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Management of C0 Sacral Fractures Based on the AO Spine Sacral Injury Classification

A Narrative Review

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Abstract: The Arbeitsgemeinschaft fur Osteosynthese fragen Spine Sacral Injury Classification hierarchically separates fractures based on their injury severity with A-type fractures representing less severe injuries and C-type fractures representing the most severe fracture types. C0 fractures represent moderately severe injuries and have historically been referred to as nondisplaced "U-type" fractures. Injury management of these fractures can be controversial. Therefore, the purpose of this narrative review is to first discuss the Arbeitsgemeinschaft fur Osteosynthese fragen Spine Sacral Injury Classification System and describe the different fracture types and classification modifiers, with particular emphasis on C0 fracture types. The narrative review will then focus on the epidemiology and etiology of C0 fractures with subsequent discussion focused on the clinical presentation for patients with these injuries. Next, we will describe the imaging findings associated with these injuries and discuss the injury management of these injuries with particular emphasis on operative management. Finally, we will outline the outcomes and complications that can be expected during the treatment of these injuries.

Key Words: AO trauma, AO spine, sacral fracture, injury management, transiliac-transsacral, screws, triangular osteosynthesis

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C0 injuries represent nondisplaced "U-type" sacral fractures as defined by the Arbeitsgemeinschaft fur Osteosynthese fragen (AO) Spine Sacral Injury Classification System. C0 fractures can be thought of as a spinopelvic dissociation injury leading to potential separation of the spine from the pelvis, but by definition, there is minimal fracture displacement. These lesions are most often osteoporotic insufficiency fractures, but post radiation therapy or other metabolic bone diseases may also predispose patients to these injuries after a low-energy trauma mechanism.[1]

As many C0 fractures are spontaneous or due to low-energy trauma, there is debate on the optimal management of these injuries. This is likely partially attributable to previous fracture classifications, which have been

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descriptive, but have failed to consider both fracture stability and potential-associated neurological injury when classifying injuries.[2] Historically, the Denis fracture classification (Fig. 1) has been the most widely used system because of its ease of categorization and its ability to give a rough estimate of the likelihood of neurological impairment based on the injury's location in relation to the neuroforamen.[2] However, this injury classification lacks the ability to guide fracture management. Recently, Lehman et al[3] created the lumbosacral injury classification system (LSICS) based on sacral fracture characteristics (kyphotic deformity, fracture comminution and displacement, and neuroforaminal encroachment), neurological status, and associated injury to the posterior ligamentous complex (Fig. 2). This system allowed the assignment of numerical grades to the injury, which in theory, would guide treatment toward operative versus nonoperative management. However, this classification system lacks subsequent validation studies by an independent party, and it has not gained widespread adoption.

The recent development of the AO Spine Sacral Injury Classification characterizes sacral fractures based on type to determine injury morphology, with neurological status and patient-specific injury modifiers to help guide management.[1] Adoption of a singular classification system may allow for improved understanding of specific injury patterns, including C0 fractures. The goals of the narrative review are to describe the AO Spine Sacral Injury Classification System, the epidemiology and etiology of C0 fractures, their typical clinical presentation and imaging findings, and the appropriate management and common complications of these injuries.

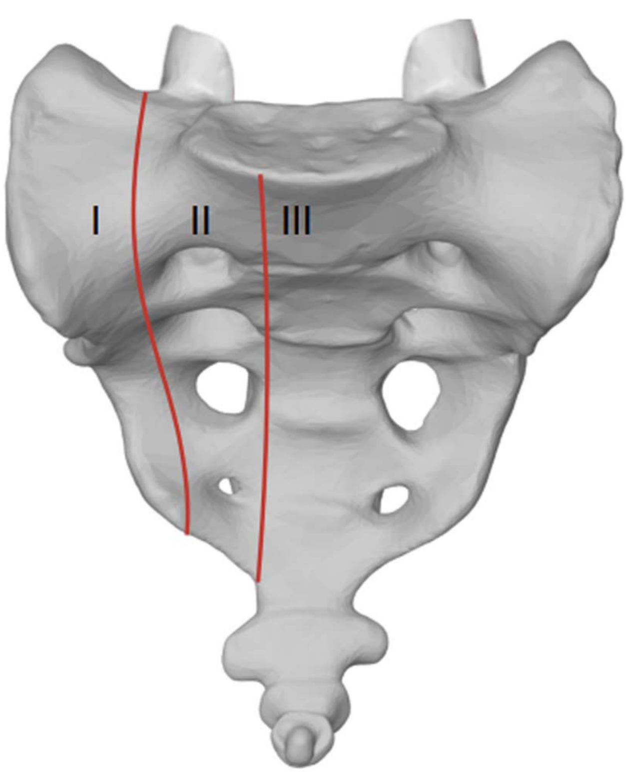

FIGURE 1. Demonstration of the Denis Classification, which is based on fracture location in relation to the neuroforaminal. full color online

CLASSIFICATION

The AO Spine Sacral Injury Classification System (Fig. 3) categorizes fractures based on their morphology (types A, B, or C) and specific fracture characteristics (0, 1, 2, or 3) to provide a simple and comprehensive classification system encompassing all fracture types in a hierarchical manner to aid in management.[4]

Fracture Type and Characterization

Fracture type (morphology) is characterized by injuries located in the lower sacrococcygeal region (type A), posterior pelvis (type B), or spinopelvic region (type C), with type C injuries being the most potentially unstable and typically requiring surgical fixation. Type A injuries are fractures caudal to the sacroiliac (SI) joints and, A1 is defined as an avulsion or coccygeal injury, A2 as nondisplaced transverse fracture , and A3 as displaced transverse fractures. Given that all these injury types are located below the SI joint, they have no effect on pelvic or spinopelvic stability.

Type B injuries are longitudinal fractures without a horizontal component. Fractures meeting these criteria medial to the neuroforamen are B1 injuries, transalar fractures lateral to the neuroforamina are B2 injuries, and fractures involving the neuroforamina are B3 injuries.

