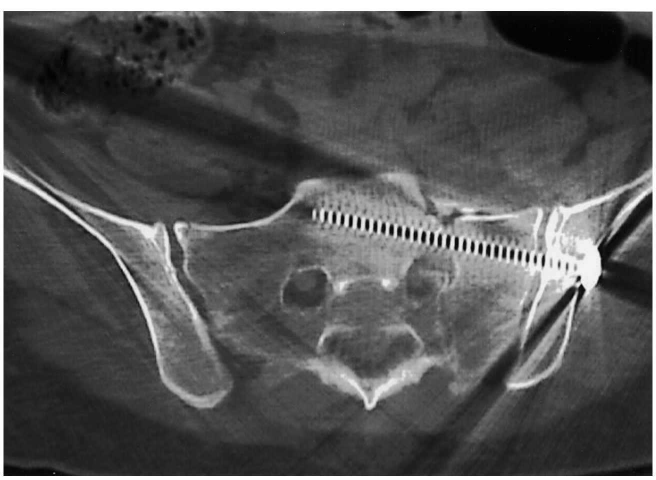

Fig. 2-B

Fig. 2-C

Fig. 2-B An attempt was made to achieve an indirect foraminal decompression in addition to accomplishing posterior stabilization of the pelvic ring with early closed reduction and a percutaneously placed sacroiliac screw. There was no improvement of the S1 radiculopathy. **Fig. 2-C** After there was no neurological improvement in the first forty-eight hours postoperatively, the decision was made to perform an early decompression of the S1 foramen. This was done under fluoroscopic guidance with a focal hemilaminotomy. Satisfactory decompression was confirmed on the postoperative computed tomography scan.

usually complex and inherently unstable, necessitating stabilization.

Spinal cord injuries have been classifed in a methodical fashion by the American Spinal Injury Association partly on the basis of the original work of Frankel[5]. This system, however, incompletely addresses sacral injuries and the greater variability of neural deficits arising from root injuries. Gibbons et al. designed a useful four-stage system specifically to grade sacral neurological injuries[21], but unfortunately this system has not come into common usage. The stages of the system consist of 1 (no injury), 2 (paresthesias only), 3 (motor loss but bowel and bladder control intact), and 4 (impaired bowel and/or bladder control).

Treatment

Early Management

Early treatment of substantial unstable sacral injuries may include temporary reduction of a displaced pelvic ring fracture and interventional radiological techniques such as angiographic embolization of bleeding pelvic vessels. Options for pelvic reduction include temporary skeletal traction, application of an anterior external fixator, placement of a pelvic clamp, or use of a wrap-around sheet. In the acute posttraumatic setting, the goal is to achieve a noninvasive form of pelvic reduction and volume reduction and to minimize additional blood loss[22].

Nonoperative Management

Nonoperative care consists mainly of activity modification aimed at preventing further fracture displacement. This may consist of prolonged bed rest in skeletal traction, bed rest in a brace or cast with a unilateral or bilateral hip spica (i.e., pantaloon spica), brace immobilization (with a thoracolumbar spinal orthosis with a hip spica) with protected weight-bearing, or early mobilization with protected weight-bearing.

The typical time frame for healing of a posterior pelvic ring fracture is two to four months. This allows for a transitional period of protected weight-bearing for one to two months[8]. Whenever treatment involves prolonged recumbency, it is necessary to address the potential dangers of thromboembolism, pulmonary complications, and skin breakdown. Countermeasures may include prophylactic anticoagulation and pneumatic compression boots as well as utilization of a spinal injury bed such as the Roto Rest bed (Kinetic Concepts, San Antonio, Texas). Vigorous pulmonary toilet to prevent atelectasis and pneumonia should also be instituted. Repeat imaging studies should be performed to verify that fracture-healing is proceeding with satisfactory alignment. Progressive fracture displacement, deterioration of neurological function, or persistent pain with attempts at mobilization may indicate failure of conservative treatment. As a result of the high cost of labor-intensive care necessary for nonoperative management, these strategies have largely fallen out of favor for the treatment of patients with unstable injuries.

