Archives of Orthopaedic and Trauma Surgery (2021) 141:593–602
https://doi.org/10.1007/s00402-020-03502-7

TRAUMA SURGERY

Fracture reduction and screw position after 3D-navigated and conventional fluoroscopy-assisted percutaneous management of acetabular fractures: a retrospective comparative study

B. Swartman[1] · J. Pelzer[1] · N. Beisemann[1] · M. Schnetzke[1] · H. Keil[1] · S. Y. Vetter[1] · P. A. Grützner[1] · Jochen Franke[1]

Received: 20 June 2019 / Accepted: 31 May 2020 / Published online: 9 June 2020

Abstract

Background Navigational techniques in orthopaedic trauma surgery have developed over the last years leaving the question of really improving quality of treatment. Especially in marginal surgical indications, their benefit has to be evident. The aim of this study was to compare reduction and screw position following 3D-navigated and conventional percutaneous screw fixation of acetabular fractures. The study hypothesis postulated that better fracture reduction and better screw position are obtained with 3D navigation.
Materials and methods Preoperative and postoperative CT scans of 37 acetabular fractures treated by percutaneous screw fixation (24 3D-navigated, 13 conventional) were evaluated. Differences in pre- and postoperative fracture gaps and steps were compared in all reconstructions as well as the screw position relative to the joint and the fracture.
Results The differences in fracture gaps and fracture steps with and without 3D navigation were not significantly different. Distance of the screw from the joint line, angle difference between screw and ideal angle relative to the fracture line, length of the possible corridor used and position of the screw thread did not show any significant differences.
Conclusion Comparison of 3D-navigated and conventional percutaneous surgery of acetabular fractures on the basis of pre- and postoperative CTs revealed no significant differences in terms of fracture reduction and screw position.

Keywords Percutaneous screw fixation · Acetabular fractures · 3D-navigation · Fracture reduction · Screw position

Introduction

With an incidence of 3/100,000 cases per year, pelvic fractures account for about 2–8% of all fractures [1]. In 15.4% of cases they are associated with acetabular fractures [2]. According to the literature, the unanimous gold standard in dislocated acetabular fractures is open reduction and internal fixation [1, 3–6].

The aim of surgical management of acetabular fractures is anatomical reduction, as this produces the best functional results [7, 13, 14]. In this context, the associated imaging procedures have been studied for their impact on intraoperative procedures and primary radiological outcomes. The superiority of 3D navigation over conventional fluoroscopy in open reduction and internal fixation in terms of fracture reduction, amongst other aspects, has been demonstrated in a prospective study [6].

Due to its less invasive nature, percutaneous screw fixation is gaining increasing importance, particularly in slightly dislocated acetabular fractures. However, it is associated with a high risk of complications because of the anatomically narrow corridors for screw positioning [3, 5, 8]. In an experimental study of 50 CTs, only very narrow corridors in the anterior and posterior columns and in the supra-acetabular region were described for safe screw positioning [8]. Technical aids have been developed with the aim of reducing the risk of complications and making percutaneous surgery safer. In particular, the field of image-assisted navigation has found its way into the percutaneous management of pelvic fractures [9–12]. Three navigation techniques are currently available: CT-, 3D- and 2D-based navigation [9].

The 3D and 2D navigation techniques for percutaneous screw fixation have already been compared with

✉ Jochen Franke
Jochen.Franke@bgu-ludwigshafen.de

[1] Department for Trauma and Orthopaedic Surgery, BG-Klinik Ludwigshafen, Trauma Surgery Clinic at Heidelberg University, Ludwig-Guttmann-Str. 13, 67071 Ludwigshafen, Germany

conventional fluoroscopy in terms of precision in artificial and cadaveric bones. 3D navigation exhibited increased precision or fewer implant misplacements [3, 12].

The 3D-navigated percutaneous technique itself has already been studied in terms of reduction outcome and has demonstrated a significant reduction with the restoration of an almost anatomical position [13].

Comparative studies of patient data on the quality of fracture reduction or implant placement in percutaneous screw fixation of acetabular fractures using various imaging procedures, including conventional fluoroscopy, have to date been lacking.

As navigation is associated with expensive procurements and increased time demands [9], our research question is whether the navigated technique achieves better results than the conventional fluoroscopic procedure in fracture reduction and implant position in the percutaneous management of acetabular fractures.

Ethical approval was granted by the local Ethics Committee on October 30, 2014 under number 837.388.14 (967).

Materials and methods

All acetabular fractures in a level 1 trauma centre were recorded during the period 2001–2015. Patients with an acetabular fracture treated by minimally invasive percutaneous surgery and for whom a preoperative and a postoperative CT or intraoperative final 3D scan were available were included. Indication for percutaneous treatment was a minimally displaced acetabular fracture. Minimal displacement was defined as steps or gaps of less than 5 mm. Patient's general health condition was also considered, whereas elderly and multimorbid patients were preferably treated conservatively. A clear cut-off in this term did not exist. The use of navigation depended on the year the operation was performed in. Since navigation became available at our department in 2007, this was the cut between the two operation techniques. Navigation was used in 357 cases between 2007 and 2015. Anatomical regions included acetabulum, posterior pelvic ring, spine, foot and ankle, tibial plateau, femur, elbow and distal radius.

