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SACRAL FRACTURES AND LUMBOSACRAL DISLOCATION

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ABSTRACT

Sacrum fractures are injuries with a high rate of mortality and risk of neurological damage usually associated with pelvis fractures and rarely observed as isolated fractures. Since it occurs as a result of high energy trauma, concomitant injuries should be suspected. Full examination including a detailed neurological and radiological examination is required in order to determine treatment modality.

Proper classification of sacral fractures may facilitate determination of optimum treatment modality. Due to the complex nature of the injuries surgical therapeutic options are still being debated. Surgical therapeutic option consisting from decompression of neural structures along with stabilization of the fractures should be considered in patients with neurological deficit, severe soft tissue damage and lumbosacral instability. Percutanous iliosacral screw placement, fixation of posterior sacral tension band and lumbopelvic or triangular fixation techniques are preferred methods.

In this paper, the authors aim to share information in the literature along with their experience about anatomy of sacrum and pelvic regions and common sacral fractures, classification of sacral fractures and current therapeutic strategies.

Key words: sacral fructures; lumbopelvic fixation; triangular fixation; trauma.

Level of Evidence: Review article, Level V

INTRODUCTION

Almost 75% of patients referring to hospital with sacrum fracture don't have any neurological sign; thus, these patients may be overlooked during their first referral and their treatment may be inadequate. In young patients, they may occur because of high-energy trauma; but in osteoporotic older patients, sacral fractures occur more often because of low energy trauma. Recently sacral insufficiency fractures following long segment instrumentation applications are more common. To prevent lower extremity muscle weakness and neurological sequels such as urinary, rectal and sexual dysfunction, anatomy of sacrum should be fully appreciated and injury mechanisms and therapeutic options along with types of treatment should be very well known. The objective in management of sacrum fractures is to recover structure and neurological functions at their best; thus, both nerve decompression and reconstruction of skeletal system should be very well understood.

ANATOMY [4]

Sacrum consists of usually 5 vertebrae fused with each other and has a kyphotic appearence. Spinal canal diameter and size of vertebral body decrease from cranial to caudal. Sacral kyphosis varies between 10°-90° and is usually about 45°–60°. Central kyphosis determines sacral inclination angle. In case there is transitional vertebra, number of sacral segments may vary. Transverse processes of sacral vertebras may form a joint or fusion at ala of sacrum and articulates with ilium at lateral via sacroiliac joint. Between vertebral bodies and sacral ala there are 4 sacral neural foramina at anterior and posterior. Upper half of S_1 vertebra and 1^{st} and 2^{nd} sacral foraminal cortex at anterior and sacral laminae are locations where the bone density is highest.

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Sacral ala itself contains spongious bone and density decreases with advancing age. Structural continuity of sacrum depends on surrounding ligaments. Thick and well developed ligaments at both sides attach to sacroiliac joints and ligaments at the most caudal region binds lumbar vertebra to pelvis. Lumbosacral plexus (L_4-S_1) and sakral plexus (S_2-S_4) are the neural structures directly affected from sacral injuries. L_5 nerve root extends distally from the lateral of sacral ala. At anterior of foramina the distance covered by sacral nerve roots is relatively the shortest at S_1 level and larger at S_4 level. Observations on cadaver dissection have revealed that S_1 and S_2 nerve roots occupy 1/3-1/4 of the foraminal distance anteriorly and S_3 and S_4 nerve roots occupies 1/6 of the foraminal distance anteriorly. Dural sac usually terminates at S_2 level. Sensorial branches of cluneal nerves arise from dorsal sacral foramina. Sacral angulation, translocation and direct compression of sacral spinal canal and ventral foramina may negatively influence function of sacral nerve roots or nerve recovery.

Biomechanically sacrum serves in transfer of the load arising from the vertebral column to both hip joints via sacroiliac joints. In supporting the vertebral column and in terms of ambulation first two sacral vertebras are very important.

EVALUATION OF THE PATIENT [4,9]

Initial assessment

Sacral fracture is usually caused by high-energy forces; thus, emergency resuscitation maybe needed and in accordance with ATLS protocols life threatining conditions should be urgently targeted and cardiopulmonary and hemodynamic stability should be established. In patients with AP compression fracture at pelvis, application of external fixator or pelvic girdle during resusitation in order to reduce pelvic volume and establish pelvic stability may be useful.

Stability of pelvic ring should be assessed by applying gentle rotational force to iliac alae. In case there is signs of laceration, wound, sensitivity, swelling or crepitation over or around pelvis sacrum injury should be suspected. Particularly, bony prominence on sacrum at posterior and presence of subcutanous palpable fluid mass that is an indicator of dissociation of lumbosacral fascia should be looked for Morel-Lavelle lesion [22]. Surgical incision over this lesion should be avoided, because it may increase risk of infection and may delay soft tissue healing.

Rectal examination should be always done in assessment of patients with sacrum fracture. Lacerations in the perinael region should also be examined for excluding a latent open fracture. In females speculum examination should't be neglected. Thoracolumbar vertebra fracture may also be present in patients with sacral fracture. Thus, other parts of the vertbrea must be fully evaluated.

Neurological Evaluation

Early evaluation of neurological status is important in sacral fractures. However, in a significant proportion of patients the severity of the trauma may impede full neorological assessment. Neurological injuries associated with U-shaped sacrum fractures are often seen as cauda equina syndrome due to injury of lower nerve roots (S_2-S_5) and manifested as bladder dysfunction, decrease in rectal tonus and saddle anesthesia. S_2-S_5 nerve injuries may be easily missed, due to absence of marked motor or sensual disorder. Perianal sensation, anal sphincter tonus, if present voluntary perianal constriction and presence of bulbocavernous reflex arc should be assessed. In unresponsive patients, perianal somatosensorial stimulation potential and EMG of anal sphincter provides valuable information about sacral plexus damage. Another frequent occurrence is L_5 or S_1 nerve root injury. L_5 nerve root injury may be seen as injury of posterior pelvic ring as result of vertical shear injury and fracture of transverse process of L_5 vertebrae may accompany it. Absence of dorsal flexion in ankle is the clinical sign of L_5 nerve root injury. Detection of cauda equina injury or open sacrum fracture is relevant in terms of the outcome and priority of the treatment.

