European Journal of Trauma and Emergency Surgery (2024) 50:2963–2973
https://doi.org/10.1007/s00068-024-02629-1

ORIGINAL ARTICLE

Compressive effect and collapse behavior of three different transsacral implants in sacral fragility fractures - a retrospective analysis of 106 cases

C. Fischer[1,2] · F. Klauke[1,2] · P. Schenk[1,3] · H. Bauerfeld[1,2] · P. Kobbe[1,2] · T. Mendel[1,2]

Received: 30 May 2024 / Accepted: 26 July 2024 / Published online: 27 August 2024

Abstract

Purpose The aim of this study were the retrospective evaluation of the compressive effect and complication rates of transsacral stabilization of osteoporosis-associated sacral fragility fractures in 106 patients using three different implants (6.0 mm sacral bar, $n=32$; 7.3 mm screw, $n=26$; 7.5 mm ISG-Rod System, $n=48$) with regard to the image morphological and clinical-perioperative outcome.

Methods For this purpose, the sacral width was determined preoperatively and postoperatively using multiplanar CT reconstructions and correlated with the measured bone density (HU). The results were compared with each other on an implant-specific basis.

Results A significant compressive effect was found for all implants (6.0 mm sacral bar 7.1 ± 3.4 mm, 7.3 mm screw 6.9 ± 1.8 mm, 7.5 mm ISG-Rod System 8 ± 2.4 mm). No implant-specific difference in compression could be detected. Overall, the washers broke into the iliac cortex in 9% of cases. The subgroups did not differ significantly in this respect (6.0 mm sacral bar: 4 [13%], 7.3 mm screw 1 [1%], 7.5 mm ISG-Rod System (5 [10%], $p=0.581$). A correlation between the degree of osteoporosis and the compressive effect could not be demonstrated. Significant implant-specific differences were found in the incision-suture time, with only ø0:39 ± 0:13 h required for implantation of the 7.5 mm ISG Rod System (6.0 mm sacral bar: ø1:09 ± 0:22 h, 7.3 mm screw: ø0:55 ± 0:20 h). The fluoroscopy time was significantly lower with the 7.3 mm screw (ø0:57 ± 0:23 min) and the 7.5 mm ISG Rod System (ø0:42 ± 00:17 min) than with the 6.0 mm sacral bar (ø1:36 ± 0:46 min).

Conclusion A significant compressive effect was demonstrated with all three implants. No implant-specific complications or surgical site complications were identified in either the overall cohort or the subgroups. The 7.5 mm ISG Rod System shows advantages with regard to the duration of surgery and fluoroscopy.

Keywords Fragility fractures of the pelvis · Transsacral stabilization · Compressive effect · Transsacral bar · Marquardt rod · Sacroiliac screw

Introduction

The incidence of fragility fractures of the pelvis (FFP) in western industrialized nations such as Germany has risen by 39% in the last decade due to demographic change and is currently 224/100,000 inhabitants [1–3]. The sacrum, with a typical transalar fracture pattern, is affected in about two thirds of cases [4]. The primary fracture is usually unilateral, but contralateral involvement can also manifest over time. In the late phase of this injury entity, it is not uncommon for transverse-connecting of bilateral fractures with U- or H-shaped eruption of the upper sacral corpus from the posterior pelvic ring to occur [5, 6].

✉ C. Fischer
christian.fischer@bergmannstrost.de

1 Department of Trauma and Reconstructive Surgery, BG Klinikum Bergmannstrost Halle gGmbH, Merseburger Strasse 165, 06120 Halle (Saale), Germany

2 Department of Trauma, Hand and Reconstructive Surgery, Martin Luther University Halle-Wittenberg, University Hospital Halle, Ernst-Grube-Straße 40, 06120 Halle (Saale), Germany

3 Department of Science, Research and Education, BG Klinikum Bergmannstrost Halle gGmbH, 06112 Halle, Germany

In the treatment of FFP, the focus is on sufficient pain relief in order to achieve early mobilization of elderly patients and avoid subsequent complications. For patients who are immobile due to pain, prompt surgical treatment of FFP has proven to be an effective therapeutic approach [7–9]. Nowadays, various osteosyntheses procedures are available for this purpose: transiliosacral procedures, various plate osteosyntheses procedures, lumbopelvic fixation and triangular osteosynthesis as a combination procedure. The selected osteosynthesis must ensure sufficient primary stability to enable immediate mobilization under full weight-bearing [8, 10, 11].

The technique of transsacral stabilization (TSS) appears to meet the biomechanical requirements for this and can also be performed in a minimally invasive manner, which is why it is becoming increasingly established for the treatment of sacral fragility fractures [12, 13]. As a rule, fully threaded implants are used for this in order to achieve the greatest possible hold in the rarefied iliosacroiliac bone. However, the possibility of fracture compression via the centrally inserted force carrier has received little attention to date.

The fixation of screws in osteoporotic bone poses particular challenges as it is less dense and weaker than healthy bone. The most important biomechanical prerequisites for the successful fixation of screws in osteoporotic bone are high primary stability and an adequate implant design. In osteoporotic bone, primary stability is impaired by the lower bone density and quality. It is therefore important to optimise screw selection and placement. Specially developed screw designs with a larger diameter, increased thread depth and different thread pitches can improve the retention force in osteoporotic bone [14–16].

In the opinion of the authors, compression of the transalar fracture zones using the lag screw technique appears to be advantageous. On the one hand, the increased static friction in the fracture area increases primary stability; on the other hand, the impaction leads to a compression of the rarefied bone substance of the fractured sacral wing and thus provides an additional consolidation stimulus.

The aim of this study was to retrospectively analyze the compressive effect of three different transsacral implants in FFP using image morphological data (primary endpoint) and to compare the perioperative outcome. The study also aimed to answer whether the extent of compression achieved correlates with the degree of osteoporosis.

Methodology

Study design

This monocentric, retrospective observational study was conducted following approval by the responsible ethics committee and in compliance with the ethical principles of the Declaration of Helsinki for medical research in its most recent form (positive vote no. 5/23).