Indications for nonoperative management are vague and historically

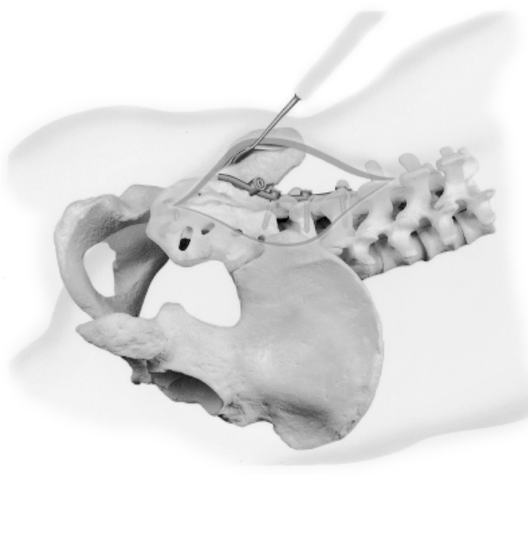

Fig. 3-A

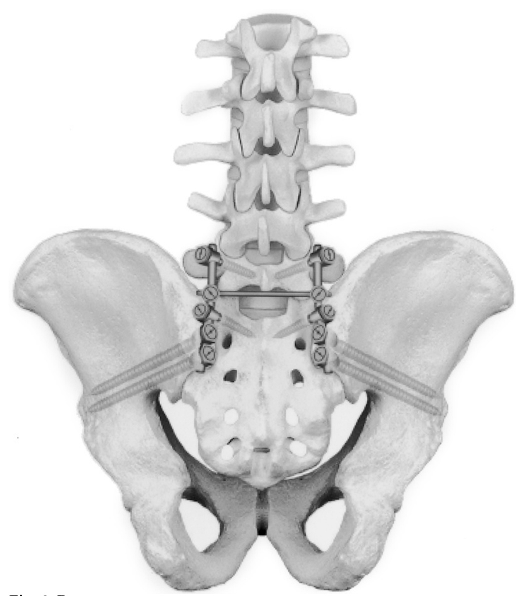

Fig. 3-B

Figs. 3-A and 3-B Technique of iliolumbar fixation. **Fig. 3-A** Following lumbar pedicle screw fixation, iliac screws are placed in a perpendicular trajectory parallel to the inclination angle of the outer table of the ilium. A suitable starting point is predictably located over the inferomedial aspect of the posterior superior iliac spinous process, with a trajectory leading 1 cm above the iliac notch. The anterior target area lies in the region of the anterior inferior iliac spinous process. Visualization of the outer iliac table and the sciatic notch as well as fluoroscopic guidance with a true lateral projection can be helpful technical aids. **Fig. 3-B** The final assembly, shown here with two iliac screws on either side, provides unparalleled stability.

Fig. 4-A

Figs. 4-A through 4-D Lumbosacral fracture fixation in a forty-eight-year-old woman who sustained multiple traumatic injuries. **Fig. 4-A** The patient was injured in a hang gliding accident. The multiple injuries included a closed head injury, blunt torso and abdominal injuries, an open tibial fracture, and the Denis zone-III, Roy-Camille type-2 sacral fracture shown here. The patient was found to have absent anal sphincter tone and to be areflexic. A computed axial tomography scan confirmed severe posterior disruption of the pelvic ring with foraminal compression of the S2 and S3 segments. Pudendal somatosensory evoked potentials confirmed the presence of a severe sacral plexus injury.

have included nearly all sacral fracture patterns. Contraindications to nonoperative care are relative but include fractures with soft-tissue compromise, an incomplete neurological deficit with objective evidence of neural compression, and extensive disruption of the posterior lumbosacral ligaments. Patients with multiple injuries often benefit from timely surgical intervention in order to facilitate rehabilitation[22]. However, we are not aware of any meaningful studies comparing the results of operative and nonoperative treatment.

Surgical Decision-Making

Surgical intervention for patients with a sacral fracture should incorporate clear and realistically attainable goals, including fracture stabilization and lumbosacral realignment, optimization of the chances for neurological recovery, adequate débridement of open injuries and compromised soft tissues, and minimization of additional morbidity.

Surgical options range from minimally invasive techniques to formal open reduction and internal fixation. Techniques for neural decompression include laminotomy and foraminotomy, anterior bone disimpaction, and lumbosacral plexus neurolysis. Anterior sacral and pelvic stabilization techniques involve various methods of anterior stabilization of the pelvic ring (e.g., application of a sacroiliac plate). Posterior stabilization techniques include percutaneous sacroiliac screw fixation, bilateral sacroiliac screw fixation with posterior tension-band plate fixation, posterior alar plate fixation, and lumbopelvic segmental fixation.

