Article published online: 2021-07-27

Current Minimally Invasive Surgical Concepts for Sacral Insufficiency Fractures

Aktuelle minimalinvasive operative Konzepte für Insuffizienzfrakturen des Sakrums

Authors

Ulrich Josef Albert Spiegl[1], Klaus J. Schnake[2,3], Bernhard Ullrich[4], Max J. Scheyerer[5], Georg Osterhoff[1], Holger Siekmann[6]

Affiliations

1 Department of Orthopaedics, Trauma and Reconstructive Surgery, University of Leipzig, Germany
2 Zentrum für Wirbelsäulen- und Skoliosetherapie, Malteser Waldkrankenhaus St Marien gGmbH, Erlangen, Germany
3 Klinik für Orthopädie und Unfallchirurgie, Universitätsklinik der Paracelsus Medizinischen Privatuniversität Klinikum Nürnberg, Nürnberg
4 Unfall- und Wiederherstellungschirurgie, BG Klinikum Bergmannstrost Halle, Germany
5 Klinik und Poliklinik für Orthopädie und Unfallchirurgie, Universitätsklinik Köln, Germany
6 Unfallchirurgie, AMEOS Klinikum Sankt Salvator Halberstadt GmbH, Germany

Key words

posterior pelvis, sacral fracture, minimally invasive stabilization, insufficiency fracture, fragility

Schlüsselwörter

hinterer Beckenring, Sakrumfraktur, Insuffizienzfraktur, minimalinvasive Versorgung, Fragilität

published online 27.07.2021

Bibliography

Z Orthop Unfall 2023; 161: 143–153
DOI 10.1055/a-1498-2975
ISSN 1864-6697

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

Correspondence

Prof. Ulrich Josef Albert Spiegl
Department of Orthopaedics, Trauma and Reconstructive Surgery, University of Leipzig
Liebigstr. 20, 04193 Leipzig, Germany
Phone: 0341/97-17105, Fax: 0341/97-17309
uli.spiegl@gmx.de

ABSTRACT

An increasing incidence of sacral insufficiency fractures in geriatric patients has been documented, representing a major challenge to our healthcare system. Determining the accurate diagnosis requires the use of sectional imaging, including computed tomography and magnetic resonance imaging. Initially, non-surgical treatment is indicated for the majority of patients. If non-surgical treatment fails, several minimally invasive therapeutic strategies can be used, which have shown promising results in small case series. These approaches are sacroplasty, percutaneous iliosacral screw fixation (S1 with or without S2), trans-sacral screw fixation or implantation of a trans-sacral bar, transiliac internal fixator stabilisation, and spinopelvic stabilisation. These surgical strategies and their indications are reported in detail. Generally, treatment-related decision making depends on the clinical presentation, fracture morphology, and attending surgeon's experience.

ZUSAMMENFASSUNG

Insuffizienzfrakturen des hinteren Beckenrings nehmen an Häufigkeit zu und stellen eine relevante Herausforderung für unser Gesundheitssystem dar. Zur Sicherung der Diagnose sollte ergänzend zu den konventionellen Röntgenaufnahmen eine Computertomografie und ggf. eine Magnetresonanztomografie erfolgen. Bei Versagen konservativer Therapieregime zeigen kleinere Serien minimalinvasiver operativer Therapieansätze vielversprechende Ergebnisse. Ziel dieser Übersichtsarbeit ist es, die aktuell eingesetzten Techniken der minimalinvasiven operativen Versorgung von Insuffizienzfrakturen des Sakrums aufzuführen und die jeweiligen Vor- und Nachteile darzulegen. Dies sind aktuell die Sakroplastie, die perkutane iliosakrale Verschraubung S I oder S I/S II, die transsakrale Verschraubung u. a. mithilfe des transsakralen „bar" und von posterior horizontalen sowie lumbopelvinen Stabilisierungen. Im Allgemeinen hängt die Entscheidungsfindung zur Therapie vom klinischen Erscheinungsbild, der Frakturmorphologie und den Erfahrungen der behandelnden Chirurgen ab.

Introduction

Poor bone quality is considered to be the primary cause of pelvic insufficiency fractures and is usually caused by bone metabolism disorders. The most frequent cause of poor bone quality is primary osteoporosis. Hence, pelvic insufficiency fractures are typically found in elderly patients, and women are more frequently affected [1]. Other causes of poor bone quality include local irradiation, with 21–34% of recipients developing sacral fractures [2], and pathologies having a negative impact on bone metabolism, resulting in secondary osteoporosis (e.g., Paget's disease, rheumatoid arthritis, hyperparathyroidism, and long-term steroid consumption) [3 – 5]. Predisposition to posterior pelvic ring fractures has also been reported during pregnancy [6]. In most cases, these fractures occur in the sacral ala and run parallel to the sacroiliac joint (SIJ) [7 – 9]. The likely cause is the high proportion of load-bearing spongy bone of the ala, which shows a disproportionately greater bone loss with increasing age than other parts of the sacrum. Moreover, the osseous stress distribution in the sacrum appears to play a role in fracture morphology [10, 11]. As a rule, sacral insufficiency fractures are unilateral or bilateral and run vertically. Fractures may develop T-, U-, and H-type pattern according to the orientation of fracture lines [12]. In up to 90% of cases, the anterior pelvic ring is also affected [13].

The comprehensive classification of fragility fractures of the pelvis (FFP) is a recently used classification for pelvic insufficiency fractures that is useful for treatment-related decision making [1]. Accordingly, surgical therapy is recommended apart from conservative therapy, especially for FFP III and IV fractures. Surgical intervention ranges from single unilateral screw fixation to triangular lumbopelvic support. Many of these techniques can be performed using minimally invasive approaches, which considerably reduce perioperative soft-tissue trauma and also decrease blood loss and infection rates [14, 15].

In this review, we describe the minimally invasive surgical techniques currently used for treating sacral insufficiency fractures and present their respective advantages and disadvantages.

The following surgical techniques have been described in this narrative review:

- Sacroplasty
- Single iliosacral screw fixation (ISF) S1
- Double ISF S1 or S1/S2
- Trans-sacral bar/trans-sacral screw fixation
- Transiliac internal fixator stabilisation
- Lumbopelvic, vertebropelvic, or triangular support
- In individual sections, indications and surgical techniques as well as current evidence are described.

Sacroplasty

The first cases of cement sacroplasty were reported in patients with metastatic disease at the beginning of the millennium [16, 17]. Similar to the use of vertebroplasty in vertebral body fractures, sacroplasty was subsequently adapted to the treatment of sacral insufficiency fractures [18].

Its indications are painful undisplaced sacral insufficiency fractures that show no clinical improvement with conservative therapy. Sacroplasty is performed using either an image converter or under computed tomography (CT) guidance. The procedure can be performed under local anaesthesia. The trocar is inserted either posteriorly or laterally. The posterior approach is further classified into a direct approach (entry at the level of the pedicle of S1 vertebral body aiming laterally) and a long-axis approach (entry lateral to the foramina of S3 and 4 vertebral bodies aimed cranially). The lateral approach follows the approach used for percutaneous ISF. Typically, 1.5–7.5 mL of polymethyl methacrylate is injected into the affected sacral ala.