Data acquisition

TSS as compression osteosynthesis was introduced in our clinic in 2014 and is still the standard procedure for the treatment of transalar mono- and bilateral fragility fractures of the sacrum. For the retrospective data acquisition, the electronic hospital information system (HIS) was first searched with a corresponding search routine for all cases in which TSS was performed up to the end of 2023 (9-year period). A minimum age of 65 years and the presence of osteoporosis were defined as study inclusion criteria. For this purpose, the individual bone quality was determined in the preoperative computed tomography (CT) scan of the pelvis (Fig. 1). The standardized measurement was performed by averaging the Hounsfield Units (HU) in elliptical region of interests (ROIs) from three consecutive axial planes in the corpus of the fifth lumbar vertebral body [17, 18]. Osteoporosis was defined if the mean HU value was < 100 [16–21]. The presence of other injuries was defined as an exclusion criterion.

Implants and surgical technique

Transssacral screw fixation using the sacral bar was first described by Vanderschot et al. in 2001 [22]. Therefore, in our study three different implants have been used in consecutive years since 2014 starting with the 6.0 mm sacral bar (Depuy-Synthes, Oberdorf, Switzerland) (Fig. 2). A this implant was not approved for use in the minimally invasive technique, a long 7.3 mm screw (Depuy-Synthes, Oberdorf, Switzerland) was subsequently used for trans-sacral screw fixation in the minimally invasive technique in 2017. Since its market launch in 2022, the 7.5 mm ISG-Rod system (Axomed, Freiburg, Germany) has been increasingly used, being a cannulated and counterable implant. Implantation was always performed in a minimally invasive technique in the prone or supine position under fluoroscopic control in lateral, inlet and outlet projection. Depending on the existence of a safe transsacral bone corridor, the TSS was performed at segment level S1 for capacious sacral variants and at level S2 for dysplastic forms.

Implantation was always performed in a minimally invasive technique in the prone or supine position under

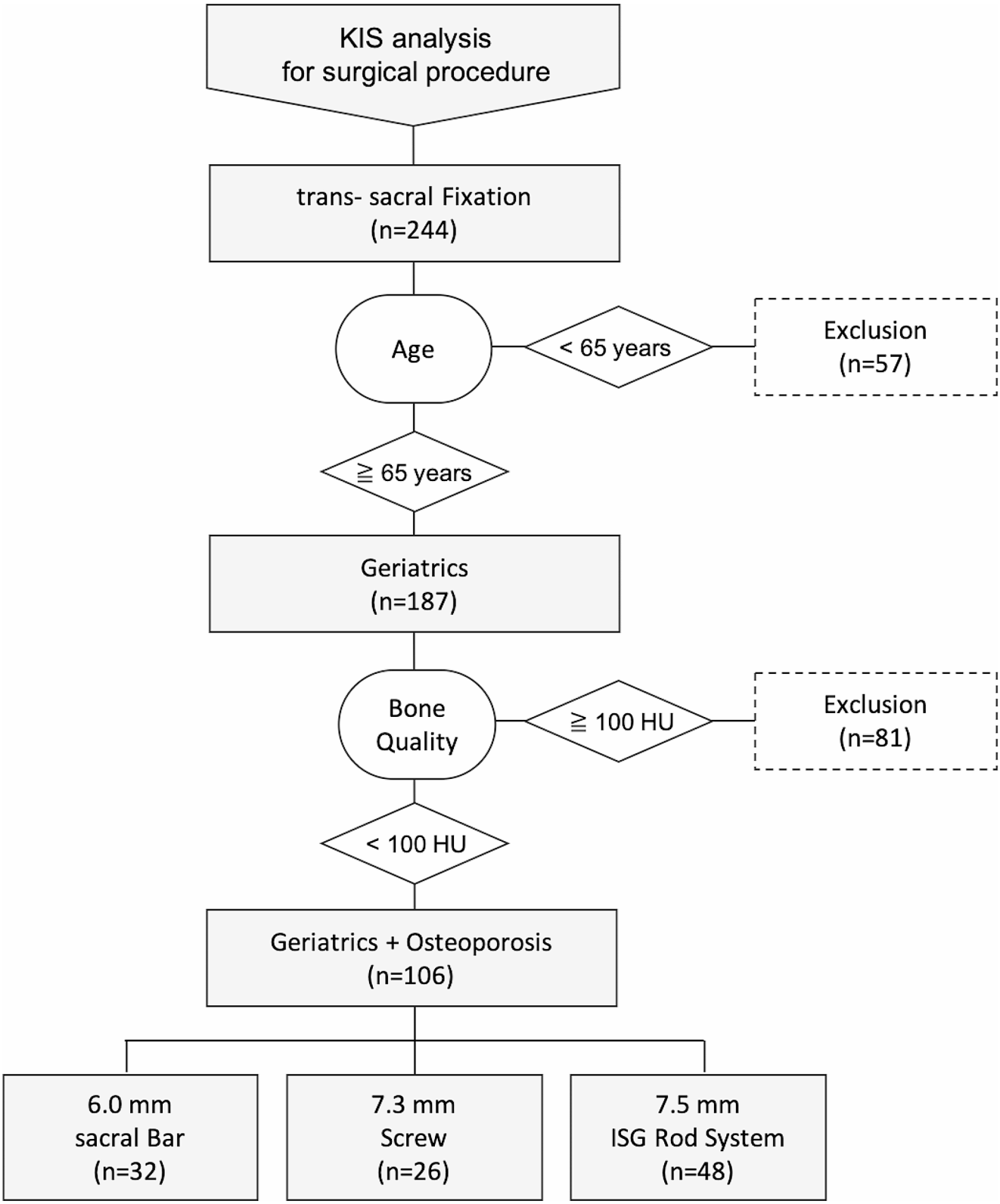

Fig. 1 Study cohort and subgroup formation based on the patient data available in the HIS

