



ORIGINAL ARTICLE

Reduction and fixation of displaced U-shaped sacral fractures using lumbopelvic fixation: technical recommendations

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Abstract

Purpose U-shaped sacral fractures are extremely rare injuries that usually occur as a result of falls from considerable heights. Almost all treatment methods described to date aim solely at stabilizing the fracture but do not contribute to supporting the reduction of such fractures. Using existing implants the purpose of this study is to present a surgical technique that facilitates both the reduction and the stabilization of these injuries. The presented technique was evaluated in a series of three cases.

Methods Polyaxial pedicle screws were placed through vertebral bodies L4 and L5. Two long pedicle screws were implanted in the posterior iliac spine. The lumbar pedicle screws were held with two longitudinal rods, and the pelvic screws with one transverse connecting rod. The lumbar longitudinal and pelvic transverse rods were connected via two hinge-like connecting elements. First, distraction was performed between lumbar pedicle screws L5 and the sacral transverse rod. Lordosis was then restored via the hinge joint, thereby eliminating kyphosis. After tightening all moving elements, the fracture was reduced and stabilized.

Results Computed tomography documented anatomical reduction and fracture healing was achieved in all cases. Two of three patients could be fully mobilized immediately; mobilization of the third patient was delayed due to multiple injuries. Two patients showed neurological symptoms. In one case, complete remission was achieved within 3 weeks, while in the other patient a clear improvement was observed. In all cases, the implant was removed after 8–12 months. There were no post-operative complications, such as infections, wound-healing disorders, neurological deterioration, implant failure, or premature loosening.

Conclusions The surgical procedure was successful, since it considerably facilitated reduction, thereby shortening surgery time. The stabilization was sufficient to fully mobilize the patients. The procedure is based on existing implant components and is thus routinely available.

Keywords U-shaped fracture · Sacral fracture · Jumper's fracture · Stabilization · Reduction · Lumbosacral spine

Introduction

Approximately 30–40% of all unstable pelvic girdle injuries reveal fractures of the sacrum. Depending on the course of the fracture line to the sacral neuroforamina, these fractures are classified into three zones described by Denis et al. [6]. A small percentage of patients (2–5%) exhibit a U-, H-, or Y-shaped fracture pattern [17, 19, 23, 24]. In functional terms, this constitutes an osseous avulsion of the lumbosacral junction from the sacrum. Unfortunately, these injuries are not consistently identified in the literature; for example, literature includes terms, such as transverse sacral fracture, U-shaped sacral fracture, bilateral sacrum fracture or suicidal jumper's fracture. Since purely descriptively, it is

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an avulsion of the first sacral vertebrae from the sacrum, some authors favor the term “sacral avulsion fracture”. The uncommon nature of this fracture is also reflected by the fact that the three largest study populations documented in literature are comprised of only 13 [17, 23] and 19 [3] patients; a surgeon is therefore not likely to acquire extensive individual experience with this injury. Hence, it is important to develop an optimal treatment strategy based on the existing data, which is mainly available in the form of case reports.

Biomechanically, a hyperflexion mechanism occurs, for example, following a suicidal leap, or other types of falls from considerable heights [23]. The casualty typically impacts the ground with the buttock and with the spine in a kyphotic position. This results in hyperflexion of the lumbosacral region with additional compression and shear forces.

In most cases, the avulsed S1 vertebra is tilted into kyphosis with more or less pronounced dorsal intrusion into the lesser pelvis (Fig. 1). Neurological deficits with involvement of the sacral nerve roots are observed in up to 90% of the cases.

This injury presents two main surgical obstacles. First, reduction is difficult because intra-operative distraction followed by restoration of lordosis is necessary. Secondly, high leverage forces act on the fixation implants. This creates difficulties in anchoring the implant in the sacrum or ilium. The aim of surgical stabilization should be to achieve early mobilization of the patient with full weight bearing. Percutaneous iliosacral screw fixation and sacro-sacral fixation of such fractures does not fulfill this requirement [17, 25]. Other lumbopelvic instrumentations are more suitable for achieving this goal. In the authors' experience; however, open reduction, in some cases with temporary fixation, is