Type C fractures are spinopelvic injuries where the connection between the spinal column and the pelvic ring is compromised. A C0 fracture is a nondisplaced U-type sacral fracture, C1 injuries are sacral U-type variants with intact posterior pelvic stability, C2 injuries are bilateral complete type B fractures without a horizontal component, and C3 injures are displaced U-type sacral fractures.

Neurological Status

The neurological classification is universal throughout all AO Spine Injury Classification Systems. Neurologically intact patients are designated as N0, transient neurological deficits are categorized as N1, patients with radicular symptoms only are given a status of N2, patients with incomplete spinal cord injury or cauda equina syndrome are defined as N3, complete spinal cord injuries are labeled as N4, and patients who cannot be examined are designated as NX. For the sacral injuries, it is not anatomically possible to sustain an N4 injury so all complete or incomplete neurological injuries are classified as N3.

Clinical Modifiers

There are 4 clinical modifiers in the sacral injury classification system:

(1) M1: soft tissue injuries
(2) M2: patients with metabolic bone disease
(3) M3: anterior pelvic ring injuries
(4) M4: SI joint injuries

Morphology Type	Points
Flexion compression	
I. ≤ 20 degrees kyphosis	1
II. ≥ 20 degrees kyphosis	2
Axial comminution (upper sacral only)	
I. Without canal or foraminal encroachment	2
II. With canal or foraminal encroachment	3
Translational or Rotational Injury	3
Blast Injury →Severe Comminution or Segmental Bone Loss	4
Posterior ligamentous Complex	**Points**
Intact	0
Indeterminate	1
Disrupted	2
Neurologic Status	**Points**
Intact	0
Only Parasthesias	1
Motor Deficit	2
Bladder/Bowel Deficit	3
Progressive Neurologic Deficit	4

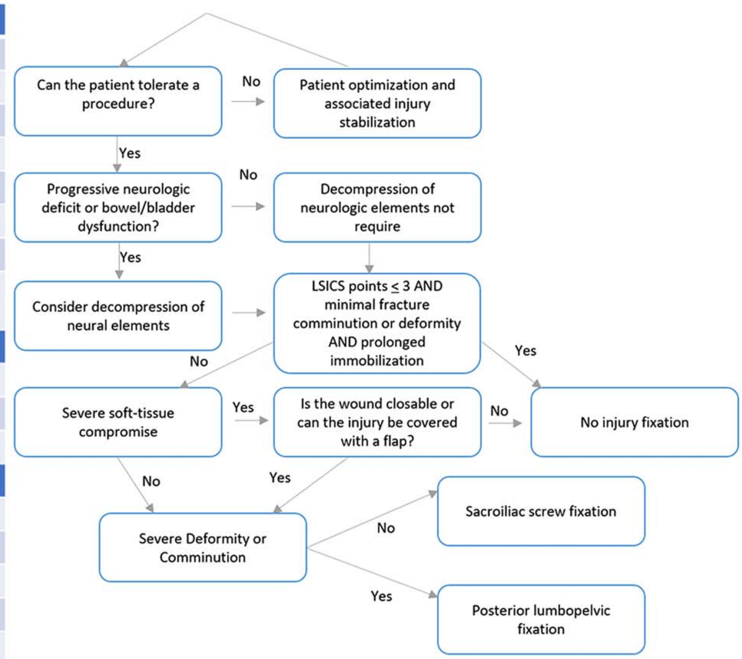

FIGURE 2. Lumbosacral Injury Classification scoring system and flowchart algorithm for determining management of sacral fractures. Image adapted from Lehman et al.[3] Adaptations are themselves works protected by copyright. So to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation. full color online

Validity of the Classification System

The validity of the AO Spine Sacral Injury Classification System was established by Vaccaro and colleagues and was found to have excellent intraobserver reproducibility for identifying type A, B, or C injuries ($\kappa = 0.83$) with substantial reproducibility in determining fracture subtypes (0, 1, 2, or 3) ($\kappa = 0.71$).[3] The interobserver reliability was also substantial ($\kappa = 0.75$). The AO Spine Sacral Injury Classification System subsequently underwent validation by an independent group of 6 fellowship-trained spine surgeons. Intraobserver reproducibility for fracture stability ($\kappa = 0.69$) and fracture characteristics ($\kappa = 0.61$) were substantial. The interobserver reliability was also substantial for type A, B, and C injuries ($\kappa = 0.68$), whereas fracture subtype reliability (0, 1, 2, or 3) was moderate ($\kappa = 0.52$).[5]

EPIDEMIOLOGY

Insufficiency fractures of the sacrum, including C0 fractures, remain challenging to diagnose, which may contribute to the paucity of studies examining the true incidence of these injuries. Because of the low-energy mechanism of injury in the geriatric population, these fractures are occasionally identified in the clinical setting instead of the emergency department. Female patients over 55 years of age presenting with a history of low back pain were found to have a sacral insufficiency fracture 1.8% of the time in the clinical setting.[6] Furthermore, in a study of patients being evaluated for possible pelvic fractures at a trauma center, 4.4% of those who underwent computed tomography (CT) scan were found to have a sacral insufficiency fracture.[7] Therefore, in both the clinical and trauma setting, a high index of suspicion for sacral fractures is warranted in the geriatric patient with posterior pelvis or low back pain.

As with many orthopedic injuries, the distribution of spinopelvic dissociative fractures is bimodal, with younger patients more likely to sustain high-energy trauma and old or osteoporotic patients more likely to sustain low-energy mechanism injury. AO Spine Classification "type C" injuries make up 2.9% of pelvic ring disruption fractures.[8] However, "type C" fractures can be accompanied by a high rate of distracting injuries or degenerative conditions leading to a delay in fracture diagnosis.[9]

The incidence of neurological injury or irritation leading to radiculopathy in C0 fractures is currently not well defined. It is important to note, however, that the lack of fracture displacement in C0 fractures does not preclude neurological injury. The rate of neurological injury in the setting of all type C sacral fractures has been reported to range from 33% to 100%,[10] whereas high-energy U-type fractures are believed to have a 94% prevalence of neurological injury with varying levels of neurological recovery.[11] Although true C0 fractures that are not displaced should not be associated with a neurological injury, care must be taken, as delayed or progressive displacement can lead to catastrophic neurological injuries.