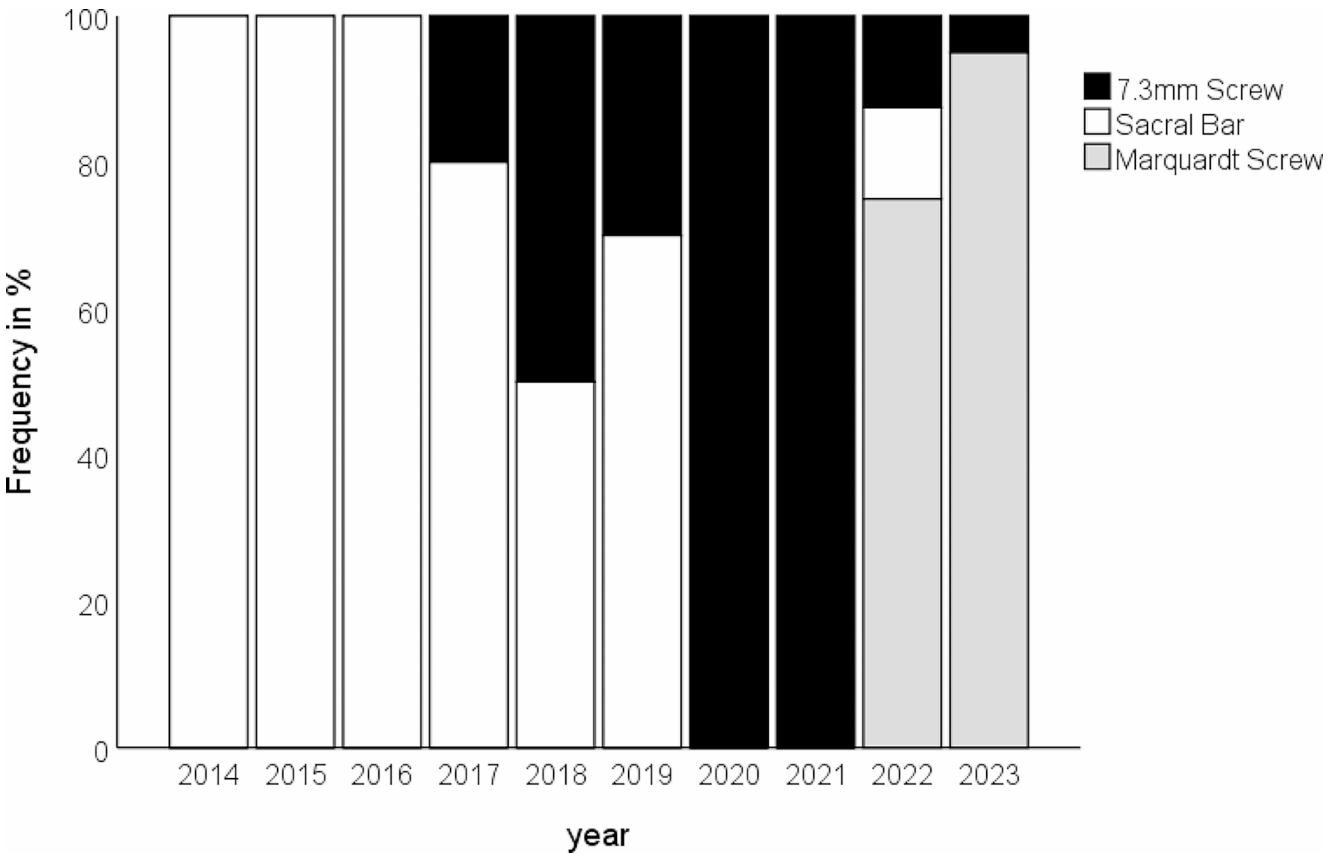

Fig. 2 Consecutive use of the various implants within the follow-up period from 2014 to 2023

fluoroscopic control in lateral, inlet and outlet projection. Depending on the existence of a safe transsacral bone corridor, the TSS was performed at segment level S1 for capacious sacral variants and at level S2 for dysplastic forms.

The following three implants were used (Fig. 3): The Sacral Bar is a 6.0 mm steel rod with a metric Iso full thread, which is locked at both ends with one washer and two nuts each. By over-drilling the ilium on both sides up to the sacral fracture zone with a 6 mm drill, the desired compression could be generated when tightening the nuts. The application is challenging as the implant is not cannulated. Later, a 7.3 mm cannulated, partially threaded screw (thread length 32 mm) with a washer was used, which enables compression of the sacrum on both sides in the manner of lag screw technique. The 7.5 mm Marquardt ISG rod system is a fully threaded rod that has a narrower iso-thread at the opposite end to accommodate the lock nut over a distance of 40 mm, so that unilateral compression can be generated on this side. The total cohort was divided into subgroups according to the implants mentioned (Fig. 3).

Investigated parameters

Epidemiological data (gender, age, height, weight, BMI, ASA classification) were collected in all cases. The type of implant used was also documented. All fractures were classified according to the FFP and OF-Pelvis classifications [23, 24].

To determine the compressive effect achieved, the width of the corridor to be instrumented was measured comparatively in the preoperative and postoperative CT data set using IMPAX software (AGFA, Mortsel, Belgium). To ensure that the length was determined at an identical location, multiplanar reconstructions were generated as follows using the IMPAX Volume Viewing MIP/MPR (Maximum intensity projection/Multi-planar reconstruction) application: The pelvis was first aligned sagittaly in the virtual coordinate system. The orientation was based on the symphysis and the spinous process of the fifth lumbar vertebral body (Fig. 4a, d). The bisector of an angle resulting from the cover plate S1 and anterior wall S1/2 was then drawn in the sagittal median plane. In the next step, a perpendicular to the angle bisector was created, which intersects the rear edge of the cover plate S1 (Fig. 4b, e). This para-coronal sectional plane was used as a standard plane for individual comparative measurement