Radiolocial Evaluation

ATLS protocol regarding imaging in injuries with suspected sacral fractures includes pelvic AP radiograpgy. Pelvic AP radiography is not ideal for revealing sacral fractures because of inclination angle of sacrum, iliac wings and intestinal gas. This may be more prominent in patients without significant asymmetry. Only 30 % of all sacral fractures may be seen in pelvic AP radiography [12]. Irregularity in sacral foramina and sacral arcuate line is a strong indicator of sacral fracture along with kyphotic deformity of sacrum revealing 'paradoxical inlet' appearence in pelvic AP radiography. Inlet and outlet radiographies of pelvis should be performed, because it's essential for better imaging of sacrum in patients with suspected pelvic ring injury.

Lateral sacrum radiography is required in order to show transverse fracture line in U-shaped fractures. Bilateral transforaminal sacral fractures, irregularity of superior sacral foraminal lines and tranverse process fracture of L_5vertebra are among other radiological clues for U-shaped sacral fracture [11].

CT imaging of both pelvis and vertebrae is important in order to observe details of the complex injury and to decide for definitive treatment. Axial sections in 5 mm or less than 5 mm thickness is recommended. Acquisition of sagittal and coronal images is important in terms of angulation and translation of the fracture, narrowing of neural canal and detection of shape of sacral fracture. Sagittal images show slippage of S_1 vertebrae over S_2 anteriorly and narrowing of the canal. Coronal images shows extension of the fracture towards foramina very well. 3 dimensional images allow understanding of the shape of the fracture exactly while getting prepraed for the surgical treatment and planning for it.

In addition, MRI assists in showing compression or neural structures and fracture lines. It may also be useful in assessment of peri-sacral soft tissues. In the period after acute injury particularly combination of MRI and neurography may be helpful in detecting lumbosacral plexus injuries. Myelography was previously used in assessment of subjects with neurological deficit but currently it's not a preferred diagnostic modality. Cystomyography and measurement of post-micturation residual urine are recommended in patients with neurogenic bladder.

CLASSIFICATION [4,9]

Depending on its localization and shape sacral fracture may distort stability of pelvic ring, lumbosacral junction or only sacrum. Classification should mainly discern whether the injury is stable or instable. In assessment of pelvic trauma systemic injury load and associated soft tissue damage, presence of neurological deficiti and its severity, displacement of the fracture, presence of ligamentous injury along with bone injury are the factors thay should be considered. The widely accepted radiological threshold between stable-instable fractures in pelvic injuries is 1 cm or more displacement of the fracture fragments. However, this measurement doesn't show the actual displacement that has occurred during the injury.

Sacral fractures were first described in the literature in 1847. Since than, advances in imaging methods and increasing awareness about the fracture itself, classification of the fracture has begun. Medelman has classified sacral fractures in 3 main categories: longitudinal, oblique and horizontal. In 1945 Bonnin have suggested another classification based on injury mechanism. In 1977 Fountain et al. have published transverse sacral fractures of 6 subjects and classified these fractures as transverse or longitudinal. Pelvic area fractures are basically classified in 3 categories.

Classification system based on injuries disrupting the structural integrity of pelvic ring was suggested by Tile, Letournel et al (AO/ASIF group). Isler based his classification on disruption of integrity of lumbosacral junction and stability. Denis et al. suggested a practical classification for sacrum fractures. Roy-Camille has added a subclassification system for transverse sacrum fractures including spinal canal (Denis Zone III) to this classification. Denis and Roy-Camille classication are complemantary rather than being distinct classifications. Classifications of other groups such as Sabiston and Wing, Kaehr and Anderson are variations of the above mentioned classification systems but they're not comprehensive.

The most understandable and practical classification system for sacrum fractures is the 3-zone system described by Denis et al. in 1988. In their study based on retrospective evaluation of 236 patients they have classified sacrum fractures according to the most internal fracture line. Fractures lateral to sacral neuroforamina are described as zone I fractures; transforaminal fractures that are usally vertical and don't extend to spinal canal are described as zone II fractures and fractures extending up to the spinal canal are described as zone III fractures. This classification based on anatomic fundamentals includes most of the sacrum injuries within the classification system and also indicates associated neurological deficit [11]. This 3 types of injury also often indicates the injuries and mechanisms of injuries. Zone I extraforaminal ala fractures occur in 50% of patients and rate of neurological deficit is 5.9 % and this includes L_4-L_5 roots of sciatic nerve. In 34% of the patient's zone-II transforaminal injuries are observed and in 28% of these patients, there is neurological deficit that includes L_5, S_1, S_2 roots. In this retrospective study, the authors have detected zone III injuries affecting spinal canal in 16 % of the patients. In 57% of them there was neurological deficit that includes sacral roots. In 76 % of patients with affected sacral roots bowel, bladder and sexual dysfunction may occur.

In the classification of Denis, the classification system doesn't include displacement of the fracture or instability stemming from the injury. Zone I and zone II fractures are usually vertically oriented fractures and related with posterior elements of the pelvic ring. In general they are the injuries occur as a result of exposure of pelvic ring to lateral compression or external rotation and they're very instable due to their nature. Bilateral zone I or II fractures are infrequent and they may also be an indicator for zone III fractures. Denis et al. have described zone I and II fractures as minimally displaced, stable or displaced-instable.

Although zone I injuries mainly affects stability of posterior pelvic ring, some zone II fractures and most of the zone III fractures may affect both pelvic ring stability and lumbosacral stability.