The percutaneous technique involves radiographic visualization of a safe periacetabular corridor and the screw placement via percutaneous stab incision. The reduction is performed by inserting the screw and using its characteristic of a lag screw in order to approximate and compress the fragments. All screws used were 7.3-mm cannulated screws. In the case of navigated screw insertion, an infra-red reflector was fixed to the iliac crest of the pelvis and referenced to a 3D-capable C-arm by a binocular camera. The gained data set was used to plan the desired screw position. For screw insertion, we place a wire into the desired corridor with the navigated drill guide. After that, the wire position is verified by intraoperative 3D-Scan. If placement is correct, the hole is drilled and the screw placed over the wire. The screw length is planned with the navigation tool and verified manually by measuring the guide wire before screw insertion. The screw trajectories were either antegrade (directed into the superior pubic ramus) or retrograde (supraacetabular). In some cases, screws in different directions were combined. An overview of the inserted screws is given in Table 1. "Postoperative" imaging was considered either as postoperative CT scan or intraoperative 3D scan by a mobile C-arm which shows the final result after fracture reduction and implant positioning. In these cases, 3D imaging was only used for diagnostic reasons. Equivalent to the corresponding preoperative CT scans, they were reconstructed in the three standard planes: coronal, sagittal and transverse. Each reconstruction was checked for the greatest occurring fracture gap and fracture step, which was then measured in mm (Impax, Agfa HealthCare, Bonn, Germany; Syngo, Siemens Healthcare, Erlangen, Germany). The differences in fracture steps or fracture gaps between the preoperative and postoperative dataset were determined as a parameter of reduction.

$$\Delta T = T_2 - T_1$$

$T_1 =$ step/gap size in mm of the preoperative CTs

$T_2 =$ step/gap size in mm of the postoperative CTs.

The screw position was assessed on the basis of four criteria: the smallest distance of the screw from the acetabular joint surface, the amount of the angle difference between the screw and the ideal angle of 90° to the fracture gap, the ratio of screw length to the maximum possible bony corridor and the complete bridging of the fracture gap by the screw thread (Fig. 1). In the presence of more than one screw, the screw nearest to the joint was chosen.

Data collection and documentation were performed using Excel 2010 (Microsoft, Seattle, USA) and statistical analysis using Excel 2010 and SPSS (SPSS Inc., Chicago, USA). In comparing the groups, Student's t test was used for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Dichotomous results were verified by Fisher's exact test. The significance level was set at $p < 0.05$ in each case.

Table 1 Number of cases with screw trajectories in navigated and conventional groups

	Conventional	Navigation
Antegrade	2	4
Retrograde	10	18
Combined	1	2

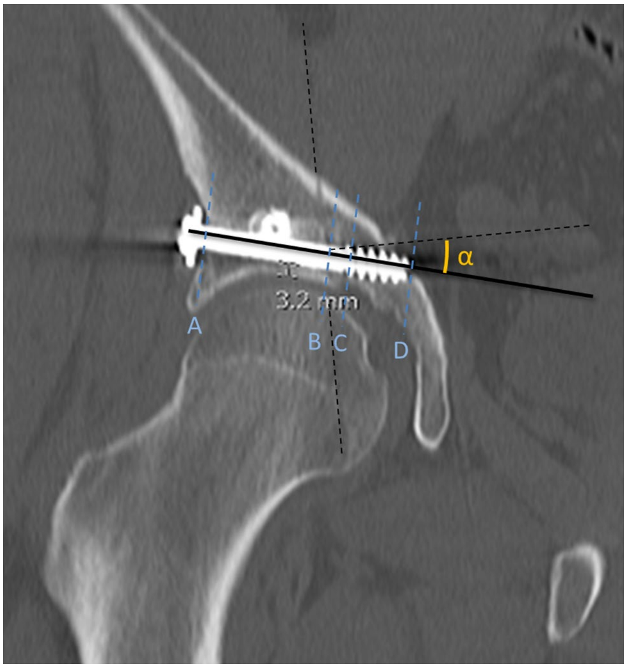

Fig. 1 Measuring methods of screw position in the 3D volume of the hip joint: the smallest distance of the screw from the acetabular joint surface (in this example 3.2 mm), the amount of the angle difference between the screw and the ideal angle of 90° to the fracture gap (*α*), the ratio of screw length (AD) to the maximum possible bony corridor (AD) and the complete bridging of the fracture gap (AB) by the screw thread (AC)

Case presentations

Case 1

A patient who, as a cyclist, was hit by an oncoming car while turning presents at our emergency department. The patient fell to the right side. There was no unconsciousness at the scene of the accident. After the fall, the patient got up and walked. In the radiological diagnostics an acetabulum fracture on the right (Letournel stage 4), fracture of the 9th rib on the right, and a cervical spine distortion were diagnosed. In addition, there were multiple abrasions. The patient was admitted to hospital (Fig. 2a–d). On the 5th day after trauma, the surgical procedure was performed using closed reduction and minimally invasive cannulated screws inserted into the anterior column (Fig. 3a–c). The patient was mobilized for 6 weeks with no weight bearing on the affected side, the subsequent X-ray control showed a proper consolidation with a good implant position (Fig. 4). The range of motion of the right hip joint at this time was extension/flexion 10–0–110 degrees, abduction/adduction 20–0–5 degrees, external/internal rotation 25–0–15 degrees.

Case 2

The patient had fallen through a roof from a height of approx. 2.5 m to the right side. After emergency medical treatment, the patient was transported to our trauma centre by ambulance. After X-ray and CT a slightly dislocated anterior column fracture of the acetabulum on the right, a distal radius fracture type 23 A3 (AO) on the right, a cerebral concussion as well as a cut in the eyebrow on the right were visible. The patient was admitted for further therapy (Fig. 5a–c). The radius fracture was surgically treated immediately after admission. On the 7th day after trauma, percutaneous 3-D navigated screw osteosynthesis of the right acetabulum was performed (Fig. 6a–c). The patient was then mobilized on armpit crutches without weight bearing of the affected leg. The radius fracture could be functionally treated. In the routine X-ray controls after 6 and 12 weeks, a regular healing process with no change in the implant position was observed Fig. 7a, b). Further controls did not take place in our hospital any more. At the end of the treatment, the patient was free of complaints.