ETIOLOGY

The sacrum is the mechanical keystone of the axial skeleton serving as both the base of the spine and posterior

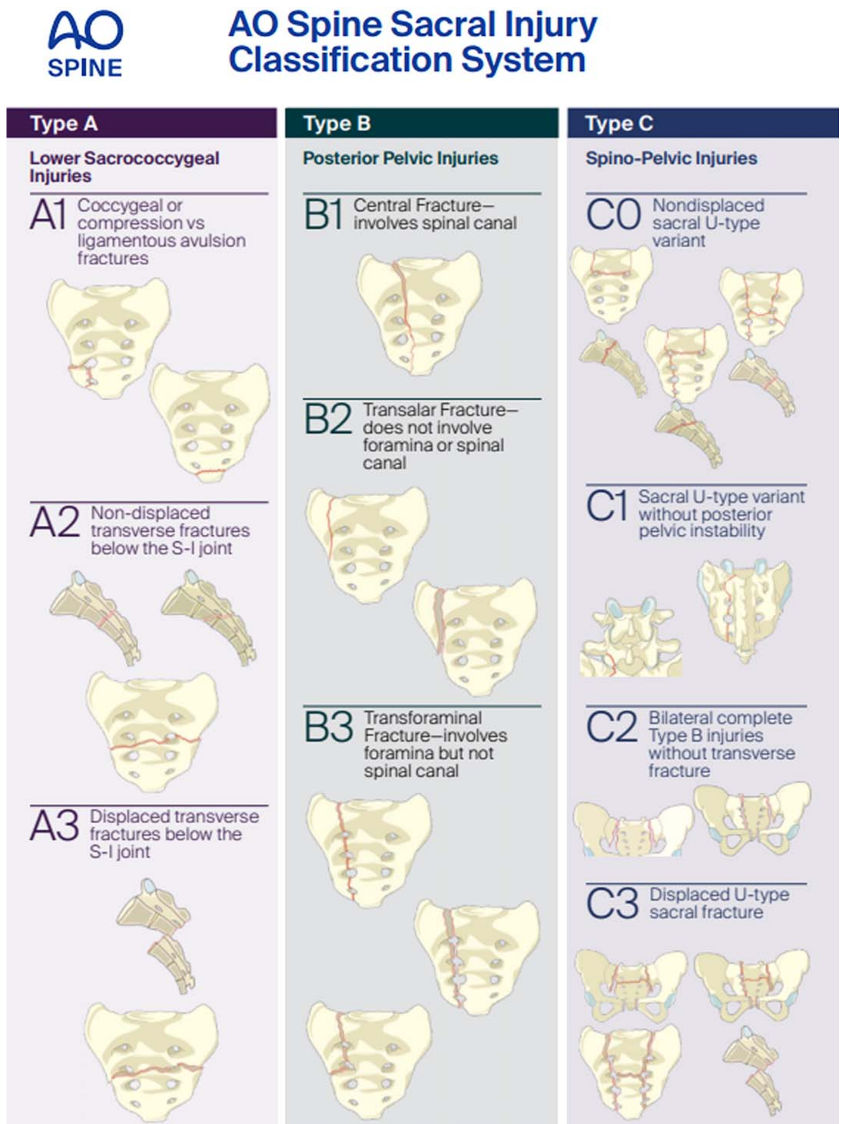

FIGURE 3. Pictorial representation of the AO Spine Sacral Injury Classification System. Permission to use this image was granted by the AO Foundation©, AO Spine, Switzerland. full color online

aspect of the pelvic ring. Nondisplaced sacral insufficiency fractures are typically caused by a combination of diminished sacral bone mineral density and decreased compliance of the adjacent SI joints. The SI joint accommodates torsional stress that is produced as a result of hip flexion and extension during normal gait. As the SI joint becomes less compliant, torsional stress is offloaded to the sacrum. In combination with the axial load of the spinal column, this torsional stress can result in a sacral fracture.[2] Finite element analysis has demonstrated stress imparted during ambulation mimics where sacral stress fractures most commonly occur. Failure through these high-stress zones during walking results in vertical fractures, as the highest stress is concentrated horizontally and typically results in the "H"-shaped or "U"-shaped fracture pattern.[12] Pathologies associated with diminished bone quality leading to sacral insufficiency fractures include osteoporosis, steroid-induced osteopenia, pelvic radiation, and rheumatoid arthritis.[13–15]

Alternatively, C0 insufficiency fractures can be late complications after lumbar arthrodesis. Typically, patients with this complication have a multilevel lumbar or thoracolumbar fusion averaging more than 4 levels.[16] One of the leading theories for the occurrence of this late complication postulates that osteoporosis is magnified by the altered structural integrity of the spinal column.[16] The C0 variant fracture thus occurs as a result of altered spinal biomechanics due to sagittal malalignment of the lumbar fusion.[17] Because of the long lever arm cranial to the fracture, these C0 fractures are at increased risk for instability and typically benefit from extension of the fusion construct to the level below the transverse component of the fracture.[18] The addition of iliac bolts or S2 alar-iliac (S2AI) fixation may provide for added stability when the fracture occurs because of sagittal malalignment.[16]

CLINICAL PRESENTATION

The diagnosis of type C0 sacral fractures can be missed or delayed because of difficulty imaging the superior portion of the sacrum and the nonspecific symptoms in the setting of the insufficiency fracture.[19,20] Patients with spinopelvic dissociation-type injuries that go unrecognized are at risk for progressive neurological dysfunction and subsequent kyphotic deformity.[19,21] Therefore, a high index of suspicion should be held for any patient with lower back and/or sacrococcygeal pain with an associated pelvic ring or spinal fracture.