Zone II sacrum fractures may be subclassified according to their effect on stability. According to classification system suggested by Isler in 1990, lumbosacral junction Isler type I fractures are stable, because longitudinal sacrum fracture extends to lumbosacral joint and the lateral of L_5-S_1 facet joint and thus stays within the stable component of sacrum[21]. If the longitudinal fracture extends to the L_5-S_1 facet joint or internal side of the joint, joint may dissociate from the sacrum totally either along with the stable sacrum fragment or by fragmentation and possibly lumbosacral instability occurs. This instable fracture type is noted in nearly 40% of the instable vertical sacrum fractures [29].

Zone III fractures consist of a wide spectrum of injuries with various fracture shapes and displacement charactestics; thus, subjective or descriptive classification system maybe useful in oral definition of multiplane sacral fractures and their virtual visualisation. Many injuries resulting with transverse sacral fractures have longitudinal or vertical components and are usually bilateral transforaminal fractures extending to lumbosacral junction and forms a type of fracture which is called as U-shaped fracture [19]. Conventional longitudinal fractures form H, Y or lambda shaped fractures and result with spinopelvic dissociation by dissociation of sacrum

Sacral fractures that includes central spinal canal (Denis zone III) were subclassified by Roy-Camille. These types of transverse fractures consisting of upper part of sacrum are in fact described for fractures caused by jumping from heights with suicidal intention; however, they may also be used for zone III injuries and for other trauma mechanisms. The relationship between the severity of the injury and probability of occurrence of neurological deficit may be predicted by using the system described by Roy-Camille [33]. Type 1 injuries includes simple flexion deformity of sacrum, type-2 injuries flexion and translation deformity and type 3 injuries complete translation of superior and inferior sacral segments. Strange-Vognsen and Lebech later added type 4 to this classification. Type 4 injuries are segmental fragmented sacral fractures without severe translation or angulation and it's suggested that they occur as a result of exposure of vertebrae directly to axial load while staying at neutral position. These 4 types are associated with the severity of the trauma and neurological deficit and may be useful for treatment plan of the patients. Although it's suggested that all of the fracture types occur as a result of axial loading, in type-1 and type-2 injuries flexion forces are also involved and it results with kyphotic angulation at transverse fracture line.

Lumbosacral injury classification system (LSICS) was suggested in 2012 in order to help surgical decision making in complex sacral fractures. LSICS is a scoring system based on the severity of injury in 3 categories (morphology, posterior ligamentous complex and neurological status). The score from these 3 categories changes between 1-10. If the total score is <4 usually conservative treatment is advised. When the total score is >4 surgical treatment is advised for sacral fractures. If the score is 4, then, the decision of treatment is left to the surgeon's opinion [25].

Lumbosacral junction trauma is considered as a different entity. These injuries may manifest as facet dislocations only or as complex lumbosacral fractures. Due to the strong ligaments supporting lumbosacral junction, substantially high degree of force is required to cause this type of fractures. In numerous case reports describing lumbosacral injuries, various injuries from facet fractures to lumbosacral dissociation were reported. These injuries are seen as unilateral or bilateral L_5-S_1 facet anterior, posterior and lateral dislocations. It was found that vertical sacrum fractures located at lateral of L_5-S_1 facet joint has no impact on lumbosacral stability. Injuries extending beyond L_5-S_1 facet joints, extra-articular fractures of lumbosacral joints and fractures extending from inside of L_5-S_1 joint to neural arc are complex and thus considered as instable.

AOSpine Sacrum classification is a new classification system and validation studies are still ongoing. It includes elements resembling to lower thoracal and thoracolomber classification systems. In this classification system, the fractures are categorized under three main subgroups. Type-A; lower sacrococygeal injuries, Type-B; posterior pelvic injuries and Type-C, Spinopelvic injuries. In type-A injuries posterior pelvis and spino-pelvic regions aren't affected but neroulogical deficit may accompany in high grade injuries. Type-2 injuries are unilateral longitudinal sacral fractures where ipsilateral S1 facet joint conserves its continuity with medial side of sacrum. These injuries have impact mainly on posterior pelvic stability and on spinopelvic stability though to a lesser extent. Type-B injuries are categorized into 3 subgrups according to the probablity of neurological deficit. Type-C injuries are injuries that result with spinopelvic instability and categorized into 4 subgroups. In this classification neurological condition of the patient is also considered in additon to fracture morphology. Finally, 4 different variables that may affect the treatment plan of sacral fractures are also taken into account in this classification (severe soft tissue injuries, metabolic bone disease, anterior pelvic ring injury, acetabulum injury or high energy injuries that may be associated with vascular injuries and changed anatomy of lumbosacral junction – anatomic or previous fusion).

NEUROLOGICAL INJURY

Sacral nerve injuries may occur as a result of different mechanisms and may manifest itself as mono-radiculopathy, numerous but unilateral radiculopathy and bilateral sacral nerve root involvement, partial or full fledged cauda equina syndrome [15,24] . Bilateral nerve root injuries at S4 or below may cause pain or motor deficits but don't cause bladder or bowel dysfunction [37]. Nerve root injuries may potentially recover and contusion, compression or traction caused by angulation or translation of fracture fragments or direct compression of bone fragments may all cause these injuries. Avulsion or cutting of nerves may cause irreversible neurological deficit. These may occur hours after the initial travuma or months after it as late injuries and their causes may be epidural hematoma, instability of fracture fragments or callus formation. In lower extremity neurological injuries muscle strength assessment for all muscle groups should be done by using 0-5 scoring. Gibbons et al. described a sacral neurological injury classification in order to detect the severity of the deficit (**Table-1**).

Table-1. Gibbons classification for Neurologic Deficits

Grade	Criteria
Grade 1	No neurologic deficit
Grade 2	Paresthesias / sensory changes only
Grade 3	Motor weakness or loss but bowel / bladder control intact
Grade 4	Motor and / or sensory deficits associated with loss of bowel / bladder control

LUMBOSACRAL DISLOCATIONS

This type of fracture dislocations were first described in the literature in 1940 by Watson-Jones. Since then, more than 100 cases have been published in the literature. Most of the reports were published as case reports or literature review [35].