Results

During the period from 2001 to 2015, 802 acetabular fractures were treated in our hospital. Of these, 313 were treated conservatively, 437 by open surgery and 52 by percutaneous surgery. Of the percutaneous patients, 33 were managed by 3D navigation and 19 by conventional fluoroscopy. For 7 patients, the preoperative CT was recorded externally and was not available and in 8 patients the postoperative three-dimensional documentation was incomplete. Thus, 37 patients, 5 women and 32 men (median age 53 years; min 18; max 80), were included in the study. Of these, 24 underwent surgery with 3D navigation and 13 with conventional fluoroscopy.

The implantation technique in the conventional fluoroscopy group involved 10 retrograde screw fixations. In the 3D-navigated group, 15 screws were implanted in a retrograde fashion.

The preoperative degree of dislocation in the individual reconstructions was recorded to be equally distributed in the two groups without significant difference (Table 2).

In the group of patients managed by conventional fluoroscopy, fracture gaps and steps were reduced by the procedure in all reconstructions. Significant differences were found for sagittal gaps ($p < 0.001$), coronal steps ($p = 0.029$), coronal gaps ($p = 0.030$) and axial gaps ($p < 0.001$). In the 3D-navigated surgery group, fracture gaps and steps were also reduced in all reconstructions. Significant outcomes were found for sagittal gaps ($p = 0.008$), coronal gaps ($p = 0.001$) and axial gaps ($p = 0.025$) (Table 3).

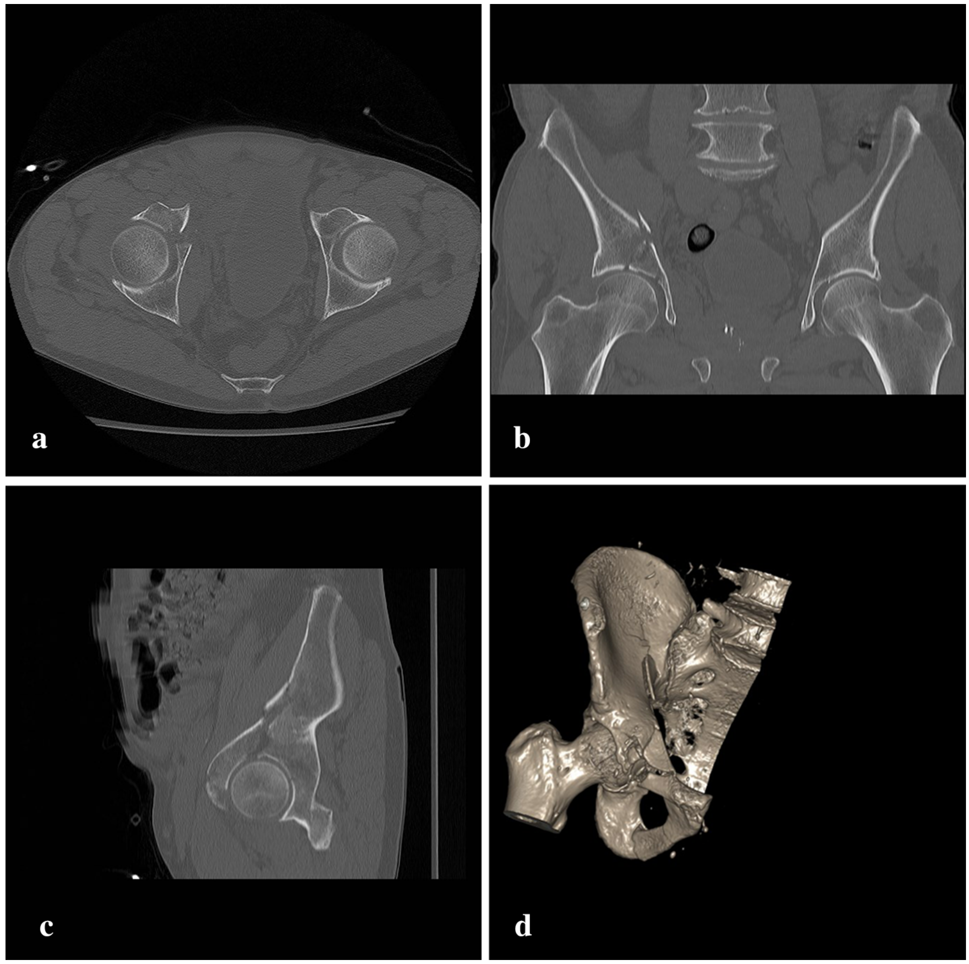

Fig. 2 **a** Transverse, **b** coronal, **c** sagittal planes and **d** 3D reconstruction of preoperative CT of the right acetabulum

The fracture gap differences with navigation were sagittal − 2.94 mm (min − 16.50; max 8.10), coronal − 2.18 mm (min − 11.00; max 5.40) and axial − 1.81 mm (min − 15.30; max 7.10). Without navigation they were sagittal − 2.72 mm (min − 5.50; max 3.80; $p = 0.868$), coronal − 2.24 mm (min − 11.50; max 3.20; $p = 0.966$) and axial − 2.39 mm (min − 6.60; max 0.60; $p = 0.582$) (Table 4).

