ORIGINAL ARTICLE

Fracture lines and comminution zones of traumatic sacral fractures

Sinan Oğuzkaya, M.D.,[1] Yasin Semih Güvercin, M.D.,[2] Turan Bilge Kızkapan, M.D.,[3] Gökay Eken, M.D.,[4] Feridun Arat, M.D.,[5] Abdulhamit Misir, M.D.[6]

[1]Department of Orthopedics and Traumatology, Çekirge State Hospital, Bursa-*Türkiye*
[2]Department of Orthopedics and Traumatology, Erciyes University Faculty of Medicine, Kayseri-*Türkiye*
[3]Department of Orthopedics and Traumatology, Başaksehir Pine and Sakura State Hospital, İstanbul-*Türkiye*
[4]Department of Orthopedics and Traumatology, Uludağ University Faculty of Medicine, Bursa-*Türkiye*
[5]Department of Orthopedics and Traumatology, Kayseri City Hospital, Kayseri-*Türkiye*
[6]Department of Orthopedics and Traumatology, Beylikdüzü Medicana International Hospital, İstanbul-*Türkiye*

ABSTRACT

BACKGROUND: Sacral fractures are uncommon and understanding three-dimensional morphology is needed to obtain proper treatment. The purpose of this study was to identify the repeatable fracture patterns and comminution zones for traumatic sacral fractures and create fracture maps.

METHODS: Computerized tomography images of 72 patients with traumatic sacral fracture were included in the study. For each fracture, fracture lines were identified and digitally reduced. All fractures were superimposed over a template and fracture maps; comminution zones and heatmaps were created for each zone.

RESULTS: There were 40 males and 32 females with a mean age of 46.5±19.9. Fifty-three (73.6%) patients sustained major trauma, and 19 (26.4%) had minor trauma. There were 37 (51.4%) Zone 1, 22 (30.6%) Zone 2, and 13 (18.1%) Zone 3 fractures. Each Denis zone showed certain fracture patterns. In Zone 1 fractures, most of the fracture lines were vertical and oblique (up to 45°) orientation on both sides. In Zone 2 fractures, fracture lines were concentrated on the S1 and S2 levels. Anterolateral and posterolateral parts of the sacrum were less affected in right-side fractures. In Zone 3 fractures, fractures were concentrated in S1, S2, and S3 levels around the sacral canal. The median sacral crest and midline remained mostly unaffected.

CONCLUSION: Sacral fractures showed specific repeatable patterns for each zone. These findings may be helpful for pre-operative planning, placement of fixation material, design of new implants, and modification of current fracture-classification systems.

Keywords: 3D; fracture pattern; heatmap; mapping; sacral fracture.

INTRODUCTION

The os sacrum is described as a "keystone" between the lumbar spine and pelvic ring. It functions as a transmitter of biomechanical forces to the lower extremities and maintains spinopelvic stability. Malalignment, deformity, and neurological impairment can affect functional outcomes after sacral fractures. The goals of sacral fracture treatment are to decrease pain, achieve stable reduction, restore lumbo-sacrococcygeal functional unit, and decompress nerves.[1–3] Mistreated fractures may cause chronic back pain, sagittal alignment distribution, bowel, bladder, and sexual dysfunction.[2]

Sacral fractures can be treated with conservative or surgical methods depending on the stability of the pelvic ring, associated injuries, displacement of fragments, and patient de-

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Address for correspondence: Sinan Oğuzkaya, M.D.
Çekirge Devlet Hastanesi, Ortopedi ve Travmatoloji Kliniği, Bursa, Türkiye
Tel: +90 224 - 294 81 00 E-mail: sinanoguzkaya@hotmail.com

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mands. Sacroiliac, trans-sacral, spinopelvic fixation, or open reduction and internal fixation with or without decompression can be chosen according to fracture pattern and associated injuries.[4] Understanding three-dimensional anatomy and the distribution of fracture lines is essential to classify appropriately and select proper treatment methods.[5]

Many authors have published fracture-mapping studies, including various appendicular skeleton bones showing repeatable fracture patterns and condensed comminution zones.[6–10] These studies significantly contributed to the literature to better understand the fracture morphology, achieve more reliable pre-operative planning and guide fixation methods, and propose new fracture classification systems.[11] To the best of our knowledge, there has been no study evaluating sacral fracture patterns based on computerized tomography (CT) images. The present study described CT images' fracture lines and comminution zones in sacral fractures. We hypothesized that sacral fractures would show specific repeatable patterns. We also hypothesized that we would be able to propose osteosynthesis directions based on fracture patterns. Furthermore, we aimed to present the difference between the fracture zones as well.