Numerous and various injury mechanisms may lead to fracture dislocations of lumbosacral transitional vertebrae resulting with different grades of spondylolisthesis and may also lead to displacements towards various directions.

Fracture dislocation is rarely seen at L_{4-5} level [10].

Neurological Findings

Neurological findings may vary widely. In case reports with or without neuorological deficit the injuries may differ from the injury of a single nerve root to severe paraparesia or full fledged cauda equina syndrome. Full dislocations occurring posteriorly may cause avulsion of dural sac and nerve fibers and in anterior dislocations dural sac may be preserved from the injury if there is bilateral pedicle or pars interarticularis fracture. It has been observed that posterior dislocations may cause more severe neurological injuries [14]. Some authors have suggested that there is a correlation between the degree of slip and neurological deficit. In injuries with more than 33% slippage incomplete cauda equina injury was more common [18].

Radiological findings

In multiple injured patients, initial imaging should include AP and lateral radiographies of lumbar vertebrae. High quality imaging is required for proper diagnosis. In AP radiographies, as a finding of a rotational injury, it may be seen that spinous processes at inferior or superior of the lesion displaced laterally or vertebrae moves to the lateral. In sagittal images slippage, short segment kyphosis, increase in interspinous distance and narrowing of disc distance may be seen. Presence of transverse process fractures should lead to suspicion for presence of lumbosacral injury [27].

Particularly in patients with transvers process fracture and multiple injuries lumbosacral junction should be assessed by CT imaging. In the literature cases with late diagnosis are reported and in these cases there was persistant lumbosacral pain with or without pain spreading to legs [2]. Sagittal reconstruction allows a good assessment of bony structures and spinal canal diameter. However, if the examination is performed in the supine position slip in L_5 vertebrae may be less than expected.

In unconscious patients full body scanning by 3 dimensional CT is required in order to see probable injuries [16].

MRI imaging may not be readily performed in emergency conditions. It provides a good preoperative assessment in stable and neurologically intact patients. Presence of disc injury or narrowing of L_5 neural foramina by disc fragment may be shown by MRG very well and it may prevent worsening of neurological condition that may occur during reduction maneuvre. However, in presence of neurological deficit or cauda equina syndrome decompression surgery should be done even though MRI has not been performed [13].

Occasionally, fracture of spinous process of L_5 vertebra or promontorium may be seen [1].

CLASSIFICATION

Aihara et al. have described 5 types. [1]

Type-1. Unilateral facet dislocation with or without facet fracture

Type-2. Bilateral facet lock with or without facet fracture

Type-3. Unilateral facet dislocation with contralateral facet fracture

Type-4. Acute spondilytic olisthesis

Type-5. Fracture of vertebra body or pedicle with dislocation of body with or without injury of lamina and facet joints. Type 5 is similar to Hangman's type of fracture.

Vialle et al. have suggested a classification with 3 types and their subgroups[39].

Type -1. Full dislocation of facet joints without fracture

IA: Unilateral rotational dislocation

IB: Bilateral facet dislocation with dislocation to lateral, disc tear may be present

IC: Bilateral dislocation with anterior slippage

Type-2. Unilateral joint fracture dislocation, anterior slippage of L_5 vertebra, asymmetrical and intervertebral disc lesions may accompany injury

Type-3. Bilateral fracture dislocation with disc injury and olisthesis

IIIA: Bilateral facet fracture with dislocation or acute fractures of pars interarticularis

IIIB: Bilateral facet fracture with rotational displacement associated with anterior slippage of L_5 vertebra

In the classification systems of Magerl et al and Blauth et al. most of the lumbosacral dislocations are classfied as type B and type C lesions[7].

CLINICAL APPEARANCE

Traumatic lumbosacral dislocations may occur as a result of high-energy trauma and may rarely be seen as isolated injuries and pulmonary, vascular and head traumas that are frequently associated with these dislocations usually require emergency interventions. Due to high mortality related with these lesions actual frequency of lumbosacral dislocations may be lower than estimated[32]. Shen et al. have reported that 10% of lumbosacral fracture dislocations are overlooked initially[36].

In a few cases isolated trauma or associated mild lesions were reported. Anterior and posterior dislocations may occur as open fracture dislocations depending on the severity of the injury; thus they should be investigated. Hematoma, open wound, abrasion and scar tissue may be seen at lumbar region in direct trauma cases.

TREATMENT APPROACH

Until the publication of a surgically treated case in 1975 by Samberg, fracture dislocations were having being treated with closed reduction and often by trunk brace or bed rest. Both in children and adults successful outcomes were obtained by conservative therapy.

In most of the cases conservative therapy has resulted with late deformity associated with secondary worsening of neurological condition and progressive low back pain.

360° fusion is recommended in cases with intervertebral disc damage in whom posterior decompression of dural sac is required. On rotational injuries with unilateral lumbosacral facet dislocation posterior instrumentation and posterolateral fusion may be sufficient. Resection of facet joints may be needed to provide reduction. To obtain circumferential fusion it may be possible to combine PLIF and ALIF methods with posterior instrumentation[39].

TRAUMATIC SPINOPELVIC DISSOCIATION:

U-SHAPED FRACTURE OF SACRUM

Sacral fractures may cause pelvic instability; on the other hand, multi-planar and substantially displaced sacral fracture dislocations may end with spinopelvic instability or dissociation. Traumatic spinopelvic dissociation or sacral U-shaped fractures are characterized with bilateral sacral fracture dislocations and transverse sacral fractures that lead to mechanical dissociation of upper part of sacrum and vertebrae from the pelvis. Anatomically these fractures dissociate lumbar vertebrae together with upper central part of sacrum from both lower part of sacrum and pelvis at sacral ala region. The term traumatic spino-pelvic dissociation is coined by Bents et al. in order to differentiate this type of injury from lumbosacral fracture dislocations or bilateral sacro-iliac joint dislocations[6]. It occurs as a result of high-energy injuries associated with high frequency of neurological deficits and debate regarding its diagnosis-treatment is still ongoing.