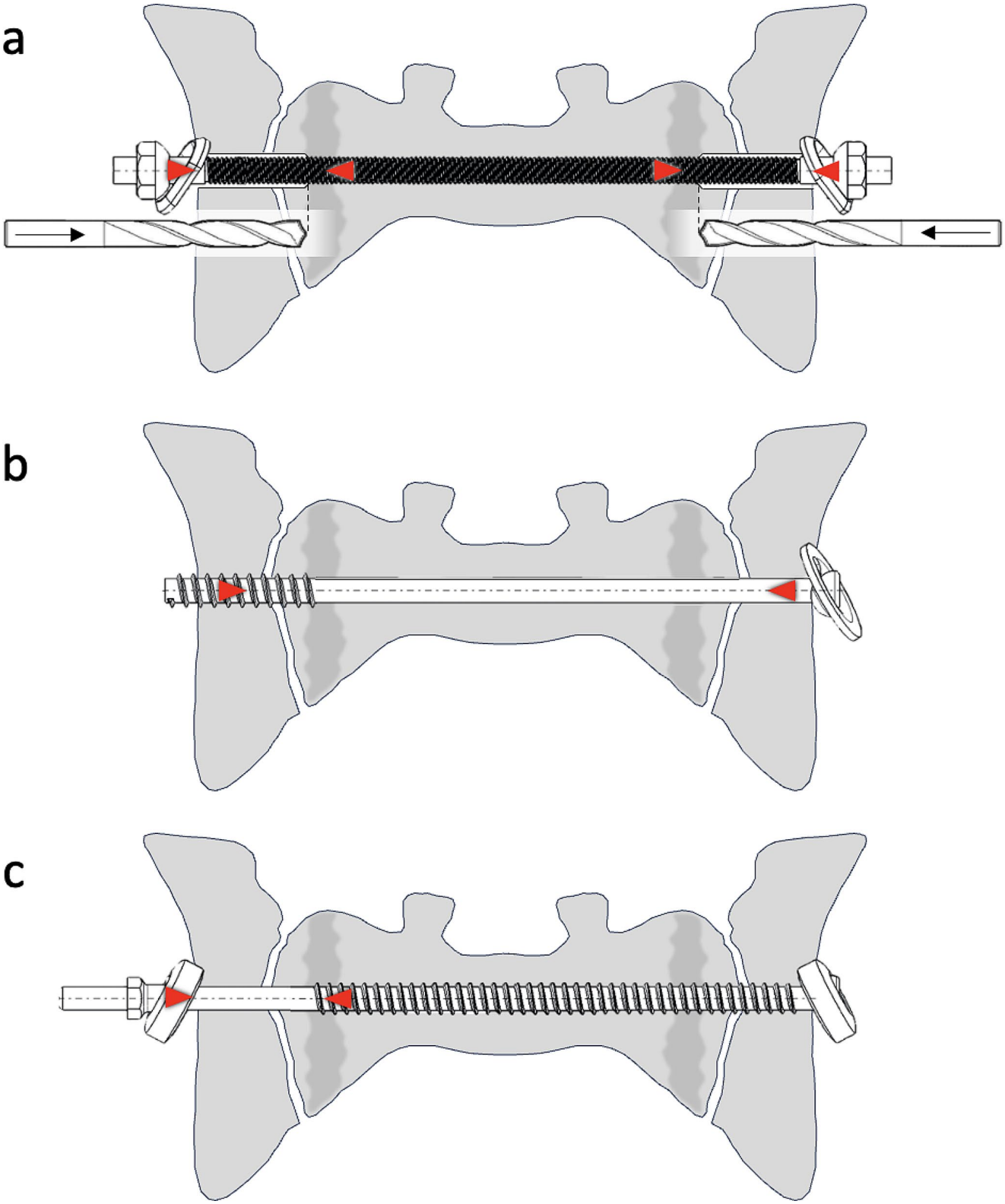

Fig. 3 (**a, b, c**) Illustration of the compression mechanisms (red) of the three implants used: (**a**) 6.0 mm Sacral Bar, (**b**) 7.3 mm cannulated partially threaded screw, (**c**) 7.5 mm Marquardt ISG Rod (axomed, Freiburg, Germany)

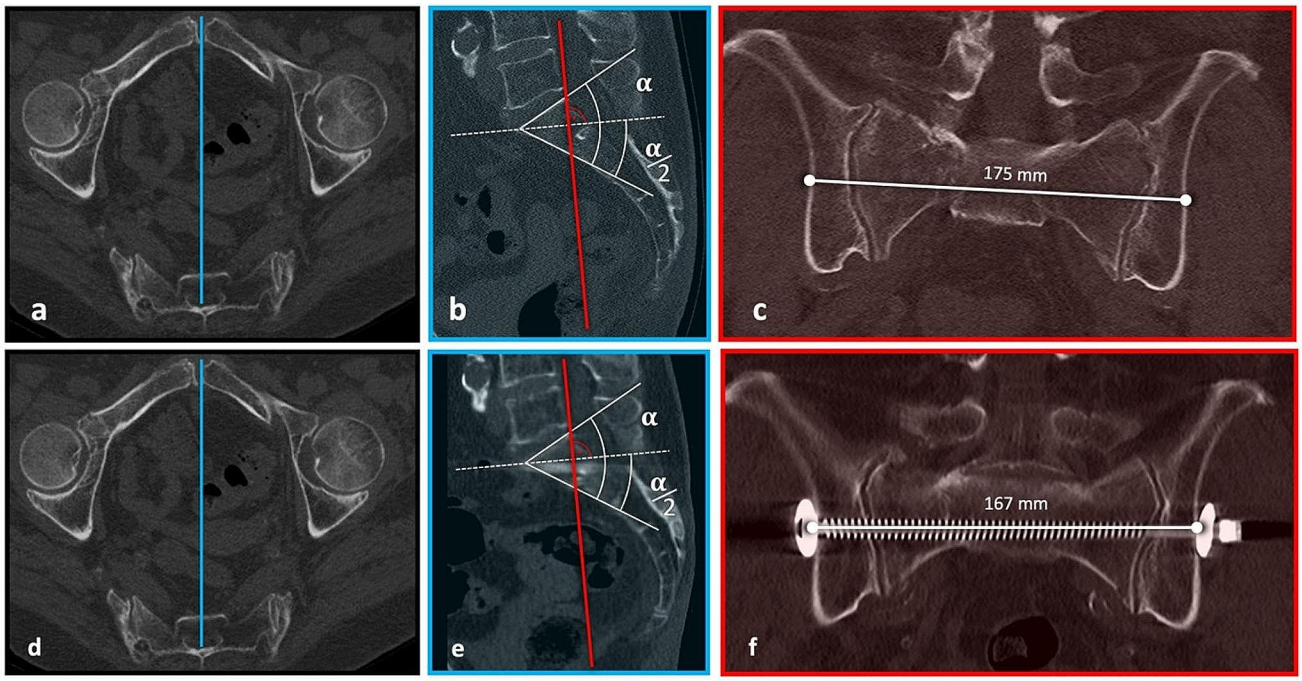

Fig. 4 Multiplanar reconstruction of a preoperative (a-c) and postoperative CT data set (d-f). Alignment of the pelvis in the sagittal median plane [blue] and generation of the para-coronary reconstruction plane [red], based on the bisector [white dashed]

of the iliosacroiliac width pre-operatively (Fig. 4c) and post-operatively (Fig. 4f). The resulting difference corresponded to the compression distance (D_{Komp}). To test the reliability of the measurement method, the measurements were carried out independently by two examiners (specialist in orthopedics and trauma surgery, specialist in radiology).

The individual implant position was categorized according to the classification system published by Gertzbein et al. (Grade A: 0 mm, Grade B: < 2 mm, Grade C: < 4 mm, Grade D: < 6 mm, grade E: > 6 mm) [25]. In addition, any collapse of the washers into the ilium caused by compression was documented.