MATERIALS AND METHODS

Patients

The present retrospective multicenter study was started after the Institutional Review Board approval (2021-04/39, April 14, 2021). CT images of 98 patients were selected from Picture Archiving and Communication System (PACS) treated between 2013 and 2020. Traumatic sacral fractures of over 18 years with adequate CT images were included in the study. The exclusion criteria were (1) pathological fractures except for osteoporosis, (2) stress fractures, (3) evident sacral dysmorphism, and (4) previous fracture or surgery from the pelvis or lumbar vertebra. After exclusions, a total of 72 patients were enrolled in the study. According to the Denis classification,[12] fractures were classified by two independent Orthopedic surgeons. Demographic variables were obtained from patient files. The trauma energy was classified as major (car accidents, fall from height, industrial accidents, and motorcycle accidents) or minor trauma (simple falls from standing height).

Mapping Process

Axial, coronal, and sagittal images of each patient were obtained with 2 mm slices from PACS. All images were transferred to a 3D Slicer software program (v 4.10.0; Brigham and Women's Hospital), and 3D reconstruction was carried out. The ileum and lumbar vertebra were removed, and the sacrum was isolated. All image sizes were equalized to fit a standard 6×6 cell grid. Fracture lines were identified and marked. Then, displaced fragments were digitally reduced using Photoshop CC 2018 software (Adobe Systems Incorporated, San Jose, CA, USA). After recognizing and reducing all identifiable fracture fragments, the remaining zones were called comminution zones. The CT image of a 25-year-old male without bone pathology was used as the template. All fractures were superimposed to the template to create a fracture map and heat map as previously described.[9] We used a black-fill effect on a white floor for all maps, with the transparency level set at 5%, applied to each layer. The comminution zone in each layer had a light gray color, resulting in an increased intensity to "black" with overlapping of multiple comminution zones. In this way, a frequency diagram based on the density of comminution zones was created. Therefore, fracture maps, heat maps, and comminution zones were created from anteroposterior, lateral, and superior views for each fracture subgroup according to the Denis classification.[12] The mapping process was carried out by a graphic designer and supervised by an Orthopedic Trauma surgeon.

Statistical Analysis

Patient characteristics were presented with frequency and percentage (%). Continuous variables were presented with mean and standard deviation (SD). The Shapiro–Wilk test performed the test of normality. The Mann–Whitney U test was used to compare two independent continuous variables. The Chi-square test was used for the comparison of the categorical variables. $P<0.05$ was considered significant. All statistical analyses were carried out using IBM SPSS for Windows, version 22 (IBM Corp. Armonk, NY, USA).

RESULTS

Seventy-two patients (40 males and 32 females) with a mean age of 46.5±19.9 were included in the study. There were 27

Table 1. Comparison of demographic data between high and low energy fractures

	Major trauma (n=53)	Minor trauma (n=19)	p
Age (mean±SD)	37.1±13.7	72.8±6.7	<0.001
Sex, n (%)			0.169
Female	21 (39.6)	11 (57.9)	
Male)	32 (60.4)	8 (42.1)	
Side, n (%)			0.168
Right	20 (37.7)	7 (36.8)	
Left	25 (47.2)	12 (63.2)	
Bilateral	8 (15.1)	0 (0)	
Fracture classification*, n (%)			
Zone 1	23 (43.4)	14 (73.7)	0.060
Zone 2	18 (34.0)	4 (21.1)	
Zone 3	12 (22.6)	1 (5.3)	

*Denis classification. SD: Standard deviation.

Table 2. Frequencies of concomitant injuries

Associated injuries	n (%)
Anterior pelvic fracture	34 (47.2)
Sacroiliac dislocation	11 (15.3)
Vertebra fracture	22 (30.5)
Lower extremity fracture	28 (38.9)
Upper extremity fracture	13 (18)
Visceral injury	25 (34.7)
Thoracic injury	14 (19.4)

(37.5%) right side, 37 (51.4%) left side, and 8 (11.1%) bilateral fractures. Fifty-three (73.6%) patients sustained major trauma and 19 (26.4%) had minor trauma. There were 37 (51.4%) Zone 1, 22 (30.6%) Zone 2, and 13 (18.1%) Zone 3 fractures. The distribution of fracture characteristics is summarized according to the trauma mechanism in Table 1. Accompanying injuries are presented in Table 2. The fracture lines, heatmaps, and comminution zones for each fracture subtype are presented in Figures 1–3, respectively.