Sacral fractures are uncommon in isolation with most sacral fractures having an associated anterior pelvic ring injury.[22] As most insufficiency fractures occur with no trauma or minimal trauma, the most common type of associated pelvic ring injury is a nondisplaced pubic or ischial rami fracture. These can involve a unilateral (ipsilateral or contralateral) or bilateral pubic and ischial rami fracture and are often associated with groin pain.[23]

However, patients with an osteoporotic/insufficiency C0 sacral fracture may present solely with posterior pelvis or sacral pain after minor trauma. As previously described, ambulation is likely one of the most frequent causes of C0 sacral fractures and only one third of these patients have a known history of trauma.[24] The most common clinical presentation for these patients is low back pain with pseudoradicular pain in their legs.[25] In patients with isolated pubic or ischial rami fractures identified on radiographs, the presence of concomitant low back pain should raise suspicion for an associated sacral fracture.[26] These fractures typically lack the neurological complications associated with their displaced variants, but inadequate treatment may lead to eventual displacement.[19]

IMAGING DIAGNOSIS

Although plain radiographs are often the first step taken in the evaluation of patients presenting with sacral fracture, it has limited utility in the diagnosis of C0 sacral fractures. In the high-energy trauma setting, standard AP, inlet, outlet, and lateral views can be taken if a sacral or pelvic fracture is suspected. These same views should be taken in the setting of a suspected insufficiency fracture, with the likely addition of lumbar AP and lateral radiographs if low back pain is the presenting symptom. Whereas displaced lumbopelvic dissociations may be visible on lateral view radiographs, the C0 variant can be obscured (or not visible due to its lack of displacement) by the relatively cephalad location of the fracture and superimposed ilia.[27] In the original description of spinopelvic dissociation by Roy-Camille,[28] the lateral projection was noted for its importance in recognizing displacement and kyphotic deformity. Insufficiency fractures of the sacrum generally appear on plain radiographs as a sclerotic band with ill-defined borders.[29] Given the association of anterior pelvic fractures with concomitant sacral fractures, it is recommended to obtain a CT scan of the pelvis in patients with pubic or ischial rami fractures.[30]

The sagittal CT reconstruction has previously been shown to be the most sensitive imaging modality for the recognition of nondisplaced or minimally displaced sacral fractures.[27] Patients without identifiable fractures on radiographs, in which there is a high clinical suspicion for sacral fracture, should undergo advanced imaging with either CT or magnetic resonance imaging (MRI). In osteoporotic patients in which bilateral vertical ala fractures are identified, sagittal CT reconstructions should be examined for an occult transverse fracture component to identify the C0 fracture type. In a study reviewing the International Classification of Diseases ninth revision codes to identify sacral fractures, 87% of patients with bilateral vertical sacral fractures were also found to have a transverse component and lumbopelvic dissociation.[31] Another study found that CT was 60%–75% sensitive for the detection of sacral fragility fractures in patients with a high clinical suspicion.[32]

The role of MRI in the diagnosis of sacral fractures is a topic of recent debate. In the acute high-energy injury setting, CT is the preferred modality for diagnosis. However, MRI has an evolving role in the diagnosis of occult insufficiency and sacral stress fractures.[28] In some insufficiency fracture patterns, in which minimal fracture displacement is present, it may be difficult to detect a fracture on CT scans (Figs. 4A, B). In these patients, MRI demonstrates hyperintensity at the fracture site on T2 and short-tau inversion recovery weighted images representing post-traumatic bone hemorrhage (Fig. 4C).[33] Furthermore, MRI has previously been reported to have a 100% sensitivity in the detection of sacral fractures.[32] Patients with a combination of an unidentifiable fracture on radiographs, chronic low back or pelvis pain with point tenderness, and a limited ability to mobilize may be indicated to receive an MRI instead of a CT scan.[30]

MANAGEMENT

Nonoperative

Few studies exist specifically examining the management of C0 sacral fractures. Historically, low-energy, nondisplaced sacral fractures were treated with prolonged bed rest to allow fracture healing.[34] However, drawbacks of prolonged bed rest outweigh the benefits, as early mobilization helps avoid devastating complications such as decubitus ulcers, deep vein thrombosis, urinary tract infections, and pneumonia.[35] As a result, the focus of nonoperative treatment for these injuries has shifted to early physical therapy and mobilization of patients with assistive devices and analgesia as needed.[34] The sacral U-type fracture, regardless of displacement, is, by definition, a spinopelvic dissociation that is inherently unstable due to sagittal deforming forces at the spinopelvic junction. Patients treated with early mobilization may experience significant pain, fracture displacement with progressive kyphotic deformity, inability to ambulate, and neurological dysfunction,[36,37] whereas expedient operative intervention facilitates early mobilization and decreases associated morbidity and mortality rates.[8,38–40]