The timing of any surgical inter-

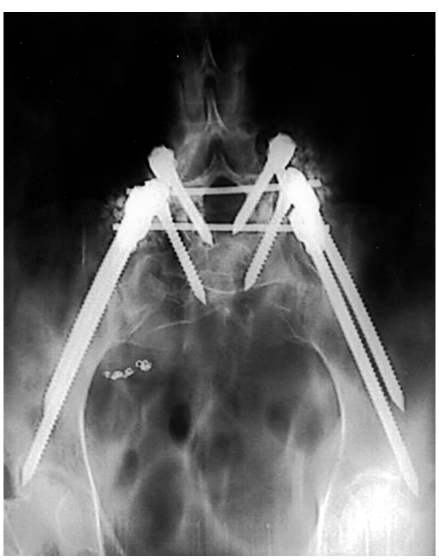

Fig. 4-B

Fig. 4-C

Fig. 4-D

After initial stabilization, posterior decompression and stabilization with lumbopelvic instrumentation was performed on the third day following the injury. At the time of writing, the patient was able to walk without pain and had recovered normal voluntary bowel and bladder control, but she reported diminished sexual function.

vention should be chosen on the basis of treatment goals, the patient's general medical status, and the invasiveness of the surgical procedure. Overly aggressive early surgery can lead to unacceptable intraoperative blood loss, soft-tissue breakdown, and infection[7]. On the other hand, delayed decompression of neural elements beyond two weeks may adversely affect chances for neurological recovery[2]. Most minimally invasive procedures require early closed reduction and are limited in terms of the amount of reduction that is attainable and the overall biomechanical stiffness of the construct. Ultimately, when the treatment is being chosen, the advantages and drawbacks of each approach should be carefully weighed; a stereotyped approach to all injuries should be avoided.

Decompression Techniques

Neurological injuries from sacral fractures range from incomplete monoradiculopathies to a complete cauda equina syndrome[3]. Sacral roots subjected to contusion, compression, or traction caused by angulation, translation, or direct compression have a theoretical chance of recovery. Neural recovery of transected or avulsed sacral nerve roots is unlikely.

Given an overall rate of neurological improvement of approximately 80% regardless of treatment, the indications for and timing of surgical decompression in patients with neurological injuries are somewhat controversial. From a neurophysiological standpoint, decompression of compromised neural elements is preferably performed early, within the first twenty-four to seventy-two hours following injury[5]. This can be accomplished indirectly with fracture reduction or directly with a laminectomy. Early surgical decompression may be associated with an increased risk of hemorrhage and wound-healing complications due to soft-tissue contusion and possibly to cerebrospinal fluid leak. Surgical decompression as an isolated procedure—i.e., without stabilization—is rarely indicated. Surgical decompression may be less useful in patients with transected sacral roots. Huittinen found a 35% prevalence of root transection in a postmortem study of transverse sacral fractures[23]. Similarly, reconstruction of nerve roots with avulsion injuries is currently impossible. Traumatically transected roots are commonly associated with Denis zone-III injuries with Roy-Camille type-3 displacement. Avulsions of the lumbopelvic plexus are associated with severely displaced zone-II injuries, such as the so-called vertical shear fracture. Surgery should be considered if there is a reasonable chance of restoring even unilateral lower sacral root function because such function is sufficient for voluntary bowel and bladder control[24].

An acceptable approach to early management of sacral injuries is an attempt at minimal reduction and stabilization. The adequacy of reduction is then assessed with computed tomography combined with repeat neurological and possibly electrodiagnostic examination to characterize persistent neurological deficits. In the presence of satisfactory skeletal stabilization but persistent neuroforaminal or spinal canal compromise, a focal limited decompression may be performed within the first two weeks after injury, with use of a limited midline exposure and fluoroscopy-guided focal laminectomy[6].

An attempt should be made to repair any dural tears that are encountered to minimize the chances of a pseudomeningocele developing. Patients presenting with a severely displaced fracture that is unsuitable for closed reduction and percutaneous stabilization should be considered for a comprehensive posterior decompression and stabilization procedure with use of the most appropriate stabilization methods available.