In the first few years of using sacroplasty for treating sacral insufficiency fractures, case reports and very small case series with short follow-up periods were mainly published. Thus far, two large prospective studies have demonstrated long-term reduction in pain after sacroplasty. These studies reported a significant reduction in pain over 10 years in comparison with conservative therapy, although only 55.7% of patients undergoing surgery were followed up. Major complications were not reported [19, 20].

Three randomised trials have compared sacroplasty with balloon kyphoplasty for the treatment of sacral insufficiency fractures [21 – 23]. After a follow-up period of 18–24 months, both techniques showed significant and clinically relevant reduction in pain without important clinical differences in outcomes. However, asymptomatic cement extravasation occurred in 8.1% of cases of sacroplasty, whereas it was not reported with balloon kyphoplasty [22]. On the other hand, the operative duration was significantly longer with balloon kyphoplasty [23].

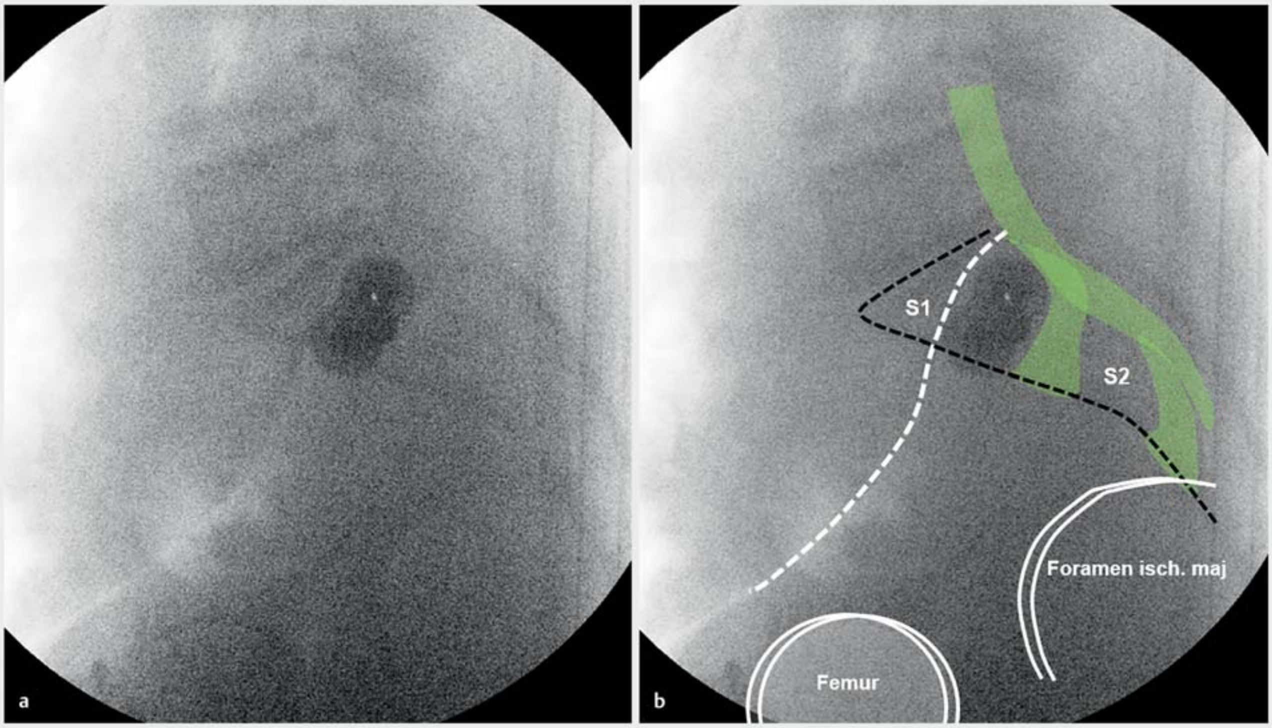
Single Iliosacral Screw Fixation (ISF) S1

Single ISF is a minimally invasive technique for stabilising the posterior pelvic ring. It is indicated for transalar, transforaminal, and trans-sacral fractures [24]. Thereby, fracture reduction cannot be performed by ISF. Thus, fracture reduction needs to be done prior screw insertion.

Precise preoperative planning with axial, coronal, and sagittal CT reconstructions and the analysis of existing bony corridors is essential [25]. It is crucial to recognise sacral dysplasia, which often makes it difficult to safely place screws in the S1 vertebra [26].

Image converter-guided screw fixation can be performed in the prone or supine position. It is helpful to draw the so-called "safe zone" of the sacrum and the planned incision in the lateral image converter view before skin incision (Fig. 1). As a rule, through a stab incision, a thick Kirschner wire is initially inserted into the S1 body under image converter guidance in the inlet, outlet, and lateral views. Next, after overdrilling to the medial aspect of the SIJ, a cannulated screw is advanced into the S1 body (usually 6.5–7.5-mm calibre with a washer) [27]. Compression can be achieved with short-thread screws according to the lag screw principle. In compressed fractures, the improved purchase provided by fully threaded screws may lead to a decreased screw-loosening rate. Attention should be paid not to make any shearing movements with the wire or guidewire across the lateral ilium to minimise the risk of superior gluteal artery injuries.

Clinically, after ISF, patients show significantly reduced pain intensity, improved independence, and rapid recovery of mobility



▶ **Fig. 1** **a** The lateral image converter view of the posterior pelvis is shown; the cannulated screws inserted in S1 bilaterally along the longitudinal axis. **b** This shows the same image with outlining of the relevant structures. The lateral view is correctly set when the right and left femoral heads (femur) and the greater sciatic foramen are superimposed over each other. The black dashed line represents the superior end plate of S1 and the anterior wall of the sacrum. The white dashed line is a radiographic superimposition of the cranial borders of both the sacral ala and arcuate line of the ilium. The green area represents the vertebral canal posterior to the sacrum with the cauda equina.

[28 – 30]. Eckardt et al., for example, reported that approximately two-thirds of patients were pain-free after 12 months [30]. Hopf et al. [29] reported a decrease in pain intensity, with a reduction in the visual analogue scale score from 6.8 at admission to 1.8 at discharge. After 1 year of treatment, the patients in the group of Höch et al. [28] achieved the pain level, quality of life (measured using the 12-Item Short Form Survey), and mobility of age-matched individuals in the general population.