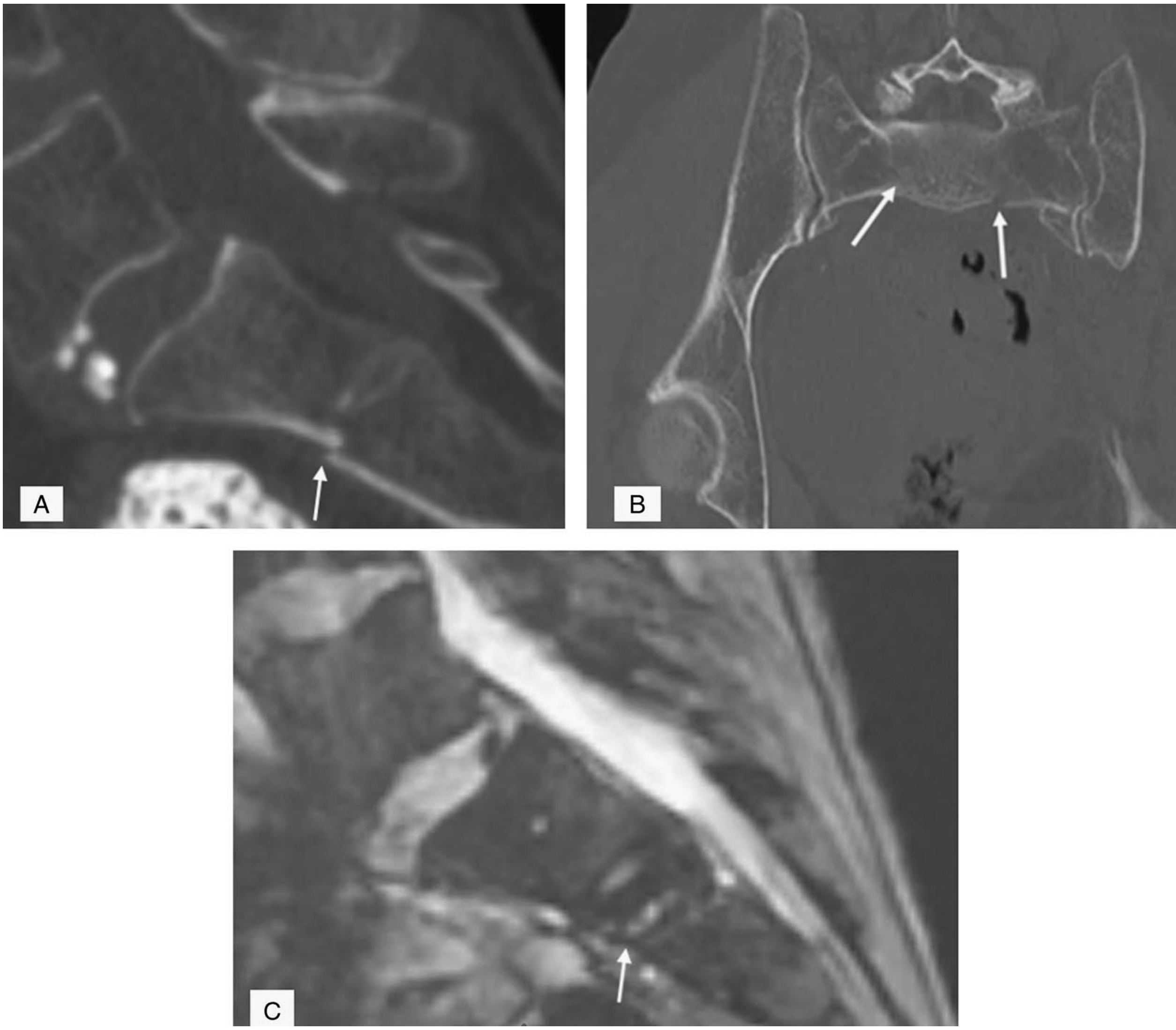

FIGURE 4. A, Sagittal view of the lumbosacral spine with evidence of anterior sacral cortical disruption demonstrating an acute C0 fracture. White arrow is pointing to the transverse component of the fracture, which is better visualized on the sagittal view. B, Coronal view of the sacrum demonstrating the vertical components of the C0 or nondisplaced "U" variant sacral fracture. The white arrows depict the vertical components of the fracture. C, The horizontal component of the fracture is best visualized on the sagittal view of the T2-weighted magnetic resonance imaging and is characterized by the bony hemorrhage.

As there is a paucity of literature examining outcomes after operative or nonoperative management in C0 fractures, the appropriate management of these fractures continues to have no clear answer. The LSICS and the current AO Spine Sacral Injury Classification System are designed to help guide the management of these "controversial" injuries. On the basis of the LSICS classification, C0 injuries with an intact (or indeterminate) posterior ligamentous complex without neurological deficit and minimal fracture comminution can be considered for nonoperative management.[2] In addition, nonoperative management may be indicated in patients whose medical comorbidities make an operative procedure prohibitive or those with concomitant bilateral lower extremity injuries that will require an extended period of immobilization.[2] However, even in these instances, the patient may be unable to sit comfortably because of injury instability, and the benefits of surgical fixation may outweigh the risks.

An additional tool for guiding the management of sacral fractures is the fragility fracture of the pelvis (FFP) classification.[23] This classification divides injures into 4 types: (1) anterior pelvic ring only injuries; (2) nondisplaced posterior pelvic ring injuries with or without associated anterior pelvic ring injuries; (3) displaced unilateral posterior pelvic ring injuries with or without associated anterior pelvic ring injuries; and (4) bilateral displaced posterior ring injuries. By definition, C0 fractures are classified as type 2 injuries. The fragility fracture of the pelvis classification recognizes that conservative management can be attempted for these fractures, but they specify that these injuries are at moderate risk of instability, especially when combined with anterior pelvic ring fractures.[23] Therefore, this classification recommends close observation during conservative management with early conversion to surgical stabilization if concern for increasing stability exists.[23] If fracture displacement occurs, the injury progresses to type IV where spinopelvic instrumentation is recommended. Therefore, treatment of the C0 fracture remains controversial, especially when associated with anterior pelvic ring injuries.

How Are Neurological Injuries Managed and Do They Change the Surgical Approach?

In the vast majority of patients with minimally displaced insufficiency or stress fractures, patients are neurologically intact. Scrupulous evaluation of the MRI and/or CT scan may suggest whether nerve root irritation is due to periosteal bone reaction or whether the radiculopathy was caused by fracture impingement on the neuroforamen.[41,42] Regardless, the radiculopathy often resolves with nonoperative management.[41,42] In instances where nonoperative management alone fails, these injuries meet the indication for surgical decompression via sacral laminectomy, which can be performed through a posterior midline approach. If the fracture is otherwise stable, decompression alone is sufficient, but if any concern for fracture instability persists during the decompression, then additional stabilization of the fracture is recommended. However, it should be noted that in the rare instances where conservative management alone is insufficient for neurological recovery, the potential for full postoperative nerve recovery is poor.[43]

Sacroplasty

Sacroplasty is a newer percutaneous technique for the management of sacral insufficiency fractures including the C0 variant. The technique consists of injecting polymethyl methacralate cement into the fracture site to improve stability. Sacroplasty has been found to improve immediate postoperative mobility and pain in the 1-day, 1-month, 3-month, and 2-year postoperative periods.[44,45] Additional benefits to this technique include the reduction in postoperative disability and diminished postoperative opioid reliance.[45]

A meta-analysis evaluating the safety and efficacy of sacroplasty found that the rate of cement leakage was 2.2%, but as most patients were asymptomatic or had resolution of their symptoms with medical management, the overall major complication rate was only reported to be 0.3%.[46] However, each patient with recalcitrant radicular symptoms required surgical decompression of the cement extravasation.[46] It is worth noting that there is currently poor evidence to determine whether sacroplasty is a reliable option for C0 sacral insufficiency variants, but it does appear to hold promise as a way to minimize pain in patients having trouble with conservative fracture management.