Only 3-5% of sacrum fractures are transverse sacrum fractures. U-shaped sacrum fractures are much rarer and publications in the literature are mostly case reports and small-sized case series.

U-shaped fractures of sacrum occur as a result of high-energy injuries leading to severe axial load on vertebrae [5]. A frequently encountered injury mechanism is jumping from heights with suicidal intent [33]. Other frequent causes are falling from heights, motor vehicle accidents and crush injuries. Rarely gunshot wounds may cause sacral injuries. Frequently local soft tissue injuries, bleeding and other orthopaedic injuries with high mortality may be associated with sacral injuries[6, 33].

Fragmentation and displacement of fracture may cause injury of sacral nerve root and this may lead to neurological deficits varying from incomplete monoradiculopathies to full fledged cauda eqina syndrome affecting lower extremity functions as well as bowel and bladder functions.

Clinical evaluation

Diagnosis of traumatic spinopelvic dissociation may be overlooked or delayed due to difficulties in imaging of upper part of sacrum and associated severe injuries. [20] If left undiagnosed and untreated painful deformities or progressive neurological deficit may occur[34]. Late corrective surgery is more difficult and outcome is usually poor. Since it's an easily overlooked injury, when a patiens presents with sacrococygeal pain sacrum injury should be suspected[38].

TREATMENT OF SACRUM FRACTURES

Conservative treatment

This treatment option includes activity modifications, bed rest, brace or cast immobilizations, lumbosacral corset with unilateral or bilateral hip extensions or skeleton traction.

Conservative treatment of sacrum fractures was mandatory befor advancement of surgical techniques but currently it's only an option.

Convervative management may be considered in patients with unilateral minimally displaced sacrum fracture without neurological deficit. In patients experiencing lumbopelvic ligamentous injury with marked displacement outcome of conservative management is poor.

In clinically stable pelvic ring injuries rotational movement, sitting in wheel-chair or assisted walking may not be markedly uncomfortable. If conservative treatment is decided in patients with marked displacement 8-12 weeks of bed rest and traction should be applied and the process should continue by application of braces. Evaluation of the outcomes of convervative treatment in patients presenting with posterior displacemet of pelvis usually reveals malunion of bones and long period of bed rest may cause pain.

Particularly in multiple injured patients prolonged bed rest is not desired. Recent studies have shown that surgical stabilization of pelvic ring injuries in multiple injured patients allowed early mobilization of patients, decreased early mortality and resulted with good long term outcomes[5, 17, 19].

Timing of intervention

Non-pathological fractures of sacrum occur as a result of high-energy trauma. The priority of the doctor should be the survival of the patient. Reducing pelvic volume may be useful in patients with open-book type pelvis ring injury associated with hypovolemic shock. Reduction of pelvic volume may be provided by various methods such as anterior external fixator, pelvic clamp or a tight wrapping (ie., bed sheet) around pelvic ring

Damage control orthopaedics principles should be applied (transient fixation and later definitive treatment). [30]

While planning for further therapies counter-measures for probable active bleeding, maintaining hemodynamic stability and evaluating neurological deficits and associated soft tissue injuries should all be considered. Active perisacral bleeding may be controlled effectively by angiographic embolization. However, bleeding due to displaced pelvic ring fractures is usually venous and thus less responsive to intravascular hemostasis.

Open sacral fracture and rectum perforation or perineal tear or dorsal soft tissue injury dictate routine surgical debridment as soon as general condition of the patient permits. In patients with progressive neurological deficit due to sacral fracture or posterior pelvic ring injury early decompression and internal fixation should be planned. In patients with established neurological deficit due to sacral injury surgical decompression is controversial, since its proper timing and risk-benefit ratio is not clearly known. In patients with displaced sacral fracture emergency surgery brings high risk of marked blood loss and high potential of wound-site infection. Thin dorsal presacral tissue region which is consisted of muscle, fascia and skin is an area prone to contusion and injuries.

Wound-site infection rate is 25% after open reduction and internal fixation of pelvic ring fractures by an intervention with posterior approach. Furthermore, potential of cerebrospinal fluid leakage following traumatic dural tear may be added to this risk. If there is sacral root cut after the trauma, early sacral decompression surgery may be a vain effort. On the other hand, prolonged compression of the nerve roots reduces the probability of neurological recovery.

In patients with traumatic lumbosacral root compression, if decompression surgery is performed in a later period exceeding 2 or 3 weeks residual sympoms such as pain and dysesthesia may become permanent. Outcome of the late decompression of post-traumatic sacral root compression is poor. Also, open reduction and internal fixation of displaced pelvic or sacral fractures after 2 weeks are more difficult.

In sacral fracture patients without neurological deficit emergency surgical intervention and open reduction is rarely indicated. In displaced transverse sacral fractures with angulation sacral soft tissue at posterior may be injured. Complex soft tissue injury may be prevented by correcting angulation of the fracture by early surgical intervention. Except above mentioned emergency surgery indications, most of the patients with sacral fractures may be operated safely and effectively between 48 hours – 2 weeks interval.

DECOMPRESSION METHODS [9, 42]

Indications of decompression surgery in patients with sacral fracture associated with neurological deficits aren't fully described. As reported in various studies, neurological recovery after sacral fractures is indepedent from whether the treatment was conservative or surgical in nearly 80 % of patients. There is consensus over performing decompression in patients with Denis zone fractures associated with cauda equina syndrome [(23)]. However, treatment of neurological deficits except cauda eqina syndrome is controversial. There is data showing positive outcomes of nerve root decompression, but except cauda equina syndrome evidence favouring nerve root decompression relative to convervative treatment in terms of more positive clinical improvement is scarce. In many patients with sacral fracture associated with neurological deficist, at least partial recovery without decompression has been reported [(3,8, 43)]. In theory, while decompression alone may increase the probability of nerve recovery in sacral nerve root injuries, and need for large surgical dissection and it prolongs the surgical time needed for surgical stabilization. Nerve decompression may not be successful by only laminectomy or foraminectomy. Without fracture alignment and stabilization decompression of nerve roots may not be possible.