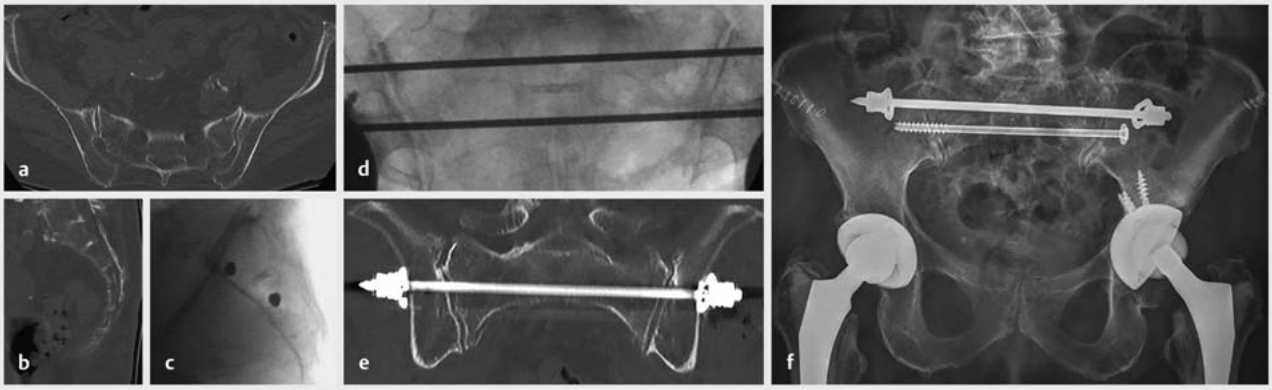
The complication rates offset the excellent results of existing studies. Screw malposition, which may be asymptomatic, is listed as the main complication in approximately 17 % of cases with conventional approaches [31, 32]. Navigated wire placement can considerably reduce the incidence of screw malposition. Alternatively, the correct position of the Kirschner wire should be confirmed using a three-dimensional (3D) image converter view before screw insertion. Screw loosening has also been reported. However, accurate reduction by appropriate closed manipulative reduction or minimally invasive reduction techniques (e.g., using joysticks) before screw insertion can minimise the incidence of screw loosening [33]. Further complications include injuries to the gluteal arteries, intrapelvic vessels, spinal nerves, and intrapelvic hollow organs.

If cement augmentation is considered along with ISF to improve stability, cement embolism must be considered as a possible complication. The risk can be reduced with the use of cannulated screw systems [28, 33]. Reliable data are only available from the field of cement augmentation of vertebral body fractures.

Double ISF S1 or S1/S2

Double screw fixation should be considered for stabilising vertically unstable fractures (FFP III or IV). Single screw fixation is usually sufficient for other fractures. Biomechanical studies have shown that two ipsilateral screws can significantly improve the stability of the posterior pelvic ring [34, 35]. This is particularly because of lower rotational instability than that of only one screw [36].

The lateral portions of S2 are extremely narrow in some patients and can only be intraoperatively visualised well with experience under the image converter. Hence, many surgeons prefer to insert a single S1 screw without inserting an S2 screw, unless CT guidance or navigation is available [27]. However, insertion of iliosacral screws, even in S2, was not associated with an increased risk of malposition, nerve lesions, or revision surgery [31]. Thus far, no difference in the incidence of surgery-related nerve complications between navigation/CT-guided and conventional techniques has been reported.



▶ **Fig. 2** A case of spontaneous onset of low back pain and evidence of a bilateral sacral fracture is shown (**a, b**). Surgical intervention was indicated because of pain-related limited mobilisation despite analgesia. A trans-sacral bar was inserted in S1. A 7.3-mm screw was inserted trans-sacrally in S2 because of the narrow transverse corridor in S2. Intraoperatively, the accurate implant placement is shown (**c, d**). This was postoperatively confirmed using CT (**e**). Postoperatively, the patient's mobility improved rapidly. Implant placement and fracture reduction remained unchanged during the postoperative course (**f**).

For S2, access can be obtained through either the same incision or a second incision. After determining the correct entry point, another K-wire can be inserted in the inlet view parallel to the K-wire left in the S1 screw. The wire is moved in the outlet view along the longitudinal axis of the sacrum caudal to the S1 foramen and drilled a few millimetres into the bone. After rechecking in the inlet view, the wire can now be driven further into the S2 body. Then, a cannulated screw is placed over it. In case of uncertainty, the positional relationship of the wire to the foramen and the anterior and posterior walls of S2 should also be determined in the lateral image converter view (▶ **Fig. 1**).

Trans-Sacral Bar/Trans-Sacral Screw Fixation

In this technique, a screw inserted through the ipsilateral ilium is passed through the sacrum and then through the contralateral ilium (▶ **Fig. 2**). These bilateral implants showed advantages over bilateral screw fixation in a biomechanical study [37]. The prerequisite for this is a matching transverse bony corridor, which is present in S1 and S2 in approximately 75–80% and 90–99% cases, respectively [25, 37]. It was shown that the S1 corridor was found significantly less frequently in women than in men [37]. An evaluation of 105 CT images showed that at least one corridor was always present in all subjects [38]. The method is particularly suitable for the treatment of bilateral insufficiency fractures of the posterior pelvic ring [39, 40]. Due to the risk of progression of unilateral pelvic insufficiency fractures to bilateral ones, some authors also use this procedure for predominantly unilateral fractures [41, 42]. This aims to prevent secondary fractures on the contralateral side [43].

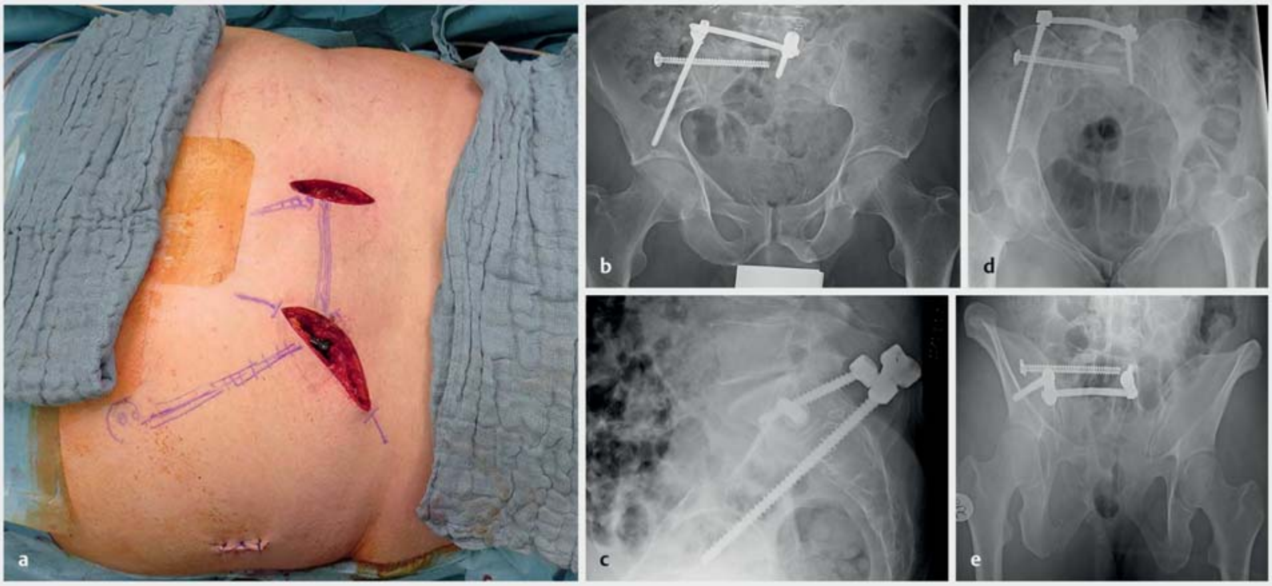
The technical implementation of the procedure is possible through the use of an image converter analogous to that of ISF. An important landmark here is the confirmation of S1 transverse corridor in the lateral view, as well as in the lateral, inlet, and outlet views [44]. The basic prerequisite is to study the individual anatomy in detail preoperatively to recognise whether trans-sacral fixation using a trans-sacral bar is possible (S1 and S2 corridors or only S2 corridor). Screws 150–180 mm in length are typically used for S1, and screws 140–160 mm in length are used for S2. Compression can be achieved using washers. When using a threaded rod, it is possible to lock the rod on both sides, which secures the compression and prevents migration. Consequently, a contralateral incision is necessary when using the trans-sacral bar.