The fracture step differences with navigation were sagittal − 0.30 mm (min − 5.00; max 2.40), coronal − 0.49 mm (min − 5.00; max 3.90) and axial − 0.50 mm (min − 6.00; max 3.00). Without navigation they were sagittal − 0.64 mm (min − 4.30; max 2.00; $p = 0.536$), coronal − 0.78 mm (min − 3.90; max 0.00; $p = 0.600$) and axial − 0.45 mm (min − 5.40; max 2.00; $p = 0.948$) (Table 4).

The distance of the screw from the joint in the navigated group was on average 6.00 mm (min 0.00; max 22.00) and in the non-navigated group 5.38 mm (min 2.50; max 10.00; $p = 0.645$). The amount of the angle difference between the screw and the ideal angle of 90° to the fracture gap with navigation was 13.88° (min 0.00; max 56.00) and without navigation was 16.18° (min 0.00; max 48.00; $p = 0.689$) (Table 4).

The ratio of screw length to the corridor in the navigated patients was 0.97 (min 0.75; max 1.00) and in the non-navigated patient 0.97 (min 0.66; max 1.00; $p = 0.976$). The fracture gap was bridged by the screw thread in 11 cases from the 24 navigated surgery patients and in 8 cases from the 13 non-navigated patients ($p = 0.495$) (Table 4).

Discussion

The surgical management of slightly dislocated acetabular fractures is a subject of dispute in the literature. Intraoperative processes, radiologically verifiable precision and clinical and radiological outcome parameters are generally studied as comparative criteria. Besides studies on artificial or cadaveric bones, experimental studies have also been conducted on previously acquired CT images. Ultimately, however, the use of direct patient data is essential to compare different treatment options of slightly dislocated acetabular fractures.

In our study, fracture gap differences and fracture step differences were determined from preoperative and

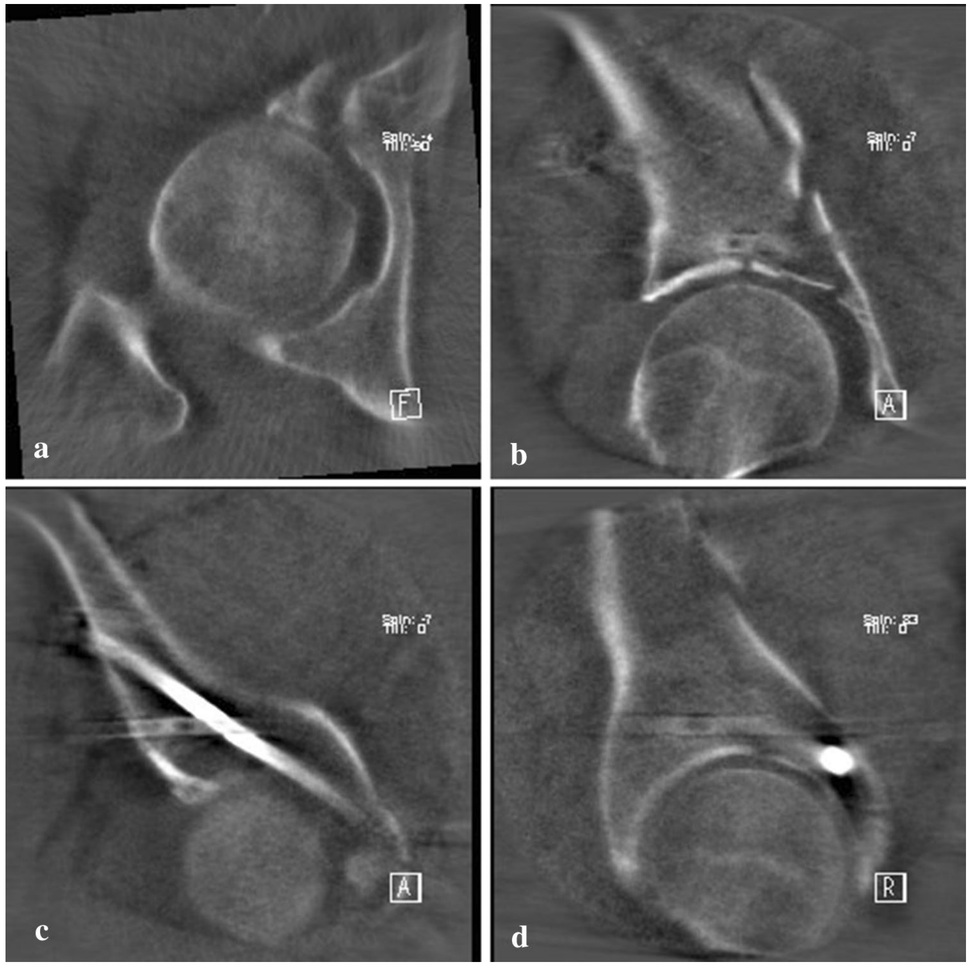

Fig. 3 **a** Transverse; **b**, **c** coronal; **d** sagittal planes of intraoperative 3D scan of the right acetabulum after closed reduction and minimally invasive screw positioning without navigation. **c** Demonstrates the reduced fracture and **d** the screw position