Transiliac-transsacral Screw Fixation

Transiliac-transsacral screw fixation is a common technique for the treatment of nondisplaced sacral U-type fractures with minimal fracture comminution because of its relatively low patient morbidity compared with larger more invasive procedures.[34,36,47,48] Intraoperative images of this technique are depicted in Figure 5. Screw placement via this technique allows for the stabilization of C0 fractures through a minimally invasive approach. The patient is typically positioned supine with a bump placed under the sacrum, which in displaced injuries will promote lordosis. Even though C0 fractures are nondisplaced, the sacral bump is still recommended to improve transiliac-transsacral screw corridor access.[49] Alternatively, in patients presenting with a C0 fracture but with subsequent displacement during intraoperative positioning, placement of pillows under the thigh may allow for increased pelvic extension and reduction of the fracture.[50]

Placement of transiliac-transsacral screws involves crossing the ipsilateral ilium, SI joint, the S1 or S2 bodies and contralateral SI joint, and lastly exiting the contralateral ilium.[47] Screws that traverse both SI joints have demonstrated superior fixation strength to screws that only cross 1 joint and this technique is generally preferred.[51,52] In patients with sacral dysmorphism, this may dictate placement of transiliac-transsacral screws across S2 due to an enlarged screw corridor compared with S1.[53,54] Alternatively, bilateral screws traversing 1 SI joint into the body of S1 or S2 may be employed depending on the fracture and sacral morphology.[36] However, S1 or S2 corridor utilization is dependent on the fracture site; if the fracture is at S1, then screws traversing the S2 corridor will provide no benefit for fracture stabilization, and triangular osteosynthesis should be considered as optimal treatment in surgical patients.

Preoperative planning is essential to map out the trajectory of safe screw placement, and thus preoperative CT scan of the pelvis is often a prerequisite to surgery as this will determine whether the patient has sacral dysmorphism and the operative corridors available for instrumentation. Illiosacral screws or S2 transiliac-transsacral screws mitigate the risk of nerve root injuries in these patients if the U component and corresponding corridor is amenable for placement of an S2 screw.[35] Preoperative advanced imaging can also identify lumbarization of S1 or sacralization of L5 that can complicate screw placement.

Limited data exists to definitively support the optimal number of screws for the fixation of sacral U-type fractures, although 2 points of fixation are commonly preferred in the upper sacral segment to mitigate sagittal/rotational deforming forces.[8,37,48] In addition, C0 fractures may be stabilized with either partially threaded or fully threaded screws.[48] In the setting of good bone quality and a simple fracture pattern, cannulated partially threaded screws are often employed because of the ease of use, although care should be taken not to excessively compress through fracture, which may cause foraminal stenosis or entrapment of the exiting nerve root within the fracture, particularly with osteopenic bone. Fully threaded screws are often used in patients with poor bone quality or comminution because of their superior biomechanics compared with partially threaded screws in unstable fractures.[55]

Despite the adequate preoperative preparation and intraoperative fluoroscopy, unintended extraosseous placement