Dorsal laminectomy may provide decompression of neural foramina and sacral canal when employed together with reduction and stabilization of both transforaminal and transverse sacral fracture components. By dorsal approach to reach kyphotic and slipped upper part of sacrum may often be possible. Reduction may be applied by different methods. Impaction of superior and inferior parts of sacrum may be dissociated by placing an elevator to transverse fracture line. After obtaining mobility between fracture ends, reduction of upper part of sacrum may be possible by fixating with Shanz screw that is placed between S_1 and S_2 roots and later this screw may be used as a maneuver lever to correct the angulation at sagittal plane. When needed traumatic dural injuries should also be repaired.

Dorsal or ventral sacral approaches are both possible but for decompression dorsal approach is clinically more preferred technique.

Ilioinguinal or low transperitoneal approach may be considered in a limited patient group with Denis zone I fracture for neurolysis when neurological deficit as a result of L_5 root entrapment caused by anterior displacement of alar region and hypertrophic new bone formation occurs. However, there is inadequate date to decide for success rate of this method.

Post-traumatic sacral foraminal narrowing usually affects the first two foraminas and may be seen after Denis zone II fractures.

Nerve root damage at foramina may be an indicator of foramina fragmentation or these injuries may occur after reduction of pelvic ring fractures. Sacral decompression should be considered if 50 % or more narrowing of first or second sacral foramina associated with symptoms like siatalgia exists.

For open reduction and internal fixation or isolated sacral foraminotomies of sacroiliac fracture dislocations unilateral or bilateral parasagittal longitudinal approaches were described. Hemilaminotomy from the midline to L_5-S_1 space is preferred over parasagittal approaches for many reasons. Midline approach provides better approach to ventral sacral foramina and better orientation despite distorted anatomy after the trauma. While comprehensive lumbopelvic stabilization may be established by similar midline approach, to reach lumbar vertebrae may not be possible by parasagittal approach. Usually bilateral parasagittal approach is required for stabilization. With this bilateral approach dorsal soft tissues that have been already injured during the trauma may further be injured and this in turn may increase complication risk during wound healing.

Central decompression of sacral spinal canal may also be performed by removal of sacrum dorsal neural arc. Subsequently, sacral roots are followed and a wide blunt probe is advanced laterally until it passes around the nerve at ventral sacral foramina. If the displaced body of sacral vertebrae is in contact with sacral root or compresses it, decompression of the canal may be provided ventrally by fracture reduction or kyphectomy. Central kyphectomy may be performed after isolation of sacral roots following sacral laminectomy. After controlling bleeding caused by dense epidural venous plexus surrounding sacral nerve roots and veins are taken to lateral in order to facilitite visualization of ventral spinal canal and surrounding structures. Fracture ends are corrected with high-speed burr or osteotom.

SURGICAL STABILIZATION METHODS

With the advances in segmental fixation instruments and improvement in sacroiliac fixation methods reduction and stabilization ability of the surgeons have increased dramatically in pelvic ring injuries including sacrum. Before trying reduction and fixation of dorsal pelvic ring the need for ventral stabilization of pelvic ring should be assessed. In pelvic ring fractures anatomic reduction and stabilization of anterior part may be easier than posterior part. Intrumentation from the anterior may provide stabilization of posterior ring alone, but it may guide the surgeon for the intervention to the posterior. Instrumentation options that may be used in the anterior are external fixation, anterior plate and retrograde pubic screws.

Methods for stabilization of posterior of pelvic ring are posterior transiliac grooved compression rods, open posterior-tension band plate method or percutanous sacroiliac screw fixation methods.

Posterior fixation by sacral bar and posterior tension band plate method aren't effective in Denis zone III fractures with transverse component. Neutralization of rotational forces at sagittal plane may be beneficial.

Sacral ala plates may be used for stabilization of transverse fracture component. Its shortcoming is inability to neutralize severe loads exceeding lumbopelvic junction because of inadeaquate fixation of fragmented or osteopenic sacral ala region. This method may be used together with iliasacral screws in order to increase stability of longitudinal fracture components.

Percutanous iliasacral screw method is a minimally invasive surgical fixation method but it can't correct sacral angulation as a disadvantage. Advantages of percutanous method are reduction of soft tissue damage and provision of rigid stabilization at supine position in traumatic patients. Indications for percutanous internal fixation are zone I and zone II fractures where efficient reduction and effective c-arm use is possible.

Recently, CT-guided sacroiliac placement is described. This method is time-consuming, reduces the chance for using external reduction maneuvers and redundant for surgeons trained for c -arm guided screw placement method. Risks of the method are reduction loss and malpositioned fixation. In rare cases penetrating injury or nerve, vessel or intrapelvic injuries due to screw are reported. If there is associated foraminal fragmentation in patients with Denis zone II fractures, secondary foraminal entrapment may occur due to overcompression during screw placement. Anatomic limitations of percutanous sacroiliac placement are failure to provide closed reduction and presence of abnormal lumbosacral anatomy.

Nork et al. have reported succeseful implementation of percutanous iliosacral screws in U-shaped mimimally displaced sacral fractures without severe canal or foraminal narrowing [(28)]. Other authors have reported that this method is not convenient in treatment of more instable, displaced, comminuted and irreducible Roy- Camille type 2-4 injuries [(34,40)]. Limitations of iliosacral screw fixation are reduction in catching force of the screw due to comminution of S_1 vertebra body, inadequacy of single iliosacral screw to stabilize sagittal deformity, iatrogenic nerve injuries due to compression or dectruction of sagittal deformity. Using 2 full grooved screw is recommended to avoid compression of fragmented bone comminution. Percutanous iliosacral fixation method is convenient for non-fragmented and minimally displaced U-shaped sacrum fractures.