Surgical Stabilization Techniques

Stabilization of sacral fractures has evolved from largely improvised use of plates and hooks to the use of specifically designed implant systems incorporating cannulated long large-fragment screws or segmental lumboiliac rod-and-screw fixation systems[1]. A major goal of surgical intervention is to restore the stability of the lumbosacral articulation. Anterior approaches to the sacrum for decompression or internal fixation have substantial approach-related morbidity and provide limited surgical exposure. The vast majority of sacral injuries can be effectively treated with posterior percutaneously based approaches. The role of external fixation, once a popular form of treatment for a variety of pelvic fractures, is now limited to the emergent management of pelvic ring disruptions and to use as supplemental treatment devices for anterior pelvic ring instability.

The need for anterior stabilization of the pelvic ring should be considered before embarking on any posterior lumbosacral procedure. Frequently, the anterior pelvic ring injury can be realigned and stabilized through limited measures such as anterior plate fixation, external fixation, or the use of retrograde pubic screws. This can provide protection for the pelvic ring during a procedure performed with the patient prone and can aid in reduction of the posterior part of the pelvic ring.

Posterior fixation ideally offers a high degree of mechanical construct stiffness while producing a low implant profile that minimizes the risk of posterior soft-tissue breakdown. Sacroiliac screws, initially described for injuries of the sacroiliac joint, can be used for stabilization of a variety of sacral fractures as well (Figs. 2-A, 2-B, and 2-C). They can be placed, with the patient either supine or prone, with use of conventional c-arm imaging and through a percutaneous approach. The insertion of sacroiliac screws with the guidance of computed tomography imaging is of limited use: it is helpful only for the treatment of displaced fractures in a multiply injured patient. The safety of percutaneously placed sacroiliac screws has been established in several large clinical series and has gained considerable acceptance within the traumatology community[6,9,12]. Potential drawbacks of this technique include limited biomechanical strength, reliance on closed reduction techniques that may be inadequate, and lack of availability of a suitable image intensifier. Injury to neural, vascular, and intestinal structures as a result of drill or screw penetration has been described as a rare complication. The risks of this surgical technique primarily consist of loss of fracture reduction and fixation in a malreduced position. Percutaneous placement of sacroiliac screws may be contraindicated in patients with anomalous transitional lumbosacral anatomy or when closed fracture reduction cannot be accomplished[9]. Potential indications for percutaneous placement of sacroiliac screws include a Denis zone-I, II, or III sacral fracture, which can be adequately reduced in a closed fashion. Denis zone-III, Roy-Camille type-2, 3, or 4 injuries are less amenable to this form of fixation as a stand-alone device because of the inability to reduce these injuries by closed means. Similarly, fixation of highly displaced zone-II fractures (vertical shear injuries) with this method is very challenging. Zone-II fractures with segmental comminution are susceptible to overcompression and secondary foraminal entrapment when an iliosacral compression screw is used. Such injuries may be considered for fixation with two static sacroiliac screws or for iliolumbar segmental fixation[12].

Open reduction of the posterior aspect of the pelvic ring with plate fixation and screw insertion into the sacral ala, as described by Roy-Camille et al.[18], is an infrequently used strategy. The application of vertically aligned plates on the posterior aspect of the sacral ala with anteroposterior small-fragment screw fixation is also of limited value because of the frequent presence of comminution and osteopenia at the fracture site[1,18]. Use of a posterior iliac tension-band plate as a supplemental internal fixation method with sacroiliac screw fixation can facilitate open fracture reduction and enhance biomechanical stiffness[25]. However, it requires a posterior two-incision approach, which has been associated with an increased rate of wound-healing complications.

From a biomechanical perspective, the most stable method of lumbosacral fixation involves the use of lower lumbar pedicle screw fixation and iliac screw fixation with longitudinal and transverse rod connections to facilitate fracture reduction (Figs. 3-A through 4-D). The technique of iliac screw placement follows the basic concept of the Galveston technique but enhances it by allowing placement of multiple large bicortical screws[11].

Lumboiliac fixation allows complete neurological decompression as needed and can enhance the surgeon's ability to perform an open reduction of a displaced sacral vertebral body. Supplemental internal fixation can be achieved with sacroiliac screws to maintain fracture reduction while the lumboiliac fixation is applied. Because of the immediate stability conferred by lumboiliac fixation, most patients can walk with weight-bearing as tolerated without the use of a brace.