A case series has already demonstrated the successful clinical applicability of the trans-sacral bar [45]. However, single trans-sacral screw fixation is biomechanically inferior to cemented S1/2 ISF [36].

Transiliac Internal Fixator Stabilisation

In 2004, Füchtmeier et al. [46] reported the first clinical results using the transiliac internal fixator in predominantly Type C unilateral pelvic ring fractures. Primarily, the screws were placed parallel to the superior gluteal line in the ilium. Purely from an anatomical perspective, particularly extra-long screws can be implanted in the supra-acetabular region, with the screw course being more angulated caudally toward the acetabulum. The screws also traverse an area of increased cancellous bone density in the supra-acetabular region [47].

Subsequently, the results after cement augmentation of this fixator arrangement have also been described in unstable insufficiency fractures [48, 49]. As a modification of this method, it is possible to use the transiliac internal fixator for the treatment of Type B unilateral pelvic ring fractures. This can be performed by shortening the posterior fixator arrangement and placing a screw on the contralateral side of the sacrum at the level of the S1 pedicle. Complementary ISF can compensate for the limited compression potential of this technique. The combination of a transiliac internal fixator with ISF, the so-called "iliosacral bridging,"



▶ **Fig. 3** A case of trans-sacral internal fixator stabilisation consisting of trans-fixation between the iliosacral screw and contralateral S1 pedicle screw is shown. ISF was also performed. The minimally invasive approach with landmarks is shown in (**a**). Postoperative radiographs in four planes shows an anatomical reduction of the pelvis fracture with accurate implant placement (**b**–**e**).

showed good results in a patient population with varying ages and injury severities [47, 50] (▶ **Fig. 3**).

The procedure is performed in the prone position using the image converter-guided technique. It is helpful to preoperatively mark the projected course of the transiliac screw, with particular emphasis on the marking of the femoral head centre. Siekmann et al. has described the surgical technique in detail [47].

In addition to general complications, risks arise from the implantation of the posterior internal fixator as well as from the use of ISF. The frequency of complications is low and because of the almost identical implantation techniques, equal to those of lumbopelvic support [51, 52].

Lumbopelvic, Vertebropelvic, or Triangular Support

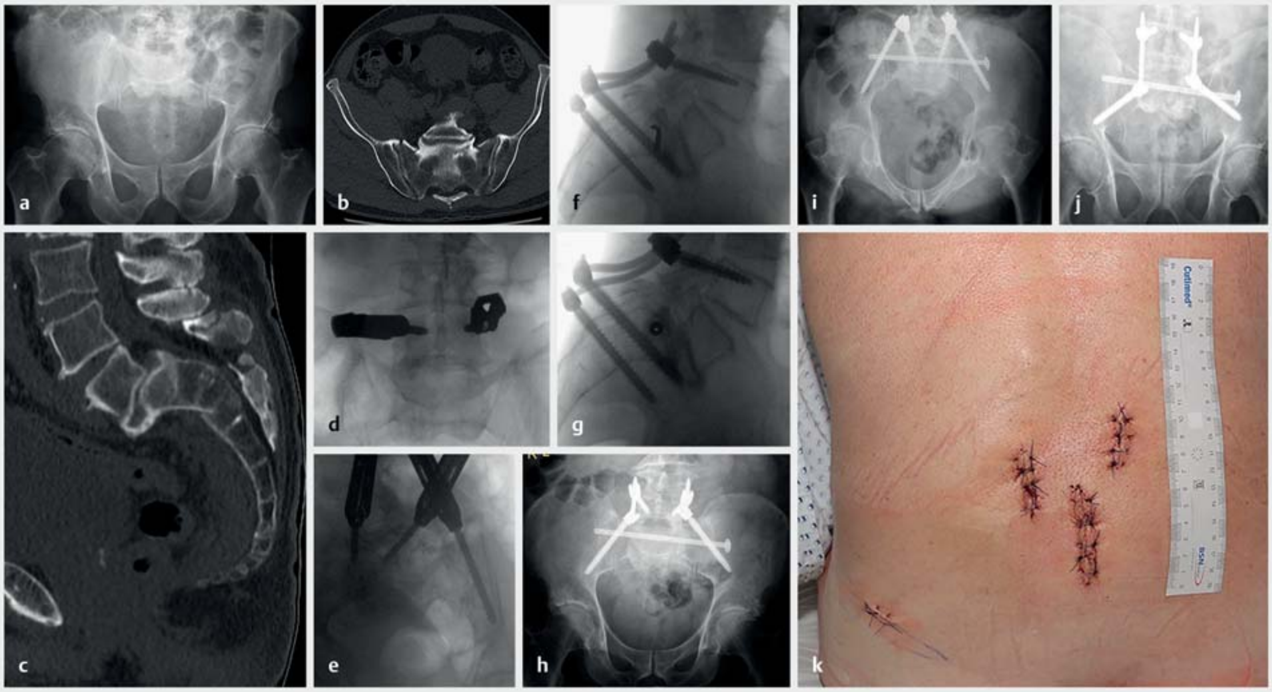
Lumbopelvic fixator support is biomechanically superior to ISF alone in fractures with vertical instability. For example, in a clinical study, Schildhauer et al. [14] reported significantly lower incidences of dislocations after performing lumbopelvic support in combination with ISF than that after ISF alone. Similarly, Acklin et al. [53] reported considerable biomechanical advantages of lumbopelvic support in combination with ISF compared with ISF alone in patients with reduced bone quality. A clinical study demonstrated the superiority of lumbopelvic support compared with ISF alone in complex bilateral sacral U- and H-type fractures with vertically instability [54], although these studies essentially only included patients without osteoporosis after high-speed traumas.

Collectively, lumbopelvic support is technically easy to perform using minimally invasive techniques [51], which significantly reduces the incidence of postoperative wound infections [51]. It also affords a relatively low complication rate in geriatric patients. For example, revision surgery due to postoperative wound infection was necessary in only 1 of 15 patients (6.7%) undergoing minimally invasive lumbopelvic fixation [49]. Other complications, such as subcutaneous hematoma (n = 1), cement extravasations into the soft tissue (n = 2), and screw rupture with only minimal symptoms (n = 1), did not require further treatment. Using a combination with additional ISF, a so-called “triangular support,” the stability of fixation can be further improved [14] (▶ **Fig. 4**). Alternatively, with the use of ISF as supplementation, compression can be achieved even using a cross-connector in bilateral lumbopelvic support, which is difficult to perform percutaneously depending on the implant used.

Furthermore, additive cement augmentation has been reported to show no therapy-related implant failure and promising clinical results over 2 years [52]. Although additive cement augmentation of screws is considered fundamentally necessary, it cannot be recommended because of insufficient supporting evidence.