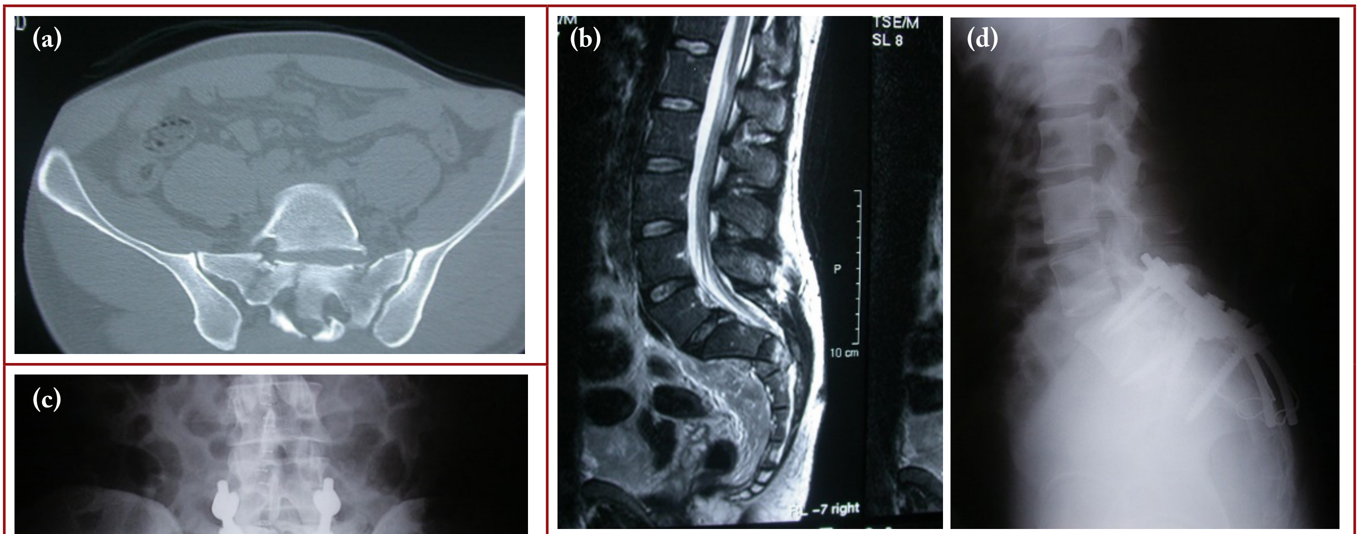
Previously, in internal fixation of zone III fractures with transverse fracture components bilateral alar plating described by Camille et al. was in limited use. However, due to collapse of fracture line and weak attachment of screws because of hypodense bone structure of ala adequate stabilization couldn't have been provided. Due to protrusion at posterior using conventional spinal instrumentation such as hook and screws in not convenient. Galveston type fixation method used in deformity surgery is not routinely used, since it's not biomechanically stable and inadaptable to trauma.

Recently two studies showing combined use of iliac screws with lumbar and sacral pedicle screw fixation system have been published. Luque rods are used in a method similar to screw pathway method of iliac component and by the help of 9 mm thick 130 mm long screws and rods tightened to L_5 and S_1 pedicle screws at superior. This method has superiority over sacroiliac fixation in terms of stability and has low profile.

In Roy-Camille 3-4 type zone III fractures the most stable internal fixation structure can be maintained by open fraction reduction following neural canal decompression, L_5 and if possible S_1 pedicle screw fixation, bilateral screw fixation and rod connection. Supportive sacroiliac screws may be placed after fracture reduction and before posterior lumbosacral fixation. In patients with lumbosacral fracture-dislocation segmental lumbosacral instrumentation using pedicle screws may be a therapeutic option. Advantages of this fixation method are absence of displacement and fixation loss despite aggressive decompression of sacral nerve decompression and causing no healing problems despite permission for early loading **(Figure-1).**

Triangular fixation is a relatively new method applied in treatment of vertically instable sacrum fractures. This fixation method is rigid; it allows early loading and decompression of neural structures[41]. In a cadaver study, translation and rotation stability after application of 2 transsacral screws were reported to be nearly as stable as triangular osteosynthesis [26] **(Figure-2).**

Recently, Rhee et al. have used newly designed segmental lumbopelvic fixation system in treatment of fragmented U-shaped fractures. In this sytem, iliac screws are tightened to rods via modular connectors and thus allows avoidance from 3 dimensional rod formation [31].



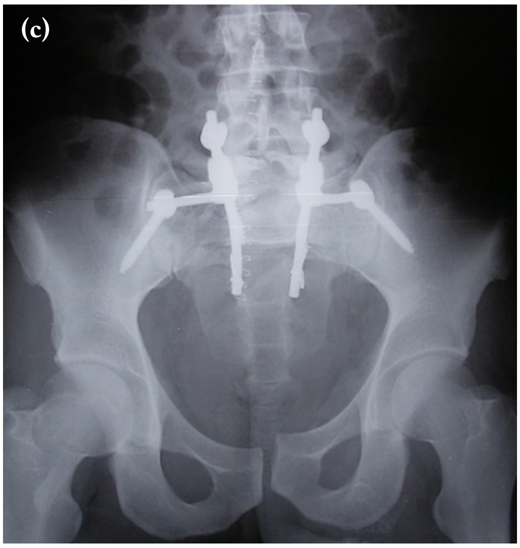


Figure -1.a and b. H- shaped sacral fractures associated with cauda equine syndrome. **c and d.** The nerve roots under compression were freed from bone fragments after sacral laminectomy, kyphectomy and reduction of the transverse fracture. Lumbopelvic fixation was applied after decompression and fracture reduction. The patient was neurologically intact at 9th months follow up.