The hospitalization time (t_{hosp}), incision-suture time (t_{CS}) and the intraoperative fluoroscopy time using an image converter (t_{BV}) were documented as process parameters. In addition, the occurrence of perioperative complications such as intra/postoperative bleeding, neurological deficits, urinary tract infections, pneumonia and postoperative anemia were recorded.

Statistical analysis

The inter-rater reliability of the measurements of sacral width, compressive effect and HU was calculated using intra-class coefficients for individual measurements [1, 3]. A multivariate general linear model (GLM) was used to test for differences between the three implants used and the baseline (preoperative) for the variables age, ASA classification, height, weight, BMI, fracture type, bone quality and sacral width S1.

Differences in the gender distribution between the groups were tested using the chi-square test (Fisher exact test). Variables with implant-dependent differences were considered as covariates for further adjustment. Implant-dependent differences (between-subjects effect) for t_{hosp}, t_{CS}, t_{BV}, D_{Komp} were tested using GLM and D_{Komp} was additionally tested using GLM for repeated measurements (GLMrm), taking the implant-dependent covariates into account. A possible correlation between D_{Komp} and HU was examined for the entire cohort and subgroups using bivariate Pearson correlation. The frequency of iliac implant collapse was analyzed using the Chi² test (Fisher's exact test). A correlation between bone quality (HU) and implant collapse was analyzed using a T-test for independent samples. Differences in D_{Komp} as a function of implant collapse of the implants used were also analyzed using univariate GLM. A p-value of 0.05 was defined as the significance level.

Results

Epidemiology

A total of 106 patients were included in the study in accordance with the inclusion criteria (Fig. 1). The age of the total cohort was ø81 ± 8 years with an average normosomic body

Table 1 Epidemiological data of the total cohort, differentiated into the respective subgroups

	6.0 mm sacral bar ($n=32$)	7.3 mm screw ($n=26$)	7.5 mm ISG Rod System ($n=48$)	Total ($n=106$)	p-value
Gender m/f	3/29	0/26	4/44	7/99	0,313
Age [y]	79,6 ± 9,9	81,5 ± 8,5	80,7 ± 9,9	83,2 ± 6,2	0,179
Height [m]	1,63 ± 0,07	1,64 ± 0,08	1,62 ± 0,07	1,65 ± 0,08	0,268
Weight [kg]	69,7 ± 11,6	68,8 ± 12,7	69,8 ± 13,9	67,6 ± 12,5	0,682
BMI (kg/m $]^2$	26,2 ± 4,4	25,6 ± 4,4	26,5 ± 5,2	24,7 ± 3,7	0,159

Table 2 Fracture distribution and classification based on the established fragility fractures of the pelvis (FFP) - and osteoporotic fractures of the pelvis (OF) classification

		6.0 mm sacral bar ($n=32$)	7.3 mm screw ($n=26$)	7.5 mm ISG-Rod System ($n=48$)	Total ($n=106$)
Fracture type	one-sided	7 (22%)	17 (65%)	23 (48%)	47 (44%)
	on both sides	25 (78%)	9 (35%)	25 (52%)	59 (56%)
FFP	IIa	2 (6%)	2 (8%)	1 (2%)	5 (5%)
	IIb	-	1 (4%)	1 (2%)	2 (2%)
	IIc	5 (16%)	14 (54%)	24 (50%)	43 (41%)
	IVb	25 (78%)	9 (35%)	22 (46%)	56 (52%)
OF-Pelvis	OF 3	7 (22%)	17 (65%)	25 (52%)	49 (46%)
	OF 4	25 (78%)	9 (35%)	23 (48%)	57 (54%)
anterior pelvic ring disruption	none	9 (28%)	6 (23%)	15 (31%)	30 (28%)
	unilateral	21 (66%)	19 (73%)	28 (58%)	68 (64%)
	bilateral	2 (6%)	1 (4%)	5 (10%)	8 (8%)

constitution and a clear predominance of females (93%). There were no differences in the epidemiological data with regard to implant-related group allocation (Table 1). The groups are therefore proven to be comparable.

Fracture type/classification

A total of 47 (44%) unilateral and 59 (56%) bilateral fractures were detected. These were classified according to the FFP and OF-Pelvis classification. Table 2 provides a descriptive overview.

Compressive effect

To rule out inter- or intraobserver variability, the image morphological evaluation of the measurements of the sacral width was carried out independently by a traumatologist and a radiologist. This revealed almost identical results. The interrater reliability of the measurement of the sacral width showed perfect agreement for both the preoperative (ICC = 0.998) and the postoperative CT (ICC = 0.994). The mean width of the transsacral corridor of primarily ø160 ± 11 mm could be significantly reduced to ø153 ± 11 mm independent of the implant used (D_{Komp}: ø7.5 ± 2.6 mm, $p=0.006$, ICC: 0.909). However, there were no differences depending on the implants used ($p=0.999$, see Fig. 5). The measurement method used therefore appears to be valid and reliable.

In the overall cohort, the targeted compressive effect of 7.5 ± 2.6 mm was clearly demonstrated. However, a correlation between the compression achieved and the extent of individual calcium salt reduction could not be shown ($p=0.885$). There were also no correlations for the three subgroups (6.0 mm sacral bar: $p=0.499$, 7.3 mm screw: $p=0.727$, 7.5 mm ISG rod system: $p=0.410$). Differences in the compressive effect depending on the presence of a unilateral or bilateral fracture could also not be demonstrated ($p=0.377$). There were also no significant differences for the type of implant used ($p=0.170$) and the interaction effect between implant and fracture ($p=0.894$).

Implant position and break-in behavior

In four patients (4%), the implants perforated the cortical bone by less than two millimeters in the transsacral course (type B). Three of these occurred in the 7.3 mm screw group and one in the 6.0 mm sacral bar group. In this respect, there were no clinically relevant implant malpositions. A break-in of the washers into the iliac cortex was found in 9% of cases ($n=10$). There were no significant differences within the subgroups in this respect (6.0 mm sacral bar: 4 [13%], 7.3 mm screw 1 [1%], 7.5 mm ISG rod system (5 [10%], $p=0.581$). In addition, no differences could be shown with regard to the correlation between bone quality and the presence of an implant perforation ($p=0.431$).