Fig. 4 A.p. view of the right hip after minimally invasive surgery without navigation

postoperative CTs as a measure of primary radiological outcome. Reduction in the sense of a significant reduction in fracture gaps and a tendency to a reduction in fracture steps was demonstrated on average in all reconstructions and in both treatment groups. For the best reduction effect, the screw should lie 90° to the fracture line, the threaded portion has to pass the fracture and the screw should have the maximal possible length. Due to the estimated higher precision while aiming for the screw corridor and the possibility of planning screw length and thread type, we hypothesized the 3D navigated group to show better fracture reduction and implant position. Comparing the two treatment groups, no significant differences were found between 3D-navigated patients and those undergoing conventional fluoroscopy in terms of gap and step differences. The implant position was evaluated on the criteria of distance of the screw from the joint, angle difference from the ideal angle, bony corridor used and bridging of the fracture gap by the screw thread. No significant difference between the two treatment modalities was found in this respect either. However, it was noticeable that the mean distance of the screw from the joint tended to be less in the conventional fluoroscopic group and lay within a markedly smaller range. It may therefore be assumed that the navigated screws were planned with more distance to the joint

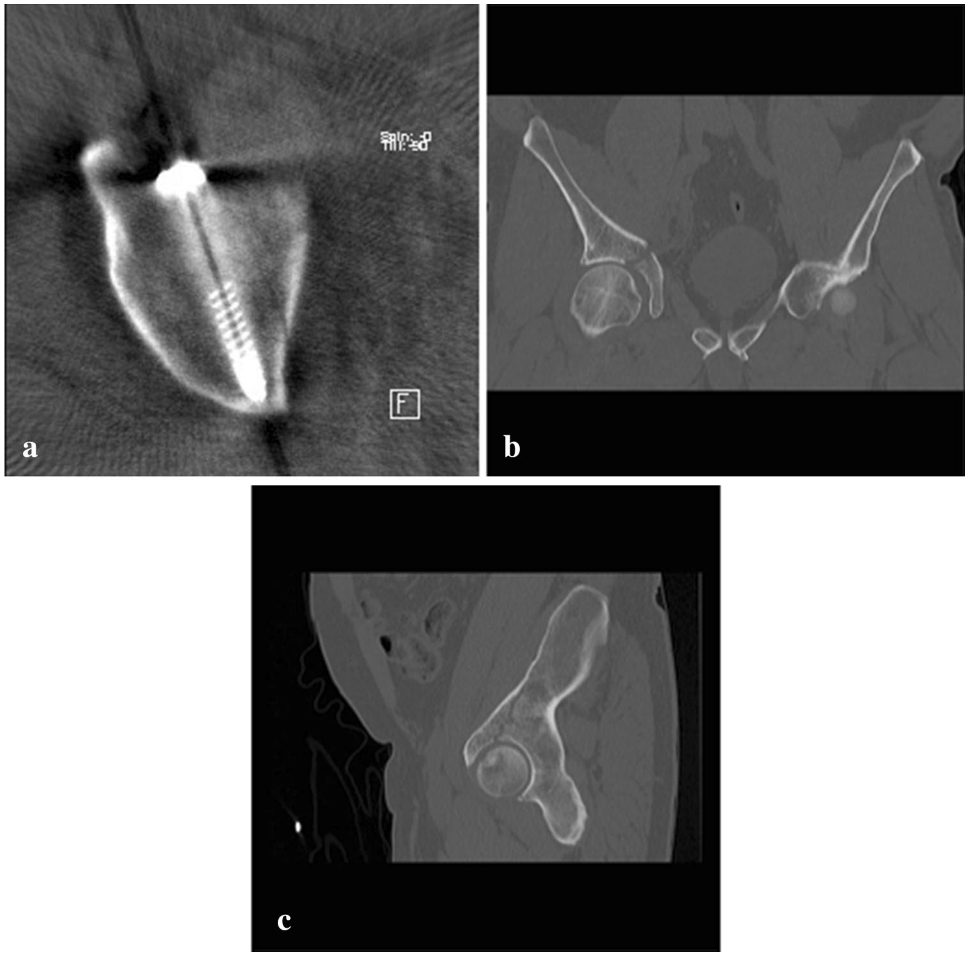

Fig. 5 **a** Transverse, **b** coronal, **c** sagittal planes and **d** 3D reconstruction of preoperative CT of the right acetabulum

for safety reasons. The screw trajectory can be planned more individually with navigation and therefore may result in a higher range. In addition, there is a difference in terms of the position of the screw thread: in the navigated group the screw thread passed beyond the fracture gaps in only 45.8% of cases. This means that in more than half the cases compression could not be exerted on the fracture gap by the screw. By contrast, with the conventional method a sufficient screw thread position is present in 61.5% of cases. This tendency to greater precision with the conventional method raises questions as to the reason for this. Firstly, the procedures were performed at different times and consequently by different surgeons. This presumably introduces the greatest bias in postoperative outcomes. The surgeon's experience must be taken into account. Obviously, the number of patients observed in this study, does not represent a high experience. Nevertheless, the overall number of percutaneous and especially navigated procedures in the study period is high. Another explanation is that, by relying on the presumed safety of navigation, the surgeon fails to measure the length and plan the screw thread position with sufficient care. In addition, the in-house treatment standard does not provide for a follow-up 3D scan after navigated placement of a screw; follow-up is therefore performed using 2D fluoroscopy.

The use of 3D Navigation is still under discussion. However, in terms of open reduction and internal fixation, most authors agree with performing 3D navigation. Oberst et al. studied 68 prospectively recorded patients after open reduction and internal fixation of acetabular fractures. Conventional fluoroscopy was compared with the 3D-navigated method. The authors demonstrated a better postoperative radiological outcome in patients undergoing 3D-navigated surgery. Significantly smaller postoperative steps were found in the 3D-navigated group. Similar to our study, no significant differences were seen in postoperative gaps. It should be noted that the preoperative fracture steps and gaps were on average twice as large those shown in our study. The greater differences can statistically be demonstrated in a more sufficient way. The reason for the smaller preoperative gaps and steps in our study is the selected patient population due to the requirement for minimally invasive surgery. Oberst also implanted some screws percutaneously, resulting in a higher heterogeneity of the investigated population.

