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Unlocking the third dimension of acetabular fracture surgery

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