In Zone 1, the sacroiliac joint's fractures and sacral and ileal surfaces were significantly affected. Fracture orientation was vertical and oblique (up to 45°) on both sides (Fig. 1). S1 foramen was the most frequently involved foramen bilaterally (Fig. 1). Comminution zones were almost always observed in sacral ala.

In Zone 2 fractures, the left side was significantly more affected and fractures were concentrated on S1 and S2 levels. Most of the fractures were vertically oriented in the left-side fractures, while an oblique fracture line involvement was observed in the right-side fractures (Fig. 2). Anterolateral and posterolateral parts of the sacrum were less affected in the right-side fractures. The sacroiliac joint was significantly less affected in the right-side fractures.

Zone 3 fractures were concentrated in S1, S2, and S3 levels around the sacral canal. The median sacral crest and midline remained primarily unaffected. In the axial plane, it was observed that significantly more fractures were concentrated at the posterior half of the sacrum. Most Zone 3 fractures showed a transverse pattern from coronal and axial planes

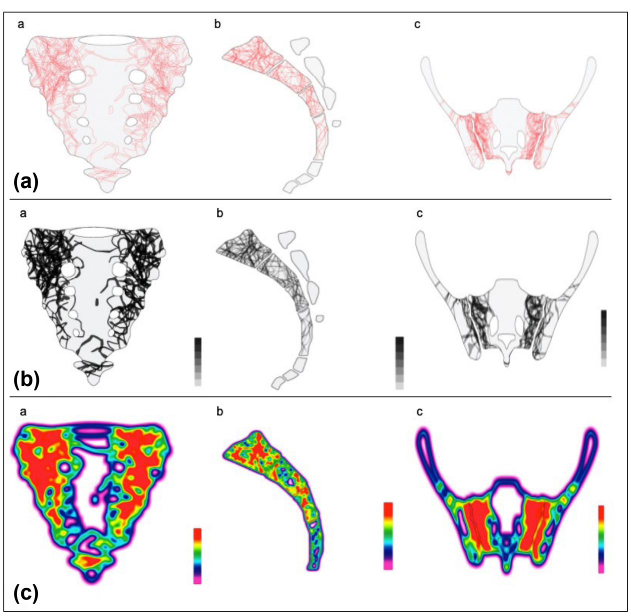

Figure 1. Fracture Line **(a)**, Comminution zone **(b)**, and Heatmap **(c)** of Zone 1 fractures. a. anterior view. b. lateral view. c. superior view.

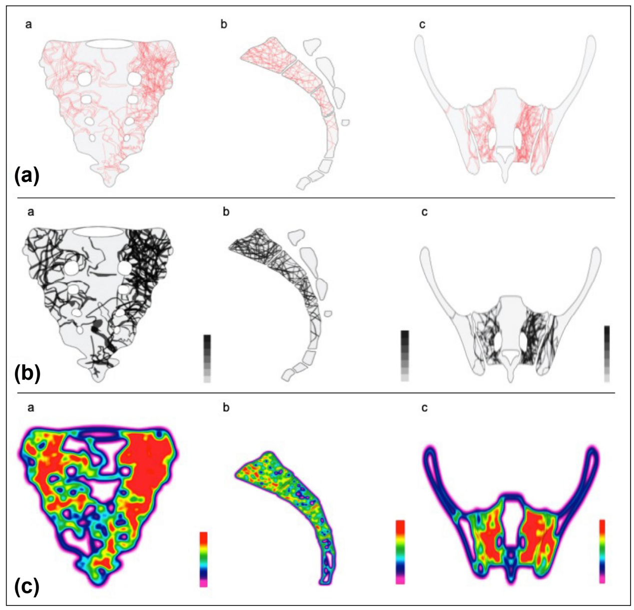

Figure 2. Fracture Line **(a)**, Comminution zone **(b)**, and Heatmap **(c)** of Zone 2 fractures. a. anterior view. b. lateral view. c. superior view.