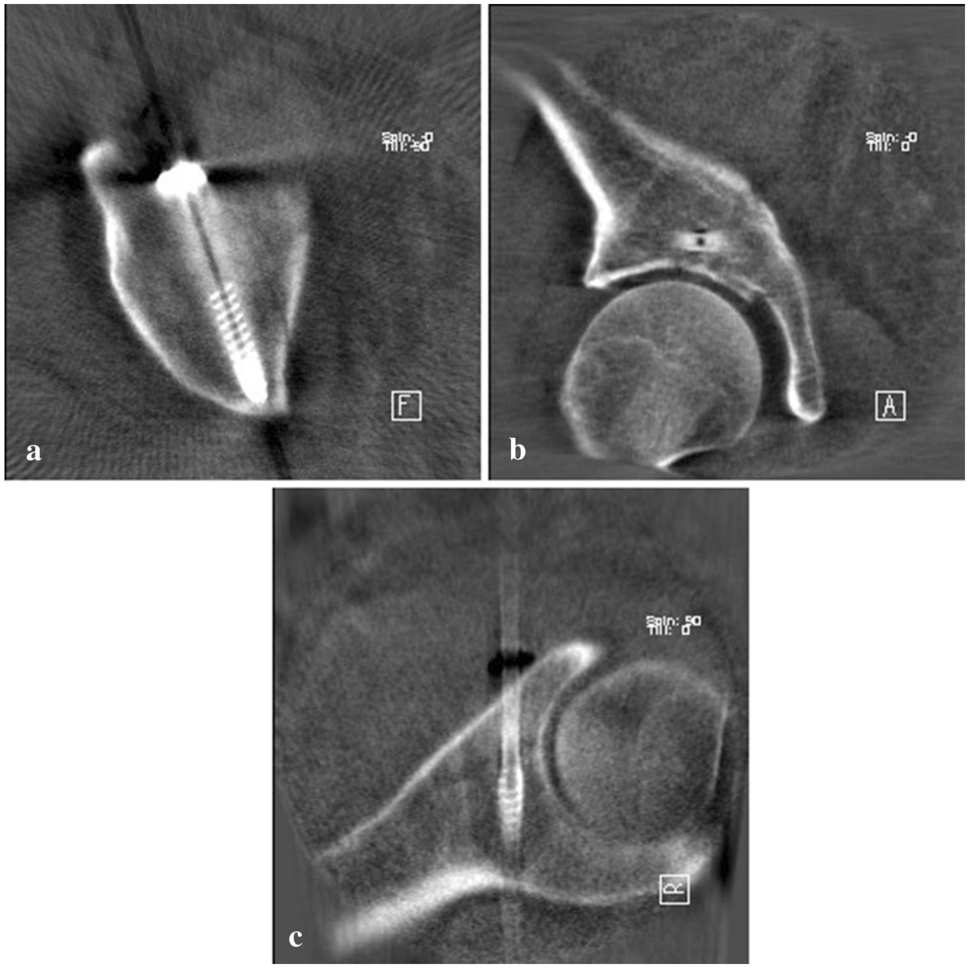

Fig. 6 **a** Transverse, **b** coronal, **c** sagittal planes of intraoperative 3D scan of the right acetabulum after closed reduction and minimally invasive screw positioning with navigation

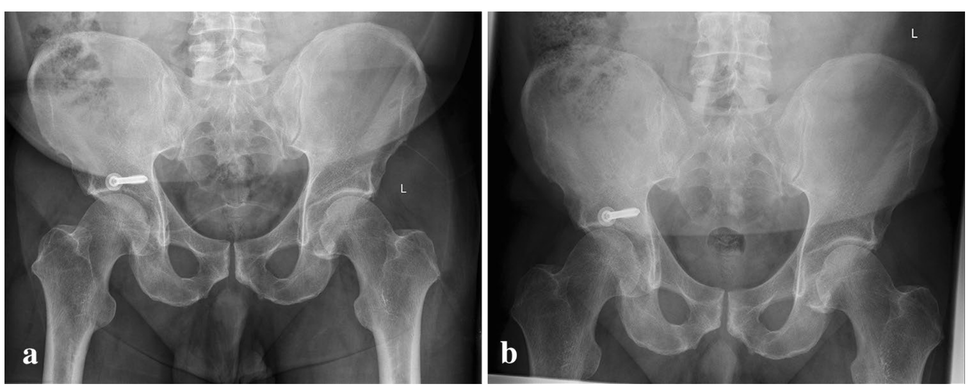

Fig. 7 Follow-up a.p. pelvis X-rays **a** 6 weeks and **b** 12 weeks after minimally invasive navigated surgery of the right acetabulum

A comparison of conventional fluoroscopy and 2D and 3D navigation in 210 supra-acetabular screw placements was conducted on artificial and cadaveric bones by Ochs et al. The authors attempted to locate a preoperatively defined corridor by the screw with the aid of different imaging techniques. In terms of precision, perforation of the acetabular joint surface and deviation of the screw from the initially planned position were recorded by means of a postoperative 3D scan. 3D navigation exhibited a lower perforation rate of the joint and smaller deviations from the planned screw trajectory than conventional fluoroscopy. Also there is evidence, that 3D navigation has a higher accuracy in inserting sacroiliac screws than conventional fluoroscopy [15]. Higher precision with 3D navigation is evident, but we were unable to demonstrate this advantage in a real-life setting in acetabular fractures. In fact, the variance of the screw position from the ideal angle in our study was smaller