Discussion

The important question in the treatment of pelvic insufficiency fractures is whether surgery is indicated or whether conservative treatment is recommended. As highly unstable fracture types are usually the exception among insufficiency fractures, pain severity and ability of mobilisation under adequate analgesia are particu-



▶ **Fig. 4** A 69-year-old patient experienced increasing pain within the last 2 weeks after a fall from a standing position some weeks ago. Diagnostic imaging showed a sacral insufficiency fracture [FFP IV b with an H component in terms of spinopelvic dissociation (**a–c**)]. Percutaneous lumbopelvic support was performed with trans-sacral screw connection (pedicle screw insertion, **d**; first iliosacral screw insertion, **e**; trans-sacral guidewire insertion, **f**; final lateral intraoperative radiograph, **g**). Postoperatively, it was possible to quickly mobilise the patient with low levels of pain with maintenance of fracture reduction and implant placement (**h–j**). Postoperative wound check was unremarkable (**k**). Both iliosacral screws were inserted through the central approach.

larly important factors to be considered for treatment decision-making. ▶ **Table 1** presents the summarised parameters that require continuation of conservative therapy. It is necessary to diagnose and treat the existing bone metabolism disorder using conservative and surgical therapies. Moreover, before making treatment-related decisions, sufficient diagnostic investigations are required; these should involve pelvic CT in addition to conventional radiography and magnetic resonance imaging (MRI), particularly for unilateral sacral fractures [55]. Alternatively, dual-energy CT can be performed [56].

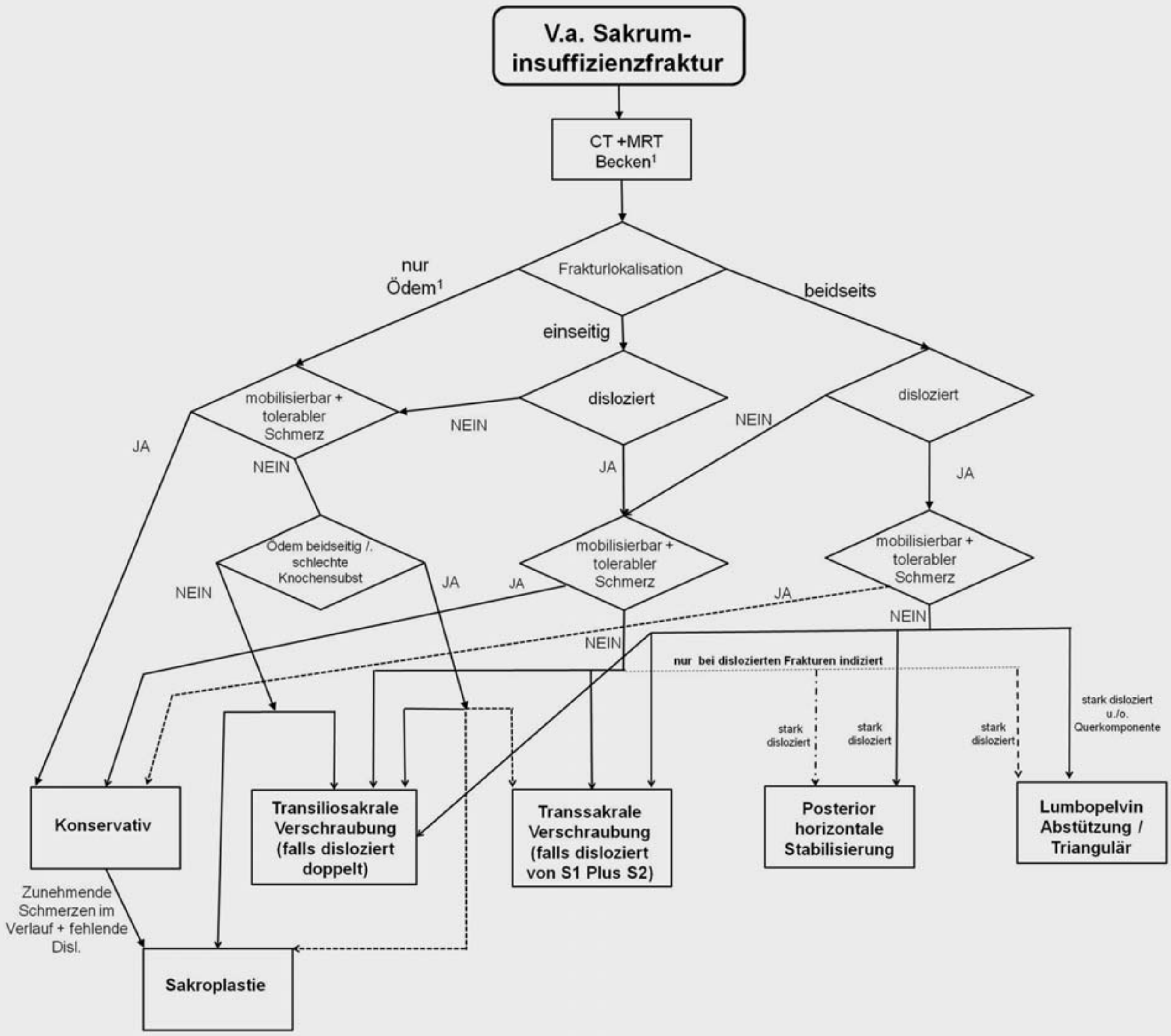
If surgery is required, many minimally invasive procedures are available for treating sacral insufficiency fractures. They differ significantly in operative time, implant cost, and stability of internal fixation. Therefore, a treatment strategy adapted to the patient and the fracture morphology needs to be selected.

▶ **Table 1** Implementation or continuation of conservative treatment.

- Tolerable pain situation under analgesia
- Relevant improvements in mobilisation
- Maintenance of fracture reduction after mobilisation
- Lack of highly unstable fractures

The lowest level of stability of internal fixation can be expected from sacroplasty. However, the results of a systematic review show that sacroplasty has positive effects on improving the quality of life and reducing pain [57]. As a limitation, the lack of data regarding dropout rates in the long-term investigations by Frey et al. [20] must be noted because these are very high in such patient groups and can strongly impact the interpretation of results. Sacroplasty is mainly indicated for undisplaced unilateral fractures. As an exception, it is used for bilateral insufficiency fractures without a cross-component or other signs of instability after failed primary conservative treatment. The clinical outcomes of conventional sacroplasty are reported to be similar to those of balloon sacroplasty [19, 20]. Consequently, conventional sacroplasty has been favoured due to reduced expenses and decreased operative times despite the increased rate of clinically “silent” cement extravasations [21 – 23]. However, the authors of the review believe that the biomechanical inferiority of the procedure and cement non-unions should be considered before making treatment decisions.

Generally, percutaneous ISF plays a crucial role in the treatment of sacral insufficiency fractures. ISF of both S1 and S2 are safe techniques with low complication rates for decreasing the pain intensity and improving mobility and quality of life [28 – 30]. Double ISF improves biomechanical stability, particularly that of the rotatory component; hence, it may be used in highly unstable



▶ **Fig. 5** A therapy algorithm for the treatment of a sacral insufficiency fracture is shown. Apart from cross-sectional imaging (CT and MRT), conventional radiography images including full pelvis, inlet, and outlet views is recommended. Treatment options are presented based on their invasiveness in the ascending order from left to right without prioritising individual treatment options. Sacroplasty is deliberately listed at the bottom because most studies listed it as an indication in cases with a lack of symptomatic improvement after initial conservative therapy. Hence, sacroplasty often plays a subordinate role in acute situations. Moreover, in cases with pure marrow enema (unilateral or bilateral), internal fixation (iliosacral or trans-sacral) should be chosen with caution. Bilateral undisplaced sacral fractures can be treated with either conservative therapy or an operative treatment using ISF or trans-sacral screw fixation. Transiliac internal fixator or lumbopelvic support is usually not indicated. In contrast, conservative therapy is an exception in bilateral displaced sacral fractures. It is only indicated in patients with only minor clinical symptoms or those with operative contraindications. The indication for double iliosacral or trans-sacral screw fixation or stabilisation using the lumbopelvic support of transiliac internal fixator is based on the extent of injury of the anterior pelvic ring, fracture position, and instability criteria, such as the presence of a transverse component. Generally, in the treatment of sacral fractures, it is necessary to consider injuries of the anterior pelvic ring and integrate them into the therapeutic model. ISF can be used with cement augmentation. This is a valuable option for the improvement of screw retention in cases with poor bone stock and limited screw purchase.