Complications

The occurrence of surgical site complications (SSC) and in-hospital complications (IHC) was also analyzed within

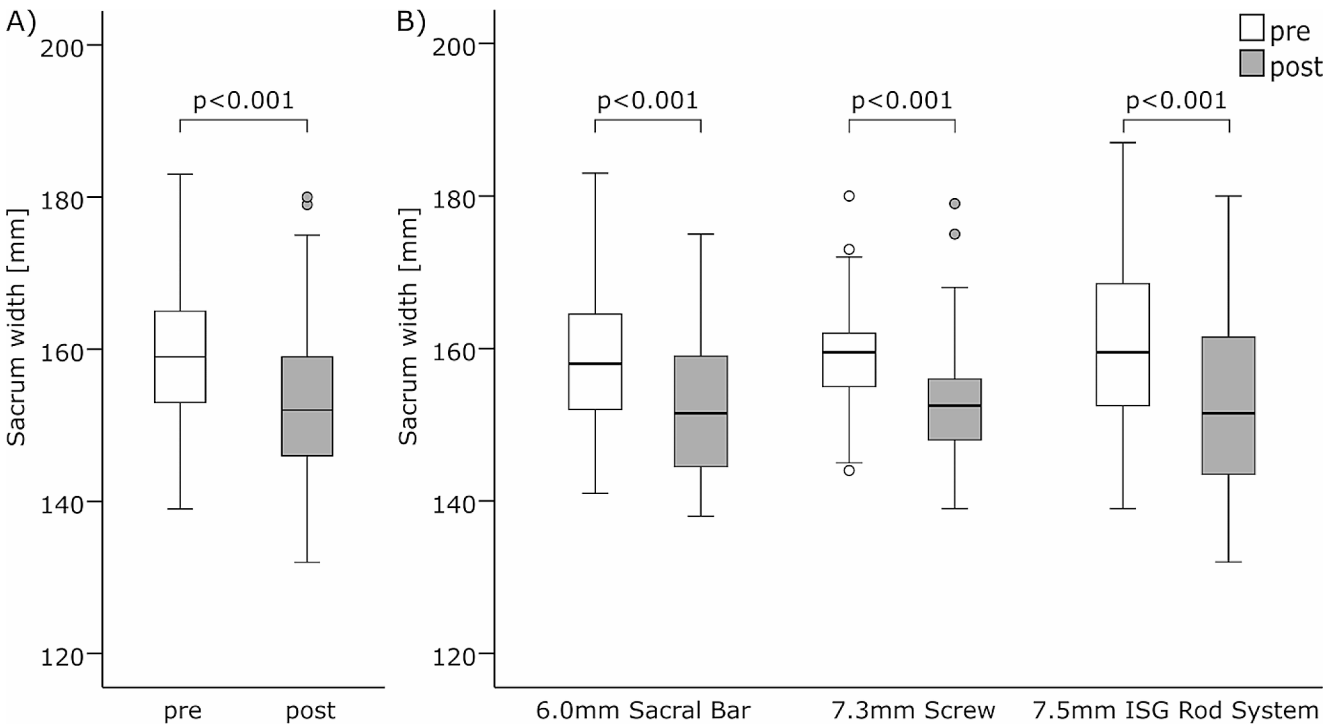

Fig. 5 Comparison of the compressive effect of the overall cohort (**A**) and within the subgroups (**B**) (with the error bars depicting the standard deviation)

the overall cohort. SSC occurred in one patient with iatrogenic injury to the superior gluteal artery (subgroup: SIJ-rod system), which was ligated. Secondary IHC occurred in 23 cases (22%) in the elderly patient population (sacral bar: urinary tract infection: $n=5$, pneumonia: $n=2$; 7.3 mm screw: urinary tract infection: $n=5$, pneumonia: $n=2$, postoperative anemia: $n=1$; SIJ-rod system: urinary tract infection: $n=4$, postoperative anemia: $n=4$). There were no significant differences in the complication rates of the subgroups. Implant failure within the subgroups could not be determined.

Discussion

The rising incidence of osteoporosis-related geriatric fragility fractures of the pelvis is becoming increasingly clinically and socioeconomically relevant [8, 26, 27]. FFP often lead to pain-related immobility and loss of social independence in affected patients. In up to 60% of cases, the sacral bone is affected, with typical unilateral or bilateral transalar fractures being seen in most cases [23]. Percutaneous transsacral screw fixation is an adequate minimally invasive and primarily load-stable procedure for this purpose [8–10, 13, 28].

Biomechanical studies have demonstrated the advantage of transsacral stabilization over alternative osteosynthesis procedures [13, 29, 30]. Transsacral stabilization appears to be fundamentally superior to monolateral sacroiliac (SI) screw fixation [13, 29]. Cintean et al. investigated the difference between transsacral and monolateral sacroiliac screw fixation using a biomechanical model. The authors concluded that transsacral screw fixation provides greater fracture stability due to significantly less interfragmentary movement [13]. Bradley et al. analyzed the fracture stability after using monolateral sacroiliac partial-thread screws of different diameters compared to a transsacral partial-thread screw. The authors were able to show that the transsacral implant offered higher primary stability in direct comparison [30]. In most studies, transsacral screw implants with a full thread were used. This involved a simple transfixation of the posterior pelvic ring, with the aim of achieving the greatest possible interfragmentary stability in the rarefied iliosacroiliac bone due to the full thread. On the other hand, Berk et al. were able to show that a monolateral SI screw fixation with two partially threaded screws had better interfragmentary stability than two fully threaded screws due to the compression achieved, whereby a type III APC injury according to Young and Burgess was simulated on an artifactual bone model for this purpose [12].

In summary, the compressive effect in the context of transsacral stabilization in FFP has received little attention to date. In particular, various authors have pointed out that overcompression can lead to entrapment of sacral nerve

roots. However, these studies investigated transforaminal fracture types [31–34]. Although the risk in transforaminal fractures is obvious, there is no evidence in the literature of such a complication in transalar fragility fractures. Consequently, there is no clinical evidence to date as to whether transsacral compression osteosynthesis provides a clinical advantage for the healing of sacral fragility fractures.

It can be assumed that compression in the alar fracture zone can achieve greater primary stability through interfragmentary static friction. It can also be postulated that compression of the alar bone substance additionally induces a bony consolidation stimulus. In a prospective study on the clinical outcome of geriatric patients after transsacral stabilization, Mendel et al. described a clear postoperative reduction in pain and a significant increase in the level of mobility after the operation using this technique, for which the patients were fitted with a pedometer. Previously immobile patients achieved a median of 308 steps per day during their postoperative inpatient stay. At the six-month follow-up, the daily step count was as high as 3,759, with all fractures being bony consolidated [8, 9].