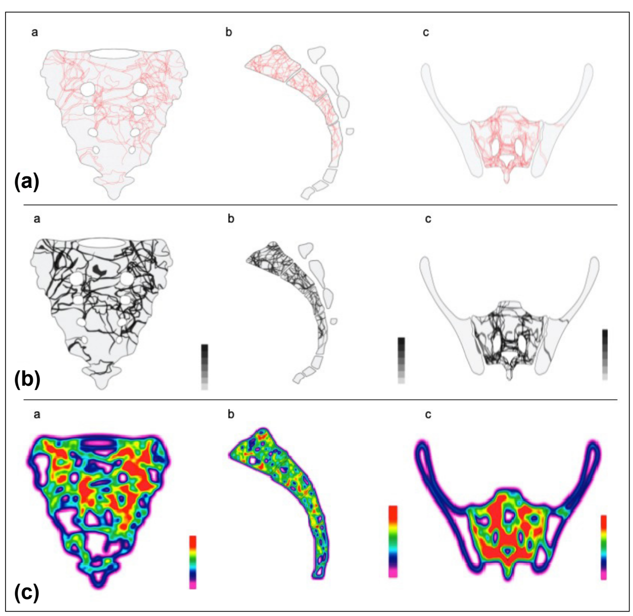

Figure 3. Fracture Line **(a)**, Comminution zone **(b)**, and Heatmap **(c)** of Zone 3 fractures. a. anterior view. b. lateral view. c. superior view.

(Fig. 3). The sacroiliac joint was less affected than Zone 1 and Zone 2 fractures. Comminution was less frequent in Zone 3 fractures. We also observed that some fractures showed transverse-oblique orientation between the S3 foramen and the contralateral S4 foramen (Fig. 3).

DISCUSSION

In this study, we presented the fracture patterns of traumatic sacral fractures. We observed that each fracture zone shows certain fracture lines and comminution zones.

Many authors attempted to classify sacral fractures based on trauma mechanism,[13] fracture location,[12] morphology, and the existence of lumbosacral instability.[14] Furthermore, a more comprehensive AO classification was proposed[15] and validated recently.[16] We observed a transverse-oblique fracture pattern between the S3 foreman and contralateral S4 foramen, which is like AO type A3 but undefined. This finding may guide researchers to modify current sacral fracture classification systems.

Due to the proximity of nerve roots, sacral fractures are frequently complicated with nerve injury. This risk is higher in Zone 2 and Zone 3 fractures.[2] We observed that S3-S4 involvement was proportionally more frequent in Zone 3 compared to Zone 2 fractures. This finding may guide surgeons to decide decompression levels.

Iliosacral screw is a minimally invasive technique that offers stability without extensive soft-tissue dissection, but it is a technically demanding procedure.[1,17] In Zone 1 fractures, we observed that fracture lines showed oblique orientation mostly (Fig. 1). Contrary to general knowledge, caudal to the cranial tilt of SI screw may be beneficial in zone 1 fractures to obtain perpendicular insertion of the screw to the fracture plane. This hypothesis should be tested with biomechanical studies.

Concomitant anterior pelvic injuries are common in sacral fractures.[1] Although most of the study population had Zone 1 fractures, concomitant lateral ileum fractures were primarily observed in Zone 2 fractures. Concomitant ileum fractures should be addressed for preoperative planning, which may affect determining the entry point of the iliosacral screw.

Surgeons must be aware of an iatrogenic nerve injury risk due to over-compression of comminuted fractures, and full threaded screws can be used for comminuted fractures. In our study, comminution was more frequently observed in Zones 1 and 2 fractures. Partially, threaded screws are recommended for Zones 1, 3, and non-comminuted Zone 2 fractures.

This is the first study on the 3D mapping of sacral fractures to the best of our knowledge. We tried to cover all traumatic sacral fractures caused by high-energy trauma and low-energy osteoporotic fractures. Treatment choice depends on many factors, such as associated injuries, soft tissue conditions, and bone quality. Understanding the 3D morphology of the fracture is also essential to decide optimal treatment. Although each fracture has its characteristics and should be assessed separately, our findings may give a general perspective to surgeons for recognizing the standard fracture lines and comminution zones of each fracture zone. We hope that our results will guide researchers to design new implants, modify the current classification systems, and extend the knowledge about the internal fixation techniques about the sacral fractures.

This study has several limitations that should be acknowledged. First, we included only traumatic fractures. Our results are not generalizable for all sacral fractures. Second, the study population is relatively low. Further studies with a larger population are needed for more reliable conclusions. Third, the os sacrum has a highly variable morphology. We attempt to exclude the dysmorphic sacrums, but some fractures may not perfectly fit our template, which was a 25-year-old male. We are aware that, these fracture maps may not be representative of all sacral fractures. Fractures should be analyzed separately and the treatment plan should make individually. Finally, our analysis was based on a qualitative assessment of the fracture maps like previous studies, making the data relatively subjective.