► **Table 2** Advantages and disadvantages of minimally invasive operative concepts for insufficiency fractures of the sacrum

Therapy strategy	Advantages	Disadvantages	Contraindications
Sacroplasty	▪ Technically relatively simple ▪ Relatively good study situation for stable fractures and persistent pain under conservative therapy	▪ Cement interference in the fracture area ▪ Danger of cement extravasation ▪ No possibility for fracture reduction or compression	▪ Unstable and/or displaced fractures
ISF	▪ Technically relatively simple ▪ Implementable both unilaterally and bilaterally in S1, S2, or both ▪ Good customisation according to fracture morphology ▪ Applicable in combination with the other types of treatment	▪ With cement augmentation; there is the danger of cement extravasation ▪ Offers fracture compression option; no possibility of fracture reduction through the implant	▪ U- and H-type fractures with transverse component through S1 ▪ Sole simple ISF with U- or H-type fractures
Trans-sacral bar/trans-sacral screw fixation	▪ Compression option using the trans-sacral bar ▪ There is no need for cement augmentation with corresponding risks.	▪ For unilateral fractures of the sacrum, an intact SIF joint is fixed and immobilised ▪ Except for the compression option, there is no possibility of fracture reduction through the implant	▪ Sacral dysplasia ▪ U- and H-type fractures with transverse component through S1 ▪ Sole trans-sacral bar with U- or H-type fractures
Transiliac internal fixator	▪ Stable fixation without bridging the segments L5/S1	▪ Limited compression options ▪ Potentially interfering implant	Relative: ▪ Stable and undisplaced fractures
Lumbopelvic support	▪ Biomechanically most stable fixation ▪ Fracture reduction option through instrumentation ▪ Applicable in combination with ISF and a trans-sacral screw fixation.	▪ Trans-fixation of the potentially intact segment L5/S1 and possibly L4/5 ▪ Potentially interfering implants ▪ Relatively high rate of wound infections.	▪ Relative: ▪ Stable and undisplaced fractures

ISF: Iliosacral screw fixation

FFP IV fractures, fractures with severe comminution zones, or in patients with extremely poor bone stock [36]. It is essential for contralateral injuries to be ruled out preoperatively for cases in which a unilateral procedure is being planned. Because injuries also include pure bone marrow edemas in such cases, preoperative MRI examinations are recommended.

Generally, it has to be considered that no fracture reduction can be performed using only ISF, except for compression using short-threaded screws. Hence, this technique should be used for either undisplaced fractures or after fracture reduction by a closed manipulative reduction through mounting or minimally invasive reduction techniques (minor extra access or joystick methods).

We recommend fully threaded screws that are as long as possible in patients with poor bone quality. Cement augmentation of the screws can further improve screw stability [36].

Similarly, if transverse bony corridors are present, extra-long screws may be placed in S1 or S2, reaching or extending beyond the contralateral SIJ. Alternatively, the trans-sacral bar may be employed. There is some contention regarding whether extra-long screws or the trans-sacral bar should be used only for bilateral sacral fractures and not for unilateral ones. The proponents of bilateral intervention argue that conservative treatment of unilateral sacral insufficiency fractures increases the risk of secondary contralateral fractures [41, 42]. The counterargument is the prevention of the unnecessary fixation of an intact SIJ.

Moreover, ISF can be combined with a lumbopelvic support or a transiliac internal fixator, which may be indicated for highly unstable fractures, such as those with spinopelvic dissociation.

The main complication of ISF is screw malposition. Therefore, use of navigation or intraoperative 3D imaging should be considered. The advantages of 3D imaging for the treatment of posterior pelvic ring fractures is apparent. Two studies reported a significant improvement in the screw placement accuracy compared with conventional two-dimensional imaging [58, 59]. However, another study using an image converter failed to confirm the advantage of this over conventional techniques [60]. Generally, a large angle between the screw directions and the use of extra-long iliosacral screws were found to be risk factors for screw misplacement [61]. Another advantage of intraoperative 3D imaging is the possibility of ensuring accurate placement of implants controlling fracture reduction accuracy, which may improve the operative results [33]. On the other hand, the disadvantages of intraoperative 3D imaging of the pelvis are the need for technical expertise, higher time expenditure for navigation, and insufficient image quality [62].

The transiliac internal fixator, implanted via puncture incisions and a minimally invasive procedure, is a soft tissue-friendly technique that can be used alone or in combination with other techniques [47]. Moreover, fracture reduction is also possible using this technique. This makes stable fixation possible even in the case of anatomical variants of the pelvis in which ISF placement may be impeded [47].

Rotational stability can be achieved particularly through a combination of an iliosacral screw and posterior fixator. Biomechanical investigations regarding this are lacking.

The most stable type of fixation is lumbopelvic support [39]. However, data regarding its application for the treatment of insufficiency fractures is limited. There are differences in vertical instability seen in pelvic fractures in patients with healthy bone stock after high-speed trauma (e.g., type Denis B fracture and Isler B or C configuration) and that in pelvic insufficiency fractures with a slowly developing fracture cascade associated with mostly intact ligaments [1]. Overall, it is recommendable to perform lumbopelvic support combined with an iliosacral screw in pelvic insufficiency fractures because of its biomechanical superiority [53].

▶ **Fig. 5** shows a potential treatment algorithm for the management of sacral fractures. The advantages and disadvantages of individual treatment strategies, including contraindications, are shown in ▶ **Table 2**. The anterior pelvic ring needs to be evaluated before making a decision regarding the treatment of sacral fractures. This has an important effect on classification and treatment strategy [1]. For instance, additional treatment of the anterior fracture component is recommended when using ISF of S1 alone for the treatment of FFP II b or IIC fractures. Depending on the fracture position and morphology, ISF can be supplemented using percutaneous screws of the anterior pelvic ring along with external (supra-acetabular) or internal (supra-acetabular) fixators. Alternatively, open fixation of the anterior pelvic ring using plates is possible in most cases via an anterior intrapelvic approach. Moreover, when selecting the type of treatment, fracture localisation in relation to the vertebral foramens must be considered when using the Denis classification of sacral fractures [63]. For instance, ISF is insufficient for a central sacral fracture of Denis Type III; instead, transiliac internal fixator is reasonable for internal stabilisation. Overall, however, insufficiency fractures are usually located in the sacral ala region [17].

Moreover, sacral fractures need to be differentiated from transiliac or iliosacral fractures, which are not the subject of this review.