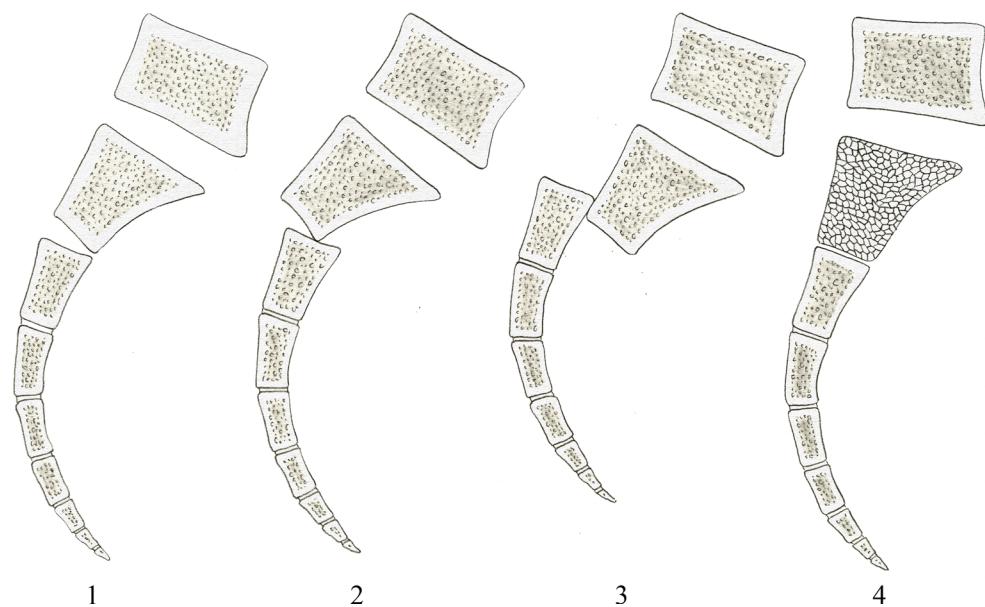
necessary prior to internal fixation. The fixation implant generally does not support the reduction. The endeavors, therefore, aimed at developing a modified surgical technique in which reduction is substantially supported by internal fixation—the implant is therefore simultaneously the instrument of reduction and fixation. The principal element of the surgical method presented in this study is the presence of a hinge joint for lordotic correction, which simultaneously offers the possibility of axial distraction. This procedure is derived from the technique of Nothofer and Neugebauer for the management of vertically unstable longitudinal sacral fractures [18].

Materials and methods

Surgical technique

Patients were put in a prone position on a radiolucent operating table. A midline longitudinal incision from L4 to S2 was made. Polyaxial pedicle screws (6.2 or 7 mm USS II Polyaxial screws, DePuy Synthes®, Umkirch, Germany) were then placed through the pedicles of L4 and L5. The cortical bone was then perforated with an awl at the highest point of the posterior iliac spine. For hard cortical bone, a drilling machine may be used. With a pedicle probe, a hole was pre-drilled at an outward angle of about 35° and downward angle of 45° between the two cortices of the ilium. The probe usually allows measuring to a depth of 5–7 cm. Pedicle screws (7 or 8 mm diameter and 50–70 mm in length) were placed through these pre-formed holes (Fig. 2). Generally, pedicle screws with the flattest possible profile should be used to minimize unavoidable irritation to soft tissue. Pre-curved

Fig. 1 Sub-classification of Denis zone 3 fractures according to sagittal plane alignment by Roy-Camille et al. [23] and Strange-Vognsen and Lebech [27]: type 1, flexion injury without translational displacement of the sacrum; type 2, flexion injury with translational displacement; type 3, extension injury of the sacrum; and type 4 (Strange-Vognsen), axial loading injury with segmentally comminuted S1 body



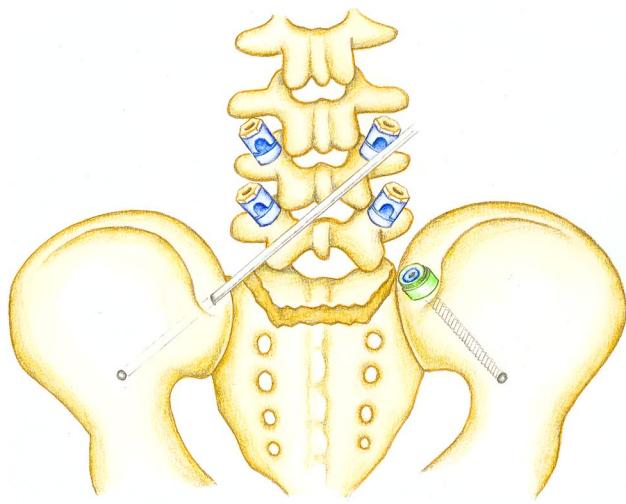


Fig. 2 Introduction of polyaxial pedicle screws. The point of entry for the pelvic pedicle screws is the posterior iliac spine. The screw runs between the two cortices of the ilium

longitudinal rods were placed into the lumbar polyaxial screws and secured with not yet tightened nuts.