Results of Treatment

The results of the treatment of sacral fractures have been infrequently reported and often poorly documented. Aside from the retrospective multicenter study by Denis et al.[2], most studies have been of small cohorts and have had considerable selection bias. The severity of the neurological injury frequently is not quantified or differentiated. Surgical techniques and timing of intervention have been highly variable or not reported. Investigators assessing the efficacy of neurological decompression in patients with sacral fractures usually have not reported the severity or type of preoperative and postoperative neurological injury. Outcomes measures such as persistent pain and pelvic instability rarely have been evaluated in a systematic fashion.

Decompression Surgery

Establishing the benefits of decompression over a nonoperative approach in neurologically impaired patients is difficult. Neurological improvement rates of up to 80% are frequently quoted, regardless of the type of operative or nonoperative management.

In a retrospective study of forty-four patients, Gibbons et al. reported neurological improvement in eleven of fifteen patients treated nonoperatively compared with seven of eight patients managed surgically[21]. Four of six patients with loss of bowel and bladder control had improvement after nonoperative treatment compared with two of two patients treated surgically. Similarly, lower-extremity motor improvement was found in four of six patients treated nonoperatively compared with three of four treated surgically.

Denis et al. reported no improvement of bowel or bladder control in three patients in whom a transverse sacral fracture had been treated nonoperatively[2]. In contrast, all of five patients treated surgically had complete return of sphincter control. Fountain et al. noted improvement of bowel and bladder control in five patients treated surgically, whereas the one patient treated nonoperatively had spontaneous improvement[26]. Sabiston and Wing generally recommended nonoperative care in a series of thirty-five patients with a sacral fracture, and they found no improvement of bowel and bladder control in only one patient with a complete cauda equina syndrome who was treated nonsurgically[15].

Instrumentation Procedures

Nork et al. reported successful results of percutaneous sacroiliac screw fixation in thirteen patients with a Denis zone-III, Roy-Camille subtype-1 or 2 fracture and no substantial neurological deficit[12]. No deterioration of the sacral kyphosis angle was found despite the fact that the posttraumatic deformity was stabilized without aggressive attempts at reduction. In one patient, it was necessary to revise the hardware because of disengagement of a single iliosacral screw. Six patients presenting with L5 or S1 incomplete radiculopathy had a decrease in the symptoms without the need for neural decompression. On the basis of their experience, the authors recommended insertion of bilateral midline-crossing sacroiliac screws when the technique is used to treat a zone-III "H" or "U" fracture configuration.

Using a cadaveric model, Schildhauer et al. demonstrated that segmental lumbopelvic fixation provided substantially better stiffness than did a dual sacroiliac screw construct[11]. They reported clinically successful results of lumbopelvic fixation in their series of thirty-four patients with a vertically unstable zone-I or II fracture. Ninety-one percent of the patients were found to have fulfilled the authors' standards for a stable fracture union. They reported a 9% rate of complications, which consisted of wound-healing problems and a 3% prevalence of iatrogenic radiculopathy. With use of the same concept but a different implant configuration, Abumi et al. treated seven patients with a vertically and rotationally displaced zone-I or II pelvic ring injury with bilateral S1 screw fixation and a transverse rod connection attached to a Galveston-type rod extension into the ilium on the injured side[27]. Satisfactory healing was reported in six of the seven patients. Complications included one deep wound infection and one unresolved neurological deficit.

Overview

Assessment and treatment of thoracolumbar and sacral fractures has improved considerably as a result of advances in general trauma management and diagnostic modalities. Surgical techniques have evolved substantially over the past ten years as well. However, several basic issues, such as the appropriate roles of operative and nonoperative care, have not been resolved conclusively. The timing of intervention and the optimal surgical techniques need to be determined on an individual basis with the potential benefits of early neural decompression, skeletal stabilization, and patient mobilization weighed against the risks of surgery, such as blood loss, infection, and anesthesia-related complications.