In summary, sacroplasty is indicated for undisplaced fractures of the sacrum and failed conservative therapy. Alternatively, percutaneous ISF can be used, which can also be used for displaced or unstable fractures of the sacrum. The essential requirement is an anatomically reduced fracture. Depending on the degree of instability, single ISF or double ISF in S1, S2, or both can be performed with cement augmentation. For bilateral sacral fractures and poor bone quality, trans-sacral screw fixation is useful. However, this requires a corresponding bone corridor. For highly unstable fractures, percutaneous lumbopelvic support or transiliac internal fixator is recommended, which, in every case, can be combined with ISF. For reducing screw misplacements, especially with dysmorphic types of pelvis, navigation or intraoperative 3D scan is useful.

Acknowledgements

We thank Dr. Thomas Mendel, who operated one of the depicted cases.

Conflict of Interest

U. Spiegl: Material Support Fa. Medacta; G. Osterhoff: Consultant: Fa. Medtronic; BW Ullrich: Consultant: Fa. Braun

References

[1] Rommens PM, Hofmann A. Comprehensive classification of fragility fractures of the pelvic ring: Recommendations for surgical treatment. Injury 2013; 44: 1733–1744

[2] Abe H, Nakamura M, Takahashi S et al. Radiation-induced insufficiency fractures of the pelvis: evaluation with 99 mTc-methylene diphosphonate scintigraphy. AJR Am J Roentgenol 1992; 158: 599–602

[3] Lapina O, Tiskevicius S. Sacral insufficiency fracture after pelvic radiotherapy: a diagnostic challenge for a radiologist. Medicina (Kaunas) 2014; 50: 249–254

[4] Dasgupta B, Shah N, Brown H et al. Sacral insufficiency fractures: an unsuspected cause of low back pain. Br J Rheumatol 1998; 37: 789–793

[5] Grangier C, Garcia J, Howarth NR et al. Role of MRI in the diagnosis of insufficiency fractures of the sacrum and acetabular roof. Skeletal Radiol 1997; 26: 517–524

[6] Deschamps Perdomo A, Tome-Bermejo F, Pinera AR et al. Misdiagnosis of sacral stress fracture: an underestimated cause of low back pain in pregnancy? Am J Case Rep 2015; 16: 60–64

[7] Finiels H, Finiels PJ, Jacquot JM et al. [Fractures of the sacrum caused by bone insufficiency. Meta-analysis of 508 cases]. Presse Med 1997; 26: 1568–1573

[8] Weber M, Hasler P, Gerber H. Insufficiency fractures of the sacrum. Twenty cases and review of the literature. Spine 1993; 18: 2507–2512

[9] Schindler OS, Watura R, Cobby M. Sacral insufficiency fractures. J Orthop Surg (Hong Kong) 2007; 15: 339–346

[10] Burge R, Dawson-Hughes B, Solomon DH et al. Incidence and economic burden of osteoporosis-related fractures in the United States, 2005–2025. J Bone Miner Res 2007; 22: 465–475

[11] Richards AM, Coleman NW, Knight TA et al. Bone density and cortical thickness in normal, osteopenic, and osteoporotic sacra. J Osteoporos 2010; 504078

[12] Linstrom NJ, Heiserman JE, Kortman KE et al. Anatomical and biomechanical analyses of the unique and consistent locations of sacral insufficiency fractures. Spine 2009; 34: 309–315

[13] De Smet AA, Neff JR. Pubic and sacral insufficiency fractures: clinical course and radiologic findings. AJR Am J Roentgenol 1985; 145: 601–606

[14] Schildhauer TA, Josten C, Muhr G. Triangular osteosynthesis of vertically unstable sacrum fractures: a new concept allowing early weight-bearing. J Orthop Trauma 2006; 20 (1 Suppl.): S44–S51

[15] Leung KS, Chien P, Shen WY et al. Operative treatment of unstable pelvic fractures. Injury 1992; 23: 31–37

[16] Dehdashti AR, Martin JB, Jean B et al. PMMA cementoplasty in symptomatic metastatic lesions of the S1 vertebral body. Cardiovasc Intervent Radiol 2000; 23: 235–237

[17] Marcy PY, Palussiere J, Descamps B et al. Percutaneous cementoplasty for pelvic bone metastasis. Support Care Cancer 2000; 8: 500–503

[18] Garant M. Sacroplasty: a new treatment for sacral insufficiency fracture. J Vas Interv Radiol 2002; 13: 1265–1267

[19] Heo DH, Park CK. Percutaneous Sacroplasty for Non-neoplastic Osteoporotic Sacral Insufficiency Fractures. Pain Physician 2017; 20: 89–94

[20] Frey ME, Warner C, Thomas SM et al. Sacroplasty: A Ten-Year Analysis of Prospective Patients Treated with Percutaneous Sacroplasty: Literature Review and Technical Considerations. Pain Physician 2017; 20: E1063–E1072

[21] Andresen R, Radmer S, Andresen JR et al. Comparison of the 18-month outcome after the treatment of osteoporotic insufficiency fractures by means of balloon sacroplasty (BSP) and radiofrequency sacroplasty (RFS) in comparison: a prospective randomised study. Eur Spine J 2017; 26: 3235–3240

[22] Andresen R, Radmer S, Andresen JR et al. Clinical Improvement and Cost-effectiveness of CT-guided Radiofrequency Sacroplasty (RFS) and Cement Sacroplasty (CSP) – a Prospective Randomised Comparison of Methods. Z Orthop Unfall 2019; 157: 524–533

[23] Yang SC, Tsai TT, Chen HS et al. Comparison of sacroplasty with or without balloon assistance for the treatment of sacral insufficiency fractures. J Orthop Surg (Hong Kong) 2018; 26: 2309499018782575

[24] Krappinger D, Kaser V, Kammerlander C et al. Inter- and intraobserver reliability and critical analysis of the FFP classification of osteoporotic pelvic ring injuries. Injury 2019; 50: 337–343

[25] Mendel T, Noser H, Kuervers J et al. The influence of sacral morphology on the existence of secure S1 and S2 transverse bone corridors for iliosacroiliac screw fixation. Injury 2013; 44: 1773–1779

[26] Laux CJ, Weigelt L, Osterhoff G et al. Feasibility of iliosacral screw placement in patients with upper sacral dysplasia. J Orthop Surg Res 2019; 14: 418

[27] Hilgert RE, Finn J, Egbers HJ. [Technique for percutaneous iliosacral screw insertion with conventional C-arm radiography]. Unfallchirurg 2005; 108: 954–960

[28] Höch A, Pieroh P, Henkelmann R et al. In-screw polymethylmethacrylate-augmented sacroiliac screw for the treatment of fragility fractures of the pelvis: a prospective, observational study with 1-year follow-up. BMC Surg 2017; 17: 132

[29] Hopf JC, Krieglstein CF, Müller LP et al. Percutaneous iliosacral screw fixation after osteoporotic posterior ring fractures of the pelvis reduces pain significantly in elderly patients. Injury 2015; 46: 1631–1636

[30] Eckardt H, Egger A, Hasler RM et al. Good functional outcome in patients suffering fragility fractures of the pelvis treated with percutaneous screw stabilisation: assessment of complications and factors influencing failure. Injury 2017; 48: 2717–2723