A transverse connecting rod was secured between the two screws introduced into the ilium. The two longitudinal rods and the transverse rod running at a right angle to it were connected to each other with T-connectors in such a way that a hinge joint was created (Fig. 3). With exception of the two screws in the ilium, all screws were not yet tightened. The transverse connecting rod typically runs between S1 and S2. Reduction was now performed by inserting two distraction forceps between the L5 pedicle screws and the connecting

elements to the transverse rod, and distracting stepwise corresponding to the impaction (Fig. 4). The lumbar polyaxial screws were then tightened. Lordotic restoration and hyperextension were then performed with the aid of the hinge joint. Depending on the type of operating table, the patient's entire trunk was elevated, or an air bag positioned under the thorax was inflated, thereby compensating for kyphosis (Fig. 5a, b). The transverse connector screws were now tightened, thereby locking the hinge joint. The fracture was reduced and fixated. In cases with moderate kyphotic displacement, raising the lower extremities might be sufficient for repositioning. After insertion of a drain, layered wound closure, the skin wound was sealed with a synthetic tissue adhesive (e.g. Dermabond®, Ethicon GmbH, Norderstedt, Germany). This was recommended due to the proximity to the anus.

Case 1

A 68 year-old female, who fell from a plum tree from a height of four meters, suffered the fracture shown in Fig. 6a. Neurologically, there was a sensory deficit in the right S1 and S2 dermatomes. The patient exhibited no motor impairments. There were no other accompanying injuries. Preoperative magnetic resonance imaging showed pinching of nerve root S2 above the fracture. The nerve root was continuously imaged by MRI scans. Surgery was performed 3 days after the accident.

Case 2

A 27 year-old female, who fell from the second floor, while in an inebriated state, suffered multiple injuries. The fall

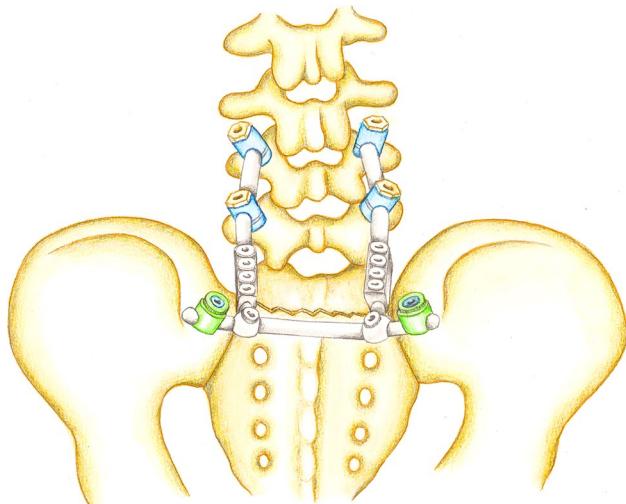


Fig. 3 The image shows the finished assembly before reduction. The lumbar pedicle screws have not yet been tightened. The screws of the hinge joint on the transverse rod are also not yet tightened

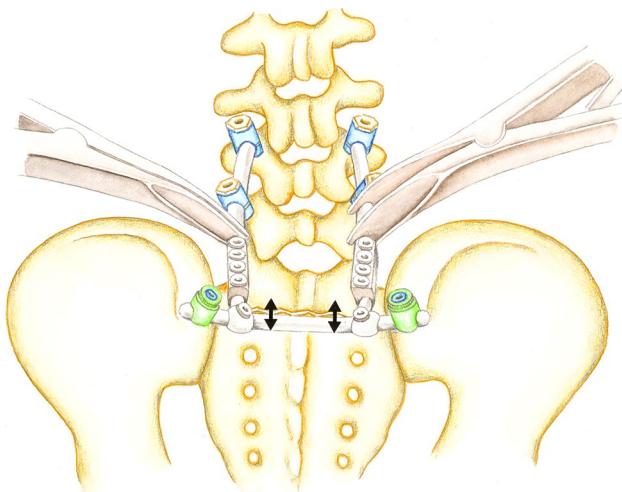


Fig. 4 The impacted fracture is distracted in a dosed manner in axial direction using two distraction forceps. The nuts of the pedicle screws on L4 and L5 are then tightened. The hinge joint still remains open