Conclusion

Sacral fractures showed specific repeatable patterns for each Denis zone. These findings may be helpful for pre-operative planning, insertion of the fixation materials, design of new implants, and modification of current fracture classification systems.

Ethics Committee Approval: This study was approved by the Sivas Cumhuriyet University Non-interventional Clinical Research Ethics Committee (Date: 14.04.2021, Decision No: 2021-04/39).

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Authorship Contributions: Concept: S.O., A.M., T.B.K.; Design: S.O., A.M., G.E.; Supervision: A.M., G.E., T.B.K.; Resource: S.O., T.B.K.; Materials: S.O.; Data: S.O., G.E., Y.S.G., F.A.; Analysis: S.O., Y.S.G., F.A.; Literature search: S.O., Y.S.G.; Writing: S.O., T.B.K.; Critical revision: A.M., Y.S.G., F.A.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Sakrum kırıklarının 3 boyutlu haritalandırılması

Dr. Sinan Oğuzkaya,[1] Dr. Yasin Semih Güvercin,[2] Dr. Turan Bilge Kızkapan,[3] Dr. Gökay Eken,[4] Dr. Feridun Arat,[5] Dr. Abdulhamit Misir[6]

[1]Çekirge Devlet Hastanesi, Ortopedi ve Travmatoloji Kliniği, Bursa
[2]Erciyes Üniversitesi Tıp Fakültesi, Ortopedi ve Travmatoloji Anabilim Dalı, Kayseri
[3]Başakşehir Çam ve Sakura Şehir Hastanesi, Ortopedi ve Travmatoloji Anabilim Dalı, İstanbul
[4]Uludağ Üniversitesi Tıp Fakültesi, Ortopedi ve Travmatoloji Anabilim Dalı, Bursa
[5]Kayseri Şehir Hastanesi, Ortopedi ve Travmatoloji Anabilim Dalı, Kayseri
[6]Beylikdüzü Medicana International Hastanesi, Ortopedi ve Travmatoloji Kliniği, İstanbul

AMAÇ: Sakrum kırıkları nadir görülür ve uygun tedavinin belirlenmesi için 3 boyutlu kırık morfolojisinin detaylı olarak anlaşılması şarttır. Mevcut çalışmanın amacı sakrum kırıklarında tekrarlayan kırık paternlerinin ortaya koyulması, parçalanma alanlarının belirlenmesi ve bilgisayarlı tomografi (BT) bazlı kırık haritalarının oluşturulmasıdır.
GEREÇ VE YÖNTEM: Travmatik sakrum kırığı tanısı almış 72 hastanın BT görüntüleri incelendi. Her kırık için kırık hatları belirlendi ve dijital ortamda redükte edildi. Tüm kırıklar bir şablonun üzerine süperpoze edilerek kırık haritaları oluşturuldu. Her kırık tipi için ayrıca parçalanma alanları ve ısı haritaları elde edildi.
BULGULAR: Çalışmaya 40 erkek 32 kadın hasta dahil edildi (ort. hasta yaşı 46.5±19.9). Elli üç hastada (%73.6) majör travma, 19 hastada (%26.4) minör travma sonrası kırık oluşmuştu. Zon 1 kırıklarda çoğu kırık hattı vertikal ve ya oblikti (45°'ye kadar). Zone 2 kırıklarda kırıkların S1 ve S2 seviyelerinde yoğunlaştığı gözlendi. Sağ taraflı kırıklarda anterolateral ve posterolateral kısımlar görece daha az etkilenmişti. Zone 3 kırıklarda kırık hatları sakral kanal çevresinde ve S1, S2 ve S3 seviyelerinin etrafında yoğunlaşmıştı. Orta hat ve median sakral krista çoğu zaman korunmuştu.
TARTIŞMA: Sakrum kırıkları her kırık tipi için bir takım tekrarlanabilir özellikler göstermektedir. Mevcut bulgular; tedavi planlaması, fiksasyon materyallerinin yerleştirilmesi, yeni implantlar geliştirilmesi ve mevcut sınıflama sistemlerinin modifikasyonu için faydalı olabilir.
Anahtar sözcükler: 3D; haritalama; ısı haritası; kırık paterni; sakrum kırığı.

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