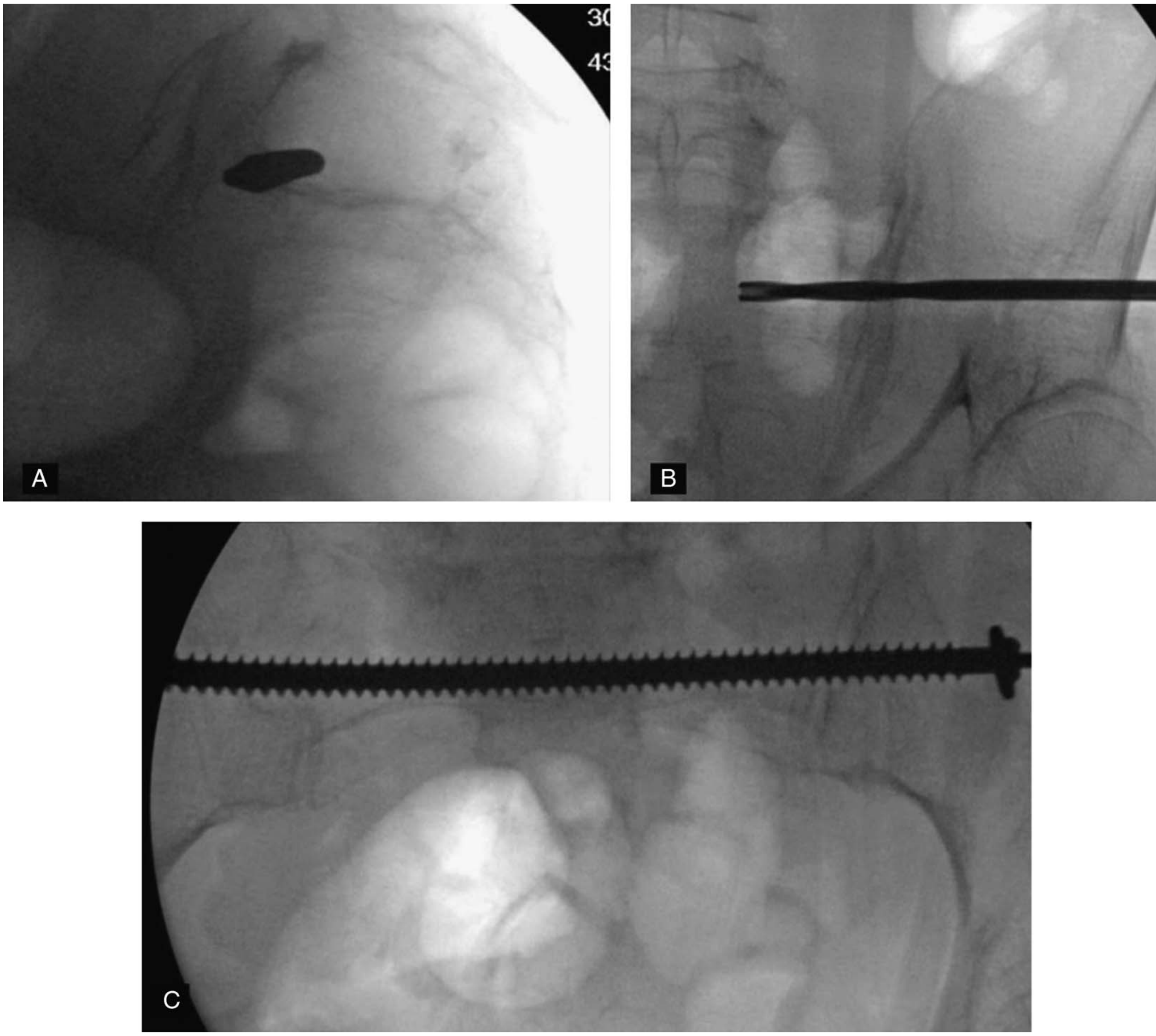

FIGURE 5. A, Intraoperative fluoroscopic image of the drill bit located with the S1 body on a lateral view of the pelvis. B, Pelvic outlet image of the drill bit demonstrating <50% penetration across the sacrum. The left S1 neuroforamen can be visualized just caudal to the drill bit indicating appropriate location of the drill bit outside the foramen. Combined with the image in 4A, the image in 4B allows the surgeon to be confident they are within the bony corridor of S1 without penetration of the neuroforamen. C, AP image demonstrating a postoperative transiliac-transsacral screw.

of iliosacral screws can occur. This can cause damage to neural or vascular contents of the pelvis. In particular, the L5 nerve root that courses anterior to the sacral ala is at risk during the placement of screws at the S1 level.

Spinopelvic Fixation/Triangular Osteosynthesis

Triangular osteosynthesis combines spinopelvic and SI fixation and is often used to increase construct stiffness. The technique involves the placement of a transiliac-transsacral screw with subsequent pedicle screw placement at L4 and L5 and bilateral iliac bolts (Fig. 6). Theoretically, this offloads the sacrum and allows for the transfer of axial and rotational forces from the lumbar spine to the pelvis. Biomechanical studies have demonstrated triangular osteosynthesis minimizes macroscopic motion at the fracture site to a greater degree than SI fixation alone when the constructs were cyclically loaded to simulate early weight-bearing and mobilization.[56] However, there is now growing evidence that S2AI fixation is superior to iliac bolts. A recent meta-analysis supported S2AI screws as an option to minimize revision surgery due to mechanical failure and wound complications (14.2% vs. 27.9%, $P<0.001$), decrease the rate of infections (2.6% vs. 25.4%, $P<0.001$), and minimize screw prominence (1.8% vs. 18.1%, $P<0.001$) when compared with iliac bolts.[57]

Compared with transiliac-transsacral screws, triangular osteosynthesis is also biomechanically superior at tolerating anteflexion, and rotational forces indicating this technique may be superior in highly unstable injuries or in

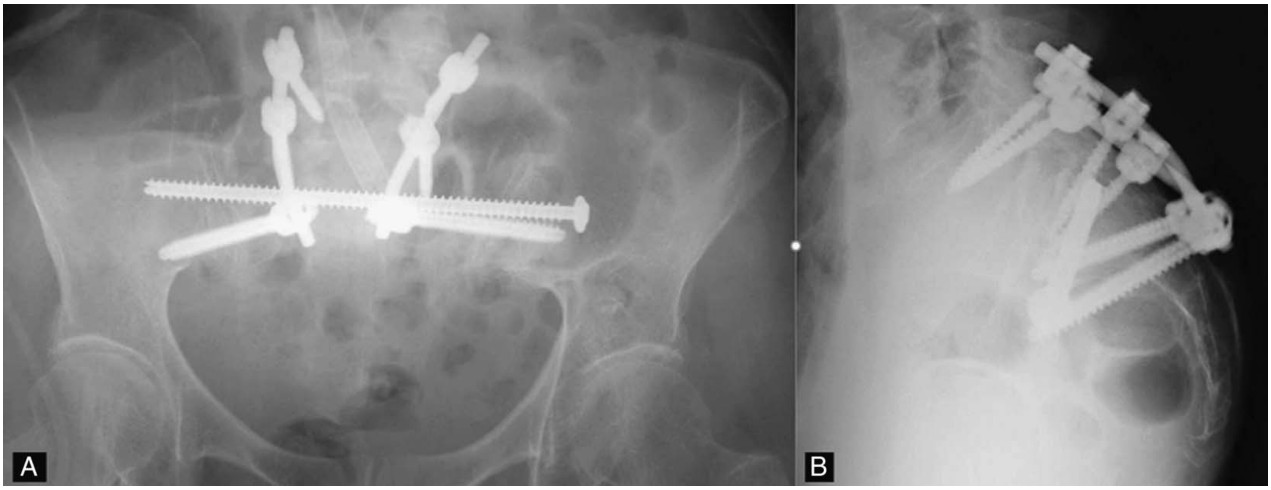

FIGURE 6. A, Postoperative AP image of a triangular osteosynthesis construct for a C0 fracture demonstrating the utilization of a transiliac-transsacral screw and lumbopelvic fixation with iliac screws. B, Lateral radiograph of the triangular osteosynthesis construct. AP indicates anterior-posterior.