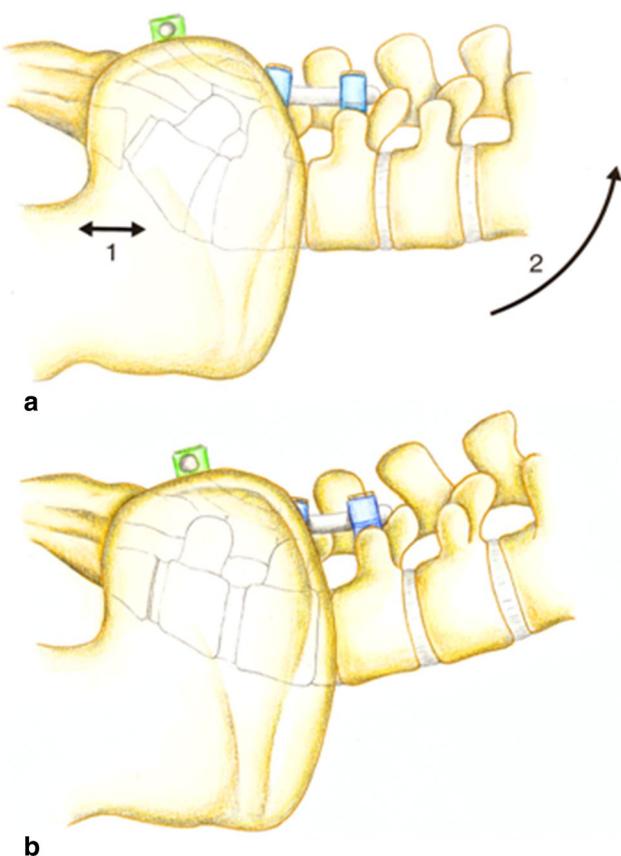


Fig. 5 **a** Sequence of reduction. First, axial distraction to release the impaction. Then tightening of the lumbar pedicle screws. **b** Lordotic restoration in the lumbosacral junction by elevating the trunk or the orthopedic table, followed by locking of the hinge joint

resulted in a transverse sacral fracture and compression of L1, a complex distal left radius fracture, a right middle hand fracture, a right ankle fracture with multiple tarsal fractures and foot compartment syndrome, as shown in Fig. 7a. The conscious and responsive patient showed no neurological deficits. After intensive medical stabilization, surgical stabilization was performed on day one following the accident (Fig. 7c, d). The unstable fracture of L1 was also stabilized monosegmentally with an internal fixator during the same session.

Case 3

A 33 year-old female was involved in a head-on car collision. Conventional radiographic diagnostic procedures performed elsewhere showed no evidence of fractures, resulting in the patient's discharge from the hospital few days later. The patient sought further treatment at our hospital 1 week after the accident because of persisting lumbosacral pain and numbness of the outer edge of the right foot. Computed tomography (CT) of the spine revealed the fracture shown in

Fig. 8a. Surgical stabilization was then performed by means of lumbopelvic osteosynthesis.

Results

Within 8–12 months, all three injuries showed osseous consolidation, demonstrated in follow-up CT scans (Figs. 6b–d, 7b–d, 8b). Implants were removed after 8–12 months in all cases. In patient 1, the sensory deficits in the S1 and 2 dermatomes regressed over several months. However, a neuropathic pain syndrome of the dorsal right thigh remained, requiring permanent pharmacologic analgesic treatment. The sensory deficits in patient 3 regressed completely within 3 weeks.

No wound-healing complications were observed. There was no implant failure or premature implant loosening. Patient 1 developed a heparin-induced thrombocytopenia, requiring further treatment with hirudine. However, there was no bleeding complication or thrombosis. The fundamental patient treatment courses are shown in Table 1. No further surgical intervention was carried out because of the pelvic injuries sustained.

Discussion

Surgical treatment of these rare sacral fractures has been frequently eschewed in the past because of the lack of adequate surgical alternatives [4, 21]. Even recent studies [3, 19] report that there are limited treatment options available, if any, for fracture reduction and effective stabilization. The endeavours therefore focused on using existing implant components to develop a safe and efficacious surgical method for the complicated fracture reduction and stable fixation even under loading.