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References

1. **Pohlemann T, Angst M, Schneider E, Ganz R, Tscherne H.** Fixation of transforaminal sacrum fractures: a biomechanical study. *J Orthop Trauma.* 1993;7:107-17.
2. **Denis F, Davis S, Comfort T.** Sacral fractures: an important problem. Retrospective analysis of 236 cases. *Clin Orthop.* 1988;227:67-81.
3. **Schnaid E, Eisenstein SM, Drummond-Webb J.** Delayed post-traumatic cauda equina compression syndrome. *J Trauma.* 1985;25:1099-101.
4. **Browner BD, Cole JD, Graham JM, Bondurant FJ, Nunchuck-Burns SK, Colter HB.** Delayed posterior internal fixation of unstable pelvic fractures. *J Trauma.* 1987;27:998-1006.
5. **Schmidek HH, Smith DA, Kristiansen TK.** Sacral fractures. *Neurosurgery.* 1984;15:735-46.
6. **Routt ML Jr, Simonian PT, Swiontkowski MF.** Stabilization of pelvic ring disruptions. *Orthop Clin North Am.* 1997;28:369-88.
7. **Kellam JF, McMurtry RY, Paley D, Tile M.** The unstable pelvic fracture. Operative treatment. *Orthop Clin North Am.* 1987;18:25-41.
8. **Tile M.** Pelvic ring fractures: should they be fixed? *J Bone Joint Surg Br.* 1988;70:1-22.
9. **Routt ML Jr, Nork SE, Mills WJ.** Percutaneous fixation of pelvic ring disruptions. *Clin Orthop.* 2000;375:15-29.
10. **Rommens PM, Vanderschot PM, Broos PL.** Conventional radiography and CT examination of pelvic ring fractures. A comparative study of 90 patients. *Unfallchirurg.* 1992;95:387-92.
11. **Schildhauer TA, Ledoux WR, Chapman JR, Henley MB, Tencer AF, Routt ML Jr.** Triangular osteosynthesis and iliosacral screw fixation for unstable sacral fractures. A cadaveric and biomechanical evaluation under cyclic loads. *J Orthop Trauma.* 2003;17:22-31.
12. **Nork SE, Jones CB, Harding SP, Mirza SK, Routt ML Jr.** Percutaneous stabilization of U-shaped sacral fractures using iliosacral screws: technique and early results. *J Orthop Trauma.* 2001;15:238-46.
13. **Letournel E.** [Surgical fixation of displaced pelvic fractures and dislocations of the symphysis pubis (excluding acetabular fractures) (author's transl)]. *Rev Chir Orthop Reparatrice Appar Mot.* 1981;67:771-82. French.
14. **Müller ME.** *Manual of internal fixation: techniques recommended by the AO-ASIF Group.* 3rd ed. New York: Springer; 1991.
15. **Sabiston CP, Wing PC.** Sacral fractures: classification and neurologic implications. *J Trauma.* 1986;26:1113-5.
16. **Gustilo RB, Anderson JT.** Prevention of infection in the treatment of one thousand and twenty-five open fractures of long-bones: retrospective and prospective analyses. *J Bone Joint Surg Am.* 1976;58:453-8.
17. **Tscherne H, Gotzen L, editors.** *Fractures with soft tissue injuries.* Berlin: Springer; 1984. p 1-58.
18. **Roy-Camille R, Saillant G, Gagna G, Mazel C.** Transverse fracture of the upper sacrum. Suicidal jumper's fracture. *Spine.* 1985;10:838-45.
19. **Strange-Vognsen HH, Lebech A.** An unusual type of fracture in the upper sacrum. *J Orthop Trauma.* 1991;5:200-3.
20. **Isler B.** Lumbosacral lesions associated with pelvic ring injuries. *J Orthop Trauma.* 1990;4:1-6.
21. **Gibbons KJ, Soloniuk DS, Razack N.** Neurological injury and patterns of sacral fractures. *J Neurosurg.* 1990;72:889-93.
22. **Latenser BA, Gentilello LM, Tarver AA, Thalgott JS, Batdorf JW.** Improved outcome with early fixation of skeletally unstable pelvic fractures. *J Trauma.* 1991;31:28-31.
23. **Huittinen VM.** Lumbosacral nerve injury in fracture of the pelvis. A postmortem radiographic and patho-anatomical study. *Acta Chir Scand Suppl.* 1972;429:3-43.
24. **Gunterberg B.** Effects of major resection of the sacrum. Clinical studies on urogenital and anorectal function and a biomechanical study on pelvic strength. *Acta Orthop Scand Suppl.* 1976;162:1-38.
25. **Simonian PT, Routt ML Jr.** Biomechanics of pelvic fixation. *Orthop Clin North Am.* 1997;28:351-67.
26. **Fountain SS, Hamilton RD, Jameson RM.** Transverse fractures of the sacrum. A report of six cases. *J Bone Joint Surg Am.* 1977;59:486-9.
27. **Abumi K, Saita M, Iida T, Kaneda K.** Reduction and fixation of sacroiliac joint dislocation by the combined use of S1 pedicle screws and the Galveston technique. *Spine.* 2000;25:1977-83.