patients where the physician is concerned about future fracture displacement.[58] It has been suggested that triangular osteosynthesis is also more useful in the setting of sacral comminution, poor bone quality, or neurological dysfunction.[59] Historically, this technique was significantly more invasive than isolated transiliac-transsacral screws, with higher rates of blood loss, as well as wound and instrumentation complications. However, this technique can be employed through a minimally invasive technique to mitigate the above complications and minimize injury to the surrounding soft tissues.[60] Even with a minimally invasive technique, patients may report persistent discomfort due to iliac screw prominence.[61] Currently, minimal evidence is available to support the use of this technique compared with percutaneous screw fixation in C0 fractures, but as the prevalence of osteoporosis increases with the aging population, utilization of percutaneous triangular osteosynthesis may optimize fracture stability, whereas minimizing complications associated with an open procedure.[36,48]

S2AI Instrumentation Technique

Instrumentation for S2AI screw fixation can be percutaneous or open, but involves entry for the S2 screw 1 mm lateral and 1 mm distal to the S1 neuroforamen (this is both medial and inferior to the iliac bolt entry point, which utilizes the posterior superior iliac spine as the landmark for entry).[62,63] The S2 screw should align with the S1 screw, and burring of the sacral cortical wall should aim toward the SI joint. This allows the screw to be placed intraosseous within the iliac wing, with screw angulation ~30 degrees anterior and 20 degrees caudal to the entry point.[63] A gearshift is used to find the appropriate tract within the sacrum keeping in mind appropriate orientation anteriorly and caudally. After breaching the SI joint, cortical resistance will be appreciated before crossing into the ilium. After crossing into the ilium, a probe can confirm the gearshift tract remained intraosseous, otherwise the gearshift needs to be redirected. Undertapping of the gearshift tract will maximize screw purchase. After screw placement, fluoroscopic images or intraoperative CT must be taken to confirm the screws are adjacent, but superior to the sciatic notch and remained intraosseous.[63] This location will maximize screw purchase, while minimizing complications.

Alternatively, navigation can be used to maximize the accuracy of screw placement during iliac and S2AI fixation. Preoperative CT scans with multiplanar reconstruction can be used to optimize surgeon orientation during screw placement.[64] For orientation purposes, usually both the gearshift and screwdriver are linked to a monitor, which provides instantaneous feedback to the surgeons on their screw or gearshift trajectory.[64] Although there are limited comparisons to freehand techniques, navigation has high accuracy rates with 83% of S2A1 screws within 5 degrees of the intended angulation in the axial and sagittal plane.[64] Navigation has also proven highly successful for ideal iliac bolt placement, while also limiting intraoperative fluoroscopic examination and surgical exposure requirements.[65]

Authors' Preferred Treatment

In most instances, C0 fractures can be managed nonoperatively with progressive mobilization with a physical therapist. Although injuries with radiculopathy are more controversial, these can also be treated with expectant management, as most cases of radiculopathy resolve with time. For the remaining cases where C0 fractures inhibit mobilization, treatment with percutaneous spinopelvic fixation (either iliac bolts or S2AI screws) are the preferred option to maximize construct stability, while also minimizing trauma to the surrounding tissues.

OUTCOMES/COMPLICATIONS

Studies focused on outcomes specifically related to the management of sacral type C0 fractures are limited. A retrospective study of 19 patients with low-energy, U-type sacral insufficiency fractures demonstrated nonoperative treatment with analgesics, nutritional optimization, progressive weight-bearing, and physical therapy failed in 10 of 12 patients because of worsening posterior pelvic pain and progressive kyphotic fracture deformity. Six patients had significant pain on presentation with an inability to ambulate so they underwent early operative intervention. The lone remaining patient had a U-type fracture nonunion after inadequate treatment at a different hospital.[37] Of the 12 patients originally treated nonoperatively, 2 did not follow up and the remaining 10 patients were all ultimately treated operatively at an average of 83 days post injury. This led to 13 patients undergoing transiliac-transsacral screw fixation with 2 screws inserted across the upper sacral segment. The remaining 3 patients assigned to surgery required alternative fixation as a result of sacral dysmorphism. In these patients, either a single transiliac-transsacral screw or bilateral SI screws were employed.[37]

Postoperatively, 14 of the 16 patients treated operatively were able to ambulate on postoperative day 1. All patients experienced a reduction in pain measured by visual analog scale pain score with average change of −3.2 [95% confidence interval, −5.0 to −1.4] in the delayed surgery group compared with −3.7 (95% confidence interval, −7.0 to −0.4) in the acute surgical group, but this did not reach significance ($P = 0.15$).[35]

In a separate retrospective series, successful outcomes were reported in 13 patients with minimally displaced sacral U-type fractures, with the majority treated with bilateral SI screw fixation.[8] No neurological deficit was found postoperatively, but 1 patient required revision instrumentation secondary to the disengagement of an iliosacral screw.[8]

Postoperative studies evaluating the efficacy of transiliac-transsacral screw stabilization generally show improved patient-reported outcome measurements.[66,67] A study evaluating 41 patients with isolated sacral insufficiency fractures demonstrated operative intervention allowed for greater pain relief measured by visual analog scale pain scores, ambulatory function, and discharge home.[66]

CONCLUSION

As the proportion of geriatric patients in the population continues to rise, there will be a resultant increase in C0 fractures managed by spine and orthopedic trauma surgeons. Creating an optimal classification system that is both descriptive and guides management is therefore imperative to improve patient outcomes after fracture. Although the management of C0 sacral fractures continues to be controversial, the use of a single fracture classification may be 1 solution to improve our understanding, management, and future research regarding these injuries.

There continues to be a paucity of literature discussing the optimal management of these injuries. Nonoperative treatment, transiliac-transsacral screws, and triangular osteosynthesis are the current options for management depending on the patient's health status and fracture characteristics. Although previous literature points to operative management providing greater pain relief and patient-reported outcomes scores compared with nonoperative management, continued investigation is warranted. Furthermore, high-quality studies comparing transiliac-transsacral screw fixation and triangular osteosynthesis in patients with C0 sacral fractures will help define which patients are best suited to each construct.

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