The reduction maneuver requires distraction of the usually impacted fracture. This is accomplished by an implant construction whereby the two longitudinal rods fixed on L4 and L5 can support themselves on a transverse rod anchored in both dorsal iliac crests. With the use of polyaxial screws, dosed distraction is not difficult to achieve; there is no undesirable jamming of the screw heads against the longitudinal rod. When the fracture has been axially released from impaction, dosed lordotic reduction of the lumbosacral spine in relation to the remainder of the sacrum can be performed using the hinge joint. After locking the hinge joint, sufficient lumbopelvic osteosynthesis is achieved.

One clinical advantage is that this technique can be used to treat different types of fractures in the classifications of Roy-Camille and Strange-Vognsen/Lebech [23, 27]. While a Type 2 fracture requires slight axial distraction and lordotic

Fig. 6 **a** Denis Type 2 injury. S1 is dislocated towards dorsal and is noticeably constricting the spinal canal. **b** Follow-up CT after 8 months before metal removal. Anatomical alignment of S1 to the remaining sacral bone. **c, d** Follow-up radiography 8 months after surgical stabilization. Intact internal fixation device without signs of implant loosening or breakage



restoration for reduction, a Type 4 fracture requires only dosed axial distraction.

Recently it was described that patients undergoing spino-sacrale fusion without pelvic fixation had an increase in pelvic incidence after surgery. These changes could be related to increased rotational mobility of the sacroiliac joints [5]. An increase in the pelvic incidence might result in increased lumbar lordosis which has been shown to correlate with increased spondylarthrosis and low-back pain [11]. Therefore, a precise reduction and a spino-pelvic fixation using the demonstrated technique could avoid a post-traumatic disturbed sagittal balance.

In a case report, Mansouri et al. showed complete restoration of pelvic incidence following anatomic reduction with subsequent full-spine radiographs. Reduction of the

deformity was achieved in this case via a trans-S2 osteotomy on the level of the fracture to correct the S1–S2 kyphosis [15]. However, this procedure seems to be much more complex than the technique described here.

Previously presented fixation methods, whether involving iliac bars, posterior plate fixation, conventional internal fixator systems or variations of Galveston-type rod constructs [1–3, 10, 12, 19, 22, 23] have the drawback of being static internal fixation techniques that facilitate fracture reduction only minimally or not at all. In our opinion, this inadequacy is also responsible for the relatively high incidence of wound-healing complications, since this risk increases with longer surgery times and more severe soft tissue damages [3, 12]. In our admittedly small series of three patients, we did not observe any wound-healing complications. We

Fig. 7 **a** Type 4 injury with axial compression fracture of S2 and axial impaction. **b** Post-operative follow-up CT with relief of axial impaction. **c, d** Post-operative X-rays, in the same session an unstable fracture of L1 has been treated with internal fixator



Fig. 8 **a** Type 1 injury with slight pelvic tilting of S1 in relation to the sacrum. Constriction of the spinal canal is evident. **b** Follow-up CT 8 months postoperatively before metal removal. Anatomical alignment within the spinal canal. The fracture shows osseous healing



Table 1 Patient treatment course

	Patient 1	Patient 2 ^a	Patient 3
Age (years)	68	27	33
Gender	Female	Female	Female
Mechanism	Fall	Suicidal fall	MVC
Fracture type	2	4	1
Neurological deficit	Sensory deficit root S1 and S2	None	Sensory deficit root S1 right side
Neurological recovery	Right side: remaining pain syndrome		Complete; within 3 weeks
OR-time (min)	200	280	195
Blood loss (ml)	800	500	320
Complications	Heparin induce thrombocytopenia		
Metal removal after months	8	12	8
Follow-up time (months)	47	33	29

MVC motor vehicle (head-on) collision

^aOperation of lumbosacral and thoracolumbar spine in one session

recommend wound sealing with a synthetic tissue adhesive due to the nearness of the distal wound margin to the anus, what represents a high risk for a smear infection of the surgical wound.