[31] Osterhoff G, Ossendorf C, Wanner GA et al. Percutaneous iliosacral screw fixation in S1 and S2 for posterior pelvic ring injuries: technique and perioperative complications. Arch Orthop Trauma Surg 2011; 131: 809–813

[32] Zwingmann J, Hauschild O, Bode G et al. Malposition and revision rates of different imaging modalities for percutaneous iliosacral screw fixation following pelvic fractures: a systematic review and meta-analysis. Arch Orthop Trauma Surg 2013; 133: 1257–1265

[33] Camino Willhuber G, Zderic I, Gras F et al. Analysis of sacro-iliac joint screw fixation: does quality of reduction and screw orientation influence joint stability? A biomechanical study. Int Orthop 2016; 40: 1537–1543

[34] van Zwienen CM, van den Bosch EW, Snijders CJ et al. Biomechanical comparison of sacroiliac screw techniques for unstable pelvic ring fractures. J Orthop Trauma 2004; 18: 589–595

[35] Zwingmann J, Konrad G, Kotter E et al. Computer-navigated iliosacral screw insertion reduces malposition rate and radiation exposure. Clin Orthop Relat Res 2009; 467: 1833–1838

[36] Osterhoff G, Dodd AE, Unno F et al. Cement Augmentation in Sacroiliac Screw Fixation Offers Modest Biomechanical Advantages in a Cadaver Model. Clin Orthop Relat Res 2016; 474: 2522–2530

[37] Vanderschot PM, Broens PM, Vermeire JI et al. Trans iliac-sacral-iliac bar stabilization to treat bilateral sacro-iliac joint disruptions. Injury 1999; 30: 637–640

[38] Trikha V, Gaba S, Kumar A et al. Safe corridor for iliosacral and trans-sacral screw placement in Indian population: A preliminary CT based anatomical study. J Clin Orthop Trauma 2019; 10: 427–431

[39] Wagner D, Ossendorf C, Gruszka D et al. Fragility fractures of the sacrum: how to identify and when to treat surgically? Eur J Trauma Emerg Surg 2015; 41: 349–362

[40] Rommens PM, Ossendorf C, Pairon P et al. Clinical pathways for fragility fractures of the pelvic ring: personal experience and review of the literature. J Orthop Sci 2015; 20: 1–11

[41] Rommens PM, Arand C, Hopf JC et al. Progress of instability in fragility fractures of the pelvis: an observational study. Injury 2019; 50: 1966–1973

[42] Mendel T, Ullrich BW, Hofmann GO et al. Progressive instability of bilateral sacral fragility fractures in osteoporotic bone: a retrospective analysis of X-ray, CT, and MRI datasets from 78 cases. Eur J Trauma Emerg Surg 2021; 47: 11–19

[43] Lattauschke A, Klauke F, Ullrich BW et al. [Course of operative treatment of a sacral insufficiency fracture: successful or serious treatment?]. Unfallchirurg 2017; 120: 890–895

[44] Mehling I, Hessmann MH, Rommens PM. Stabilization of fatigue fractures of the dorsal pelvis with a trans-sacral bar. Operative technique and outcome. Injury 2012; 43: 446–451

[45] Moed BR, Whiting DR. Locked transsacral screw fixation of bilateral injuries of the posterior pelvic ring: initial clinical series. J Orthop Trauma 2010; 24: 616–621

[46] Füchtmeier B, Maghsudi M, Neumann C et al. [The minimally invasive stabilization of the dorsal pelvic ring with the transiliacal internal fixator (TIFI)–surgical technique and first clinical findings]. Unfallchirurg 2004; 107: 1142–1151

[47] Siekmann H, Becherer L, Neef R. “Iliosacral bridging” – A new alternative minimal invasive fixation of unstable pelvic ring fractures. Arch Surg Clin Res 2018; 2: 29–46

[48] Schmitz P, Baumann F, Grechenig S et al. The cement-augmented transiliacal internal fixator (caTIFI): an innovative surgical technique for stabilization of fragility fractures of the pelvis. Injury 2015; 46 (Suppl. 4): S114–S120

[49] Schmitz P, Baumann F, Acklin YP et al. Clinical application of a minimally invasive cement-augmentable Schanz screw rod system to treat pelvic ring fractures. Int Orthop 2019; 43: 697–703

[50] Ebraheim NA, Lin D, Xu R et al. Computed tomographic evaluation of the internal structure of the lateral sacral mass in the upper sacra. Orthopedics 1999; 22: 1137–1140

[51] Williams SK, Quinnan SM. Percutaneous Lumbopelvic Fixation for Reduction and Stabilization of Sacral Fractures With Spinopelvic Dissociation Patterns. J Orthop Trauma 2016; 30: e318–e324

[52] Schmitz P, Lüdeck S, Baumann F et al. Patient-related quality of life after pelvic ring fractures in elderly. Int Orthop 2019; 43: 261–267

[53] Acklin YP, Zderic I, Richards RG et al. Biomechanical investigation of four different fixation techniques in sacrum Denis type II fracture with low bone mineral density. J Orthop Res 2018; 36: 1624–1629

[54] Schroeder GD, Savage JW, Patel AA et al. Spinopelvic Fixation in Complex Sacral Fractures. JBJS Reviews 2015. doi:10.2106/JBJS.RVW.N.00007

[55] Spiegl UJA, Schnake KJ, Osterhoff G et al. Imaging of Sacral Stress and Insufficiency Fractures. Z Orthop Unfall 2019; 157: 144–153

[56] Palm HG, Lang P, Hackenbroch C et al. Dual-energy CT as an innovative method for diagnosing fragility fractures of the pelvic ring: a retrospective comparison with MRI as the gold standard. Arch Orthop Trauma Surg 2020; 140: 473–480

[57] Chandra V, Wajswol E, Shukla P et al. Safety and Efficacy of Sacroplasty for Sacral Fractures: A Systematic Review and Meta-Analysis. J Vasc Interv Radiol 2019; 30: 1845–1854

[58] Ghisla S, Napoli F, Lehoczky G et al. Posterior pelvic ring fractures: Intraoperative 3D-CT guided navigation for accurate positioning of sacro-iliac screws. Orthop Traumatol Surg Res 2018; 104: 1063–1067

[59] Behrendt D, Mutze M, Steinke H et al. Evaluation of 2D and 3D navigation for iliosacral screw fixation. Int J Comput Assist Radiol Surg 2012; 7: 249–255

[60] Briem D, Windolf J, Rueger JM. [Percutaneous, 2D-fluoroscopic navigated iliosacral screw placement in the supine position: technique, possibilities, and limits]. Unfallchirurg 2007; 110: 393–401

[61] Takao M, Hamada H, Sakai T et al. Factors influencing the accuracy of iliosacral screw insertion using 3D fluoroscopic navigation. ArchOrthop Trauma Surg 2019; 139: 189–195

[62] Thakkar SC, Thakkar RS, Sirisreetreerux N et al. 2D versus 3D fluoroscopy-based navigation in posterior pelvic fixation: review of the literature on current technology. Int J Comput Assist Radiol Surg 2017; 12: 69–76

[63] Denis F, Davis S, Comfort T. Sacral fractures: an important problem. Retrospective analysis of 236 cases. Clin Orthop Relat Res 1988; 227: 67–81