Table 2 The mean measurements of the preoperative fracture steps and gaps in the individual reconstructions are given in mm

	Sagittal step (mm)	Sagittal gap (mm)	Coronal step (mm)	Coronal gap (mm)	Axial step (mm)	Axial gap (mm)
Conventional fluoroscopy						
Mean	1.17	5.28	1.07	4.79	1.12	5.70
Min	0.00	1.70	0.00	0.00	0.00	1.00
Max	4.30	12.90	3.90	14.40	5.40	15.80
3D navigation						
Mean	0.66	5.56	1.30	5.71	1.38	6.06
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	5.00	21.00	5.00	12.10	9.00	17.70
p value	0.330	0.846	0.657	0.545	0.714	0.784

The significance level was $p < 0.05$

CTs of 24 patients with conventional fluoroscopy and 13 patients with 3D navigation after percutaneous screw fixation of the acetabulum were analysed

Table 3 The fracture gaps and steps in pre- and postoperative CTs are presented in mm as a measure of fracture reduction

	Conventional fluoroscopy (mean, range)			3D navigation (mean, range)		
	Preoperative	Postoperative	*p* value	Preoperative	Postoperative	*p* value
Sagittal step (mm)	1.17 (0.00–4.30)	0.53 (0.00–2.90)	0.097	0.66 (0.00–5.00)	0.36 (0.00–2.40)	0.124
Sagittal gap (mm)	5.28 (1.70–12.90)	2.57 (0.00–7.40)	< 0.001*	5.56 (0.00–21.00)	2.62 (0.00–12.40)	0.008*
Coronal step (mm)	1.07 (0.00–3.90)	0.28 (0.00–2.70)	0.029*	1.30 (0.00–5.00)	0.81 (0.00–3.90)	0.127
Coronal gap (mm)	4.79 (0.00–14.40)	2.55 (0.00–7.20)	0.030*	5.71 (0.00–12.10)	3.53 (0.00–11.40)	0.001*
Axial step (mm)	1.12 (0.00–5.40)	0.66 (0.00–4.60)	0.214	1.38 (0.00–9.00)	0.88 (0.00–4.50)	0.100
Axial gap (mm)	5.70 (1.00–15.80)	3.31 (0.00–9.20)	< 0.001*	6.06 (0.00–17.70)	4.25 (0.00–12.10)	0.025*

*Significant *p* values. 24 patients were treated with conventional fluoroscopy and 13 patients with 3D navigation in percutaneous screw fixation of the acetabulum. The significance level was $p < 0.05$

Table 4 CTs of 24 patients with conventional fluoroscopy and 13 patients with 3D navigation after percutaneous screw fixation of the acetabulum were analysed

	Conventional fluoroscopy (mean, range)	3D navigation (mean, range)	*p* value
Fracture gap differences (mm)[a]			
Sagittal	− 2.72 (− 5.50/3.80)	− 2.94 (− 16.50/8.10)	0.868
Coronal	− 2.24 (− 11.50/3.20)	− 2.18 (− 11.00/5.40)	0.966
Axial	− 2.39 (− 6.60/0.60)	− 1.81 (− 15.30/7.10)	0.582
Fracture step differences (mm)[a]			
Sagittal	− 0.64 (− 4.30/2.00)	− 0.30 (− 5.00/2.40)	0.536
Coronal	− 0.78 (− 3.90/0.00)	− 0.49 (− 5.00/3.90)	0.600
Axial	− 0.45 (− 5.40/2.00)	− 0.50 (− 6.00/3.00)	0.948
Distance of screw from joint (mm)[b]	5.38 (2.50/10.00)	6.00 (0.00/22.00)	0.645
Amount of angle difference[c]	16.18° (0.00/48.00)	13.88° (0.00/56.00)	0.689
Ratio of screw length to corridor[d]	0.97 (0.66/1.00)	0.97 (0.75/1.00)	0.976
Bridging of fracture gap by screw thread (% of occurrence)	61.5%	45.8%	0.495

The significance level was $p < 0.05$

[a]Fracture gap differences and fracture step differences between pre- and postoperative CT in mm

[b]Defines the shortest distance of the screw to the acetabular joint surface in mm

[c]The angle difference between the screw and the ideal angle of 90° to the fracture gap

[d]The ratio of screw length to the available bony corridor

with screws inserted under conventional fluoroscopy. In our view, different surgeons could be a reason for this, as mentioned earlier. Again, the number of cases and the surgeons' experience have to be taken into account. In addition, with the conventional method the surgeon is forced to orientate himself by means of the more detailed landmarks that are possible on plain film. In the fracture situation, navigation has its limitations due to changing fragment position after reduction. Navigation has its advantages after reduction. Nonreducible steps are a problem for both techniques. Moreover, Ochs' method is not directly comparable to ours, since in the study by Ochs et al. a pre-operatively planned screw position had to be obtained by conventional fluoroscopy in the corresponding treatment arm.

Xu et al. tested conventional fluoroscopy versus 3D navigation by placing 8 supra-acetabular screws in 2 cadaveric pelvises per group. Increased precision was again observed here in the form of less cortical penetration under 3D navigation. In the tests described, the soft tissues of the preparations were removed and visual control was therefore possible when inserting the screws. The only criterion was cortical penetration. In our study, no penetration of the acetabular joint surface occurred in any of the cases. The artificial setting of an in vitro study possibly provides different conditions from those that pertain in everyday surgical practice.