In our opinion, percutaneous iliosacral stabilization [7, 13, 17] as recommended by individual authors, offers only slight advantages compared to non-operative treatment. As reported by these authors, a small improvement of only 1° in the sacral kyphosis angle has been observed in this group. A later loss of correction before bony healing is also described [13]. The stability of this method is certainly not sufficient to allow early mobilization of the patient. At the most, it allows an 8–12 week mobilization in a wheelchair with an additional thoracic–lumbar–sacral–hip orthosis. We have mobilized our patients to a standing position within the first post-operative week. This was achieved starting from supine position with the aid of a tilt table into the vertical position; this process is designed to avoid any forward bending of the trunk. The patients are then instructed to walk strictly erect with the aid of a wheeled walker. An upright sitting at the edge of the bed was allowed during trunk control from the third week. So far, we have prescribed our patients an additional thoracolumbar orthosis for posture control, however, we consider even this unnecessary for patients who are compliant. Because of the large leverage forces, we regard it as important to avoid any forward movement of the trunk in the first 8–12 weeks.

None of our patients showed signs of premature implant loosening or breakage, while in a listing of Bellabarba [3], at least one of the bars or screws failed in 6 of 19 patients (31%) during follow-up.

Considering the high reduction quality achieved with the procedure presented in this report, which was demonstrated by CT, we judge the indication for surgical decompression of the nerve roots in patients with neurological

deficits to be dispensable. Reports published so far consistently state neurological remission rates of about 80%, regardless of the method of treatment [3, 8, 9, 17, 20, 24]. Therefore, the decision on operative decompression should be made based of the individual situation and the preoperative neurological impairment. With a case series of three patients, it is naturally not feasible to make any valid statements in this respect; however, this was not the purpose of this study.

The two pelvic screws introduced into the posterior iliac spine were, as previously described, inserted at a 45° angle to caudal and a 30°–45° angle to lateral. The target point is the sciatic notch. In this way, a screw length of 50–70 mm can be achieved. Schildhauer [26] recommends horizontal introduction also at the level of the posterior iliac spine, but with a target direction of inferior anterior iliac spine. With this approach, screw lengths of 140 mm in male and 130 mm in female patients may be obtained. In contrast, Zheng et al. showed that short iliac screws (70 mm) offer similar mechanical stability compared to long iliac screws (130 mm) under physiologic torsional and compressive loading conditions [28].

We observed no problems in terms of loosening or implant failure when using a delicately closed transverse rod connector. Rod connectors should be fastened to the longitudinal rod and to the t-connector using two setscrews each. The implant manufacturer also supplies other forms of rod connectors although these may cause problems especially when the transverse rod has to be slightly bent to minimize irritation of the overlying soft tissues. Earliest possible metal removal is recommended, since asthenic patients, in particular, suffer from prominent screw heads positioned directly underneath the skin. While in a supine position, consistent pressure relief using foam cut-out pads or a similar material is recommended. Other studies report stage 3 decubital

ulcers [3], especially in skinny patients, or patients with pronounced post-traumatic weight loss.

In literature, there seems to be no consensus as to whether the aforementioned injury should be classified as a spinal or pelvic injury. Besides the classifications of Denis, Roy-Camille and Strange-Vognsen/Lebech [6, 23, 27], some authors [17] apply the AO classification [16]. In our view, the classification of such fractures as a pelvic girdle injury 61 A 3.3 does not adequately reflect the degree of instability and the underlying pattern. In contrast to Nork [17], we would recommend classifying such injuries as spinal injuries. Accordingly, a Type 1 fracture would correspond to a B 2.1 lesion, a Type 2 fracture would correspond to a B 2.3, and a Type 3 injury to a B 3.2 injury in the classification of thoracolumbar spinal injuries proposed by Magerl et al. [14].

Conclusion

In conclusion, we found that the presented stabilization procedure can be useful in treating displaced U-shaped sacral fractures. For dislocated fractures, axial distraction, usually in combination with lordotic restoration, is required. In surgical reduction and stabilization, the use of a lumbopelvic osteosynthesis with lockable hinge joint has proved successful. Although there is no clear evidence if anatomical reduction can be achieved, surgical nerve decompression might be unnecessary. Sealing of the wound with a tissue adhesive is recommended due to the proximity to the anus. Careful pressure relief of the skin above the posterior iliac spine and the screw heads positioned in this region is important, especially in intensive care patients.

Under strict physiotherapeutic guidance, patients undergoing these procedures can be mobilized at an early stage, i.e., in the immediate post-operative period. Metal removal after fracture healing is recommended due to local soft tissue irritations and because of the otherwise permanent iliosacral blockade.

Compliance with ethical standards

Conflict of interest This study has received no financial sponsorship. The authors have received nothing of value.

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