The primary aim of this study was to provide image morphological evidence of the compressive effect using three different patient cohorts after the use of different implant systems. Breaking of the implant-specific washers into the iliac cortex was assumed to be a limiting factor. Other possible complications of this technique, such as the potential compression of sacral nerve roots, were also analyzed.

In principle, a relevant compressive effect of 7.5 mm on average was demonstrated in all three subgroups. The extent of compression does not depend solely on whether the fracture is mono- or bilateral. Unexpectedly, there was no significant difference between the subgroups. This could be due to the fact that although all included patients had osteoporosis by definition, the individual calcium salt content differs considerably (HU: ∅61, range 34–83), which certainly has a decisive influence. In addition, there is the individual influence of the surgeon performing the operation. To summarise, the extent of the compressive effect is influenced multifactorially. The individual extent of calcium salt reduction had no significant influence, especially not on the compression-induced iliac collapse of the washers, which occurred in only 9% of cases. Perioperative process parameters such as the incision-to-suture time (ø52 min) and fluoroscopy time (ø1.02 min) appear to be consistently excellent in the literature comparison, irrespective of the implant system. For example, other authors report fluoroscopy times of 1.4 to 4.6 min per SI screw [35, 36]. No effects of the compressive effect on the width of the sacral foramina or the incarceration of nerve roots could be determined either morphologically or clinically.

The average postoperative hospital stay was only eight days and can be interpreted as an expression of low-complication surgical treatment with sufficient pain relief [8, 9, 12].

Our study has some strengths and limitations. For the first time, clinical results are presented that take into account the aspect of the transsacral compressive effect in the treatment of FFP. However, the limited sample sizes and the retrospective design increase the selection bias and thus allow only a limited interpretation of the results. In addition, the chosen age limit of ≥ 65 years is certainly a limitation. Individual calendar age sometimes differs significantly from physical, i.e. biological age. This aspect was taken into account in our study by defining high energy trauma as an exclusion criterion, and the underlying osteoporosis was defined as an inclusion criterion, whereby all included patients had an HU value of < 100 in the preoperative CT. However, numerous other studies dealing with the outcome of fragility fractures of the pelvis have also chosen this age limit [2, 32, 37, 38]. Finally, it must be mentioned that the different diameters of the three implants used also have a potential influence on the degree of compression achieved. Biomechanical studies have shown that a larger screw diameter increases stability by increasing the contact surface and thus a higher torque moment can be expected [14–16, 34].

In addition, there is no comparative cohort in which transsacral screw fixation was performed without compression. Further experimental biomechanical investigations and clinical comparative studies are therefore required to substantiate the beneficial effect of compression. Investigations based on a finite element model taking different implant geometries into account are currently being carried out by our working group.

In this study, a significant compressive effect could be demonstrated by computer tomography when treating FFP using the transsacral technique. With dosed compression, the breaking of the washers into the ilium (< 10% of cases), regardless of the implant used, represents a negligible limiting factor of the compressive effect. There was no intervention-related risk due to compression. In particular, the risk of incarceration of sacral nerve roots due to the applied compression appears negligible, as the effect is most likely to occur in the bone-reduced alar zone. Relevant implant malpositions could not be detected using our own fluoroscopic technique. Promising clinical results of the described technique with regard to early, low-pain mobilization under full weight-bearing and timely bony fracture consolidation [8, 9] should be substantiated by further clinical and experimental studies [8, 9].

Author contributions C. Fischer wrote the main manuscript text and prepared all figures. All authors reviewed the manuscript.

Funding No funding was received for conducting this study.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.
All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics approval Approval of the responsible ethics committee and compliance with the ethical principles of the Declaration of Helsinki for medical research (positive vote no. 5/23).