Our study is the first to evaluate percutaneous screw placement in the case of slightly dislocated acetabular fractures in the clinical setting.

The low inclusion rate due to the lack of available image material may be regarded as a limitation of our study. This limitation could be reduced by using a prospective design in which the number of cases and hence the power of the study could be increased. Fracture classifications were not considered, which might result in a bias in terms of comparability. However, the absolute degrees of dislocation of the preoperative CTs revealed no significant difference between the two treatment groups. In addition, a minimally invasive surgical technique was required as a standard criterion, which certainly has a homogenizing effect in terms of fracture geometry. We therefore consider the groups to be comparable.

The fluoroscopy time within the groups was not determined. Both procedures required intraoperative 3D scans, either for navigation referencing or to check the wire position. These primarily account for a higher radiation exposure to the patient, whereas the surgeon generally receives less radiation in navigated procedures [15]. In connection with much higher radiation exposure to the patient due to regular preoperative CT scans, we considered the reduced radiation exposure with navigation to be negligible.

Conclusion

The study hypothesis could not be confirmed. In the percutaneous management of acetabular fractures in clinical practice, concerning the small patient number, 3D navigation seems to show no benefits over conventional fluoroscopy in terms of fracture reduction and implant position.

Funding No external funding was received.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

References

1. Briffa N, Pearce R, Hill AM, Bircher M (2011) Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br 93(2):229–236. https://doi.org/10.1302/0301-620x.93b2.24056 **(PubMed PMID: 21282764)**
2. Gansslen A, Pohlemann T, Paul C, Lobenhoffer P, Tscherne H (1996) Epidemiology of pelvic ring injuries. Injury 27(Suppl 1):S-a13-20 **(PubMed PMID: 8762338)**
3. Ochs BG, Gonser C, Shiozawa T, Badke A, Weise K, Rolauffs B et al (2010) Computer-assisted periacetabular screw placement: Comparison of different fluoroscopy-based navigation procedures with conventional technique. Injury. 41(12):1297–1305. https://doi.org/10.1016/j.injury.2010.07.502 **(PubMed PMID: 20728881)**
4. Borrelli J Jr, Goldfarb C, Ricci W, Wagner JM, Engsberg JR (2002) Functional outcome after isolated acetabular fractures. J Orthop Trauma 16(2):73–81 **(PubMed PMID: 11818800)**
5. Crowl AC, Kahler DM (2002) Closed reduction and percutaneous fixation of anterior column acetabular fractures. Comput Aid Surg 7(3):169–178. https://doi.org/10.1002/igs.10040 **(PubMed PMID: 12362377)**
6. Oberst M, Hauschild O, Konstantinidis L, Suedkamp NP, Schmal H (2012) Effects of three-dimensional navigation on intraoperative management and early postoperative outcome after open reduction and internal fixation of displaced acetabular fractures. J Trauma Acute Care Surg 73(4):950–956. https://doi.org/10.1097/ta.0b013e318254308f **(PubMed PMID: 22710769)**
7. Matta JM (1996) Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am Vol 78(11):1632–1645 **(PubMed PMID: 8934477)**
8. Puchwein P, Enninghorst N, Sisak K, Ortner T, Schildhauer TA, Balogh ZJ et al (2012) Percutaneous fixation of acetabular fractures: computer-assisted determination of safe zones, angles and lengths for screw insertion. Arch Orthopaed Trauma Surg 132(6):805–811. https://doi.org/10.1007/s00402-012-1486-7 **(PubMed PMID: 22358222)**
9. Stockle U, Schaser K, Konig B (2007) Image guidance in pelvic and acetabular surgery–expectations, success and limitations. Injury. 38(4):450–462. https://doi.org/10.1016/j.injury.2007.01.024 **(PubMed PMID: 17403522)**

10. Gras F, Marintschev I, Klos K, Muckley T, Hofmann GO, Kahler DM (2012) Screw placement for acetabular fractures: which navigation modality (2-dimensional vs. 3-dimensional) should be used? An experimental study. J Orthopaed Trauma 26(8):466–473. https://doi.org/10.1097/bot.0b013e318234d443 **(PubMed PMID: 22357092)**
11. Mosheiff R, Khoury A, Weil Y, Liebergall M (2004) First generation computerized fluoroscopic navigation in percutaneous pelvic surgery. J Orthop Trauma 18(2):106–111 **(PubMed PMID: 14743031)**
12. Xu P, Wang H, Liu ZY, Mu WD, Xu SH, Wang LB et al (2013) An evaluation of three-dimensional image-guided technologies in percutaneous pelvic and acetabular lag screw placement. J Surg Res 185(1):338–346. https://doi.org/10.1016/j.jss.2013.05.074 **(PubMed PMID: 23830362)**
13. Schwabe P, Altintas B, Schaser KD, Druschel C, Kleber C, Haas NP et al (2014) 3D-fluoroscopy navigated percutaneous screw fixation of acetabular fractures. J Orthopaed Trauma. https://doi.org/10.1097/bot.0000000000000091 **(PubMed PMID: 24662989)**
14. Magu NK, Gogna P, Singh A, Singla R, Rohilla R, Batra A et al (2014) Long term results after surgical management of posterior wall acetabular fractures. J Orthopaed Traumatol 15(3):173–179. https://doi.org/10.1007/s10195-014-0297-8 **(PubMed PMID: 24879360; PubMed Central PMCID: PMCPmc4182623)**
15. Berger-Groch J, Lueers M, Rueger JM et al (2020) Accuracy of navigated and conventional iliosacral screw placement in B- and C-type pelvic ring fractures. Eur J Trauma Emerg Surg 46(1):107–113