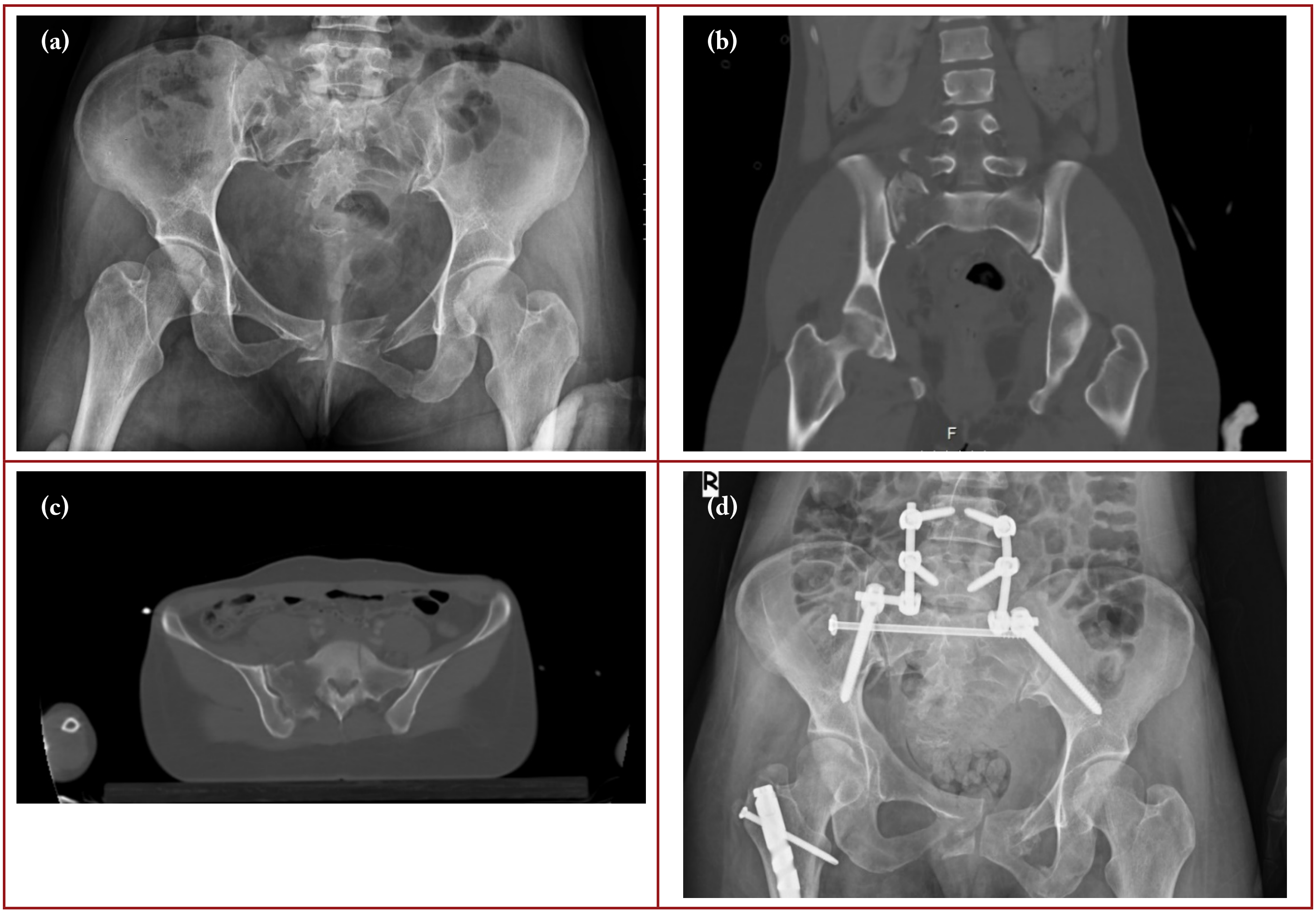


Figure – 2 a,b and c. Initial CT and x-ray images from illustrative case. Longitudinal fractures are noted in the right sacral ala and L5 transverse processes and in the left sacral body with involvement of the anterior pelvic ring. **d.** Post-operative radiograph demonstrating triangular osteosynthesis for bilateral sacral fractures.

RESULTS

The most important factor that has an impact on life quality of the patients is neurological deficit. In a significant proportion of patients due to the severity of associated injuries a proper neurological examination may not be performed. Thus, assessment of recovery or worsening of neurological condition may be difficult after surgical treatment of sacrum fractures. In sacral fractures manifested as spinopelvic instability neurological recovery is independent from whether the treatment was conservative or surgical in nearly 80% of patients. However, the type of the incident that caused the injury, the degree of recovery and criteria of assessment reduce the reliability and relevance of the reported recovery.

Vaccaro et al. have reported little chance of neurological recovery when bilateral nerve root cut-off or avulsion exist [38]. However, decompression and fracture reduction have substantial impact on recovery if the cause of nerve deficit is fracture fragments or nerve root compression due to angulation of fracture line, and early recovery may be observed. Schidhauer et. al have reported greater chance of recovery when neurological deficit is incomplete [34]. In their series recovery from bowel and bladder dysfunction was 85 % in patients with intact nerve root; however, in those with at least one sacral nerve root injury recovery rate was 36 %. It was shown that decompresion increased the rate of nerve recovery.

Proper reduction and fixation lead to nearly perfect bone union rates. Nork et al. have published succeseful outcome of sacroiliac screw treatment performed in 13 patients with non-fragmented minimally displaced Denis zone III fractures [28]. In a publication by Gribnau et al. regarding life quality of patients after U-shaped sacral fractures, in 8 patients treatment included percutaneous iliosacral fixation, transsacral plateosteosynthesis and transsacral plate or triangular osteosynthesis with or without plates. Following 36 months of follow up pain and mobility problems influenced general health status of the patients [17].

COMPLICATIONS

Complications associated with surgical treatment of sacrum fractures may be related with the wound-site such as hematoma, seroma and infection. Skin irritation caused by iliac screw may cause local pain and rarely decubitus ulcers and infection. This may cause severe problems particularly in patients with multitrauma and patients losing weight due to catabolic causes. Diet of these patients should be closely monitored. This problem may be solved by shaving of posterior iliac processes where iliac screws will be located by rounger or placing them more medially.

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