References

1. Oberkircher L, Ruchholtz S, Rommens PM, Hofmann A, Bücking B, Krüger A. Osteoporotic Pelvic Fractures. Vol. 115, Deutsches Arzteblatt international. NLM (Medline); 2018. pp. 70–80.
2. Andrich S, Haastert B, Neuhaus E, Neidert K, Arend W, Ohmann C et al. Epidemiology of pelvic fractures in Germany: considerably high incidence rates among older people. PLoS ONE. 2015;10(9).
3. Rupp M, Walter N, Pfeifer C, Lang S, Kerschbaum M, Krutsch W, et al. Originalarbeit: Inzidenz Von Frakturen in Der Erwachsenenpopulation in Deutschland. Dtsch Arztebl Int. 2021;118(40):665–9.
4. Wagner D, Hofmann A, Kamer L, Sawaguchi T, Richards RG, Noser H, et al. Fragility fractures of the sacrum occur in elderly patients with severe loss of sacral bone mass. Arch Orthop Trauma Surg. 2018;138(7):971–7.
5. Linstrom NJ, Heiserman JE, Kortman KE, Crawford NR, Baek S, Anderson RL, et al. Anatomical and biomechanical analyses of the unique and consistent locations of sacral insufficiency fractures. Spine (Phila Pa 1976). 2009;34(4):309–15.
6. Rommens PM, Arand C, Hopf JC, Mehling I, Dietz SO, Wagner D. Progress of instability in fragility fractures of the pelvis: an observational study. Injury. 2019;50(11):1966–73.
7. Rommens PM, Boudissa M, Krämer S, Kisilak M, Hofmann A, Wagner D. Operative treatment of fragility fractures of the pelvis is connected with lower mortality. A single institution experience. PLoS ONE. 2021;16(7 July).
8. Mendel T, Ullrich BW, Schenk P, Hofmann GO, Goehre F, Schwan S, et al. Perioperative outcome of minimally invasive stabilisation of bilateral fragility fractures of the sacrum: a comparative study of bisegmental transsacral stabilisation versus spinopelvic fixation. Eur J Trauma Emerg Surg. 2023;49(2):1001–10.
9. Mendel T, Schenk P, Ullrich BW, Hofmann GO, Goehre F, Schwan S, et al. Cite this article. Bone Joint J. 2021;103(3):462–8.
10. Rommens PM, Wagner D, Arand C, Boudissa M, Hopf J, Hofmann A. Minimally invasive stabilization of fragility fractures of the pelvis with transsacral bar and retrograde transpubic screw. Oper Orthop Traumatol. 2022;34(2):153–71.
11. Wagner D, Kisilak M, Porcheron G, Krämer S, Mehling I, Hofmann A et al. Trans-sacral bar osteosynthesis provides low mortality and high mobility in patients with fragility fractures of the pelvis. Sci Rep. 2021;11(1).
12. Berk T, Zderic I, Varga P, Schwarzenberg P, Lesche F, Halvachizadeh S et al. Evaluation of Cannulated Compression Headless Screw (CCHS) as an alternative implant in comparison to standard S1-S2 screw fixation of the posterior pelvis ring: a biomechanical study. BMC Musculoskelet Disord. 2023;24(1).
13. Cintean R, Fritzsche C, Zderic I, Gueorguiev-Rüegg B, Gebhard F, Schütze K. Sacroiliac versus transiliac–transsacral screw osteosynthesis in osteoporotic pelvic fractures: a biomechanical comparison. Eur J Trauma Emerg Surg. 2023.
14. Giannoudis PV, Schneider E. Principles of fixation of osteoporotic fractures. Br]. 2006;88:1272–80.
15. Bogunovic L, Cherney SM, Rothermich MA, Gardner MJ. Biomechanical Considerations for Surgical Stabilization of Osteoporotic Fractures. 44, Orthopedic Clinics of North America. 2013. p. 183–200.
16. Hollensteiner M, Sandriesser S, Bliven E, von Rüden C, Augat P. Biomechanics of osteoporotic fracture fixation. Current Osteoporosis Reports. Volume 17. Springer; 2019. pp. 363–74.
17. Deshpande N, Hadi MS, Lillard JC, Passias PG, Linzey JR, Saadeh YS, et al. Alternatives to DEXA for the assessment of bone density: a systematic review of the literature and future recommendations. J Neurosurg Spine. 2023;38(4):436–45.
18. Pinto EM, Neves JR, Teixeira A, Frada R, Atilano P, Oliveira F, et al. Efficacy of Hounsfield Units measured by lumbar computer tomography on Bone Density Assessment: a systematic review. Spine (Phila Pa 1976). 2022;47(9):702–10.
19. Ullrich BW, Schenk P, Spiegl UJ, Mendel T, Hofmann GO. Hounsfield units as predictor for cage subsidence and loss of reduction: following posterior-anterior stabilization in thoracolumbar spine fractures. Eur Spine J. 2018;27(12):3034–42.
20. Pickhardt PJ, Pooler B, Dustin, Lauder T, Muñ O, Del Rio A, Bruce RJ, Binkley N. Opportunistic Screening for Osteoporosis Using Abdominal Computed Tomography Scans Obtained for Other Indications [Internet]. 2013. Available from: www.annals.org.
21. Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL, Au AG. Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. J Bone Joint Surg. 2011;93(11):1057–63.
22. Vanderschot P, Meuleman C, Lefèvre A, Broos P. Trans iliac-sacral-iliac bar stabilisation to treat bilateral lesions of the sacroiliac joint or sacrum: anatomical considerations and clinical experience [Internet]. Vol. 32, Int. J. Care Injured. 2001. www.elsevier.com/locate/injury
23. Rommens PM, Hofmann A. Comprehensive classification of fragility fractures of the pelvic ring: recommendations for surgical treatment. Injury. 2013;44(12):1733–44.
24. Ullrich BW, Schnake KJ, Spiegl UJA, Schenk P, Mendel T, Behr L et al. OF-Pelvis classification of osteoporotic sacral and pelvic ring fractures. BMC Musculoskelet Disord. 2021;22(1).

25. GERTZBEIN SD, ROBBINS SE. Accuracy of Pedicular Screw Placement in vivo. Spine (Phila Pa 1976). 1990;15(1):11–4.
26. Nanninga GL, de Leur K, Panneman MJM, van der Elst M, Hartholt KA. Increasing rates of pelvic fractures among older adults: the Netherlands, 1986–2011. Age Ageing. 2014;43(5):648–53.
27. Breuil V, Roux CH, Carle GF. Pelvic fractures: Epidemiology, consequences, and medical management. Current Opinion in Rheumatology. Volume 28. Lippincott Williams and Wilkins; 2016. pp. 442–7.
28. Hopf JC, Krieglstein CF, Müller LP, Koslowsky TC. Percutaneous iliosacral screw fixation after osteoporotic posterior ring fractures of the pelvis reduces pain significantly in elderly patients. Injury. 2015;46(8):1631–6.
29. Mears SC, Sutter EG, Wall SJ, Rose DM, Belkoff SM. Biomechanical Comparison of Three Methods of Sacral Fracture Fixation in Osteoporotic Bone. Vol. 35, SPINE.
30. Bradley H, Pierce B, O'neill D, Jo CH, Ahn J, Farahani F, et al. Biomechanical comparison of 4 Transsacral Fixation Constructs in a type 61 C, Zone II pelvic fracture model. J Orthop Trauma. 2022;36(10):503–8.
31. Hack J, Safi M, Bäumlein M, Lenz J, Bliemel C, Ruchholtz S et al. Is cement-augmented sacroiliac screw fixation with partially threaded screws superior to that with fully threaded screws concerning compression and pull-out force in fragility fractures of the sacrum?– a biomechanical analysis. BMC Musculoskelet Disord. 2021;22(1).
32. Wagner D, Ossendorf C, Gruszka D, Hofmann A, Rommens PM. Fragility fractures of the sacrum: how to identify and when to treat surgically? European Journal of Trauma and Emergency Surgery. Volume 41. Springer Berlin; 2015. pp. 349–62.
33. Osterhoff G, Dodd AE, Unno F, Wong A, Amiri S, Lefaivre KA, et al. Cement augmentation in Sacroiliac Screw fixation offers Modest Biomechanical advantages in a Cadaver Model. Clin Orthop Relat Res. 2016;474(11):2522–30.
34. Fan S, Chen S, Xiang H, Mai Q, Zhu Z, Chen Y et al. Biomechanical comparison of ve iliosacral screw xation techniques for Tile C1.3 pelvic fracture under two-legged standing load: a cadaver study. 2024; https://doi.org/10.21203/rs.3.rs-4005527/v1
35. chiproutt1995.
36. Schep NWL, Haverlag R, Van Vugt AB. Computer-assisted versus conventional surgery for insertion of 96 cannulated iliosacral screws in patients with postpartum pelvic pain. J Trauma - Injury Infect Crit Care. 2004;57(6):1299–302.
37. Rommens PM, Wagner D, Hofmann A. Fragility fractures of the pelvis. JBJS Rev. 2017;5(3).
38. Deutsches Ärzteblatt: Archiv Osteoporotic Pelvic Fractures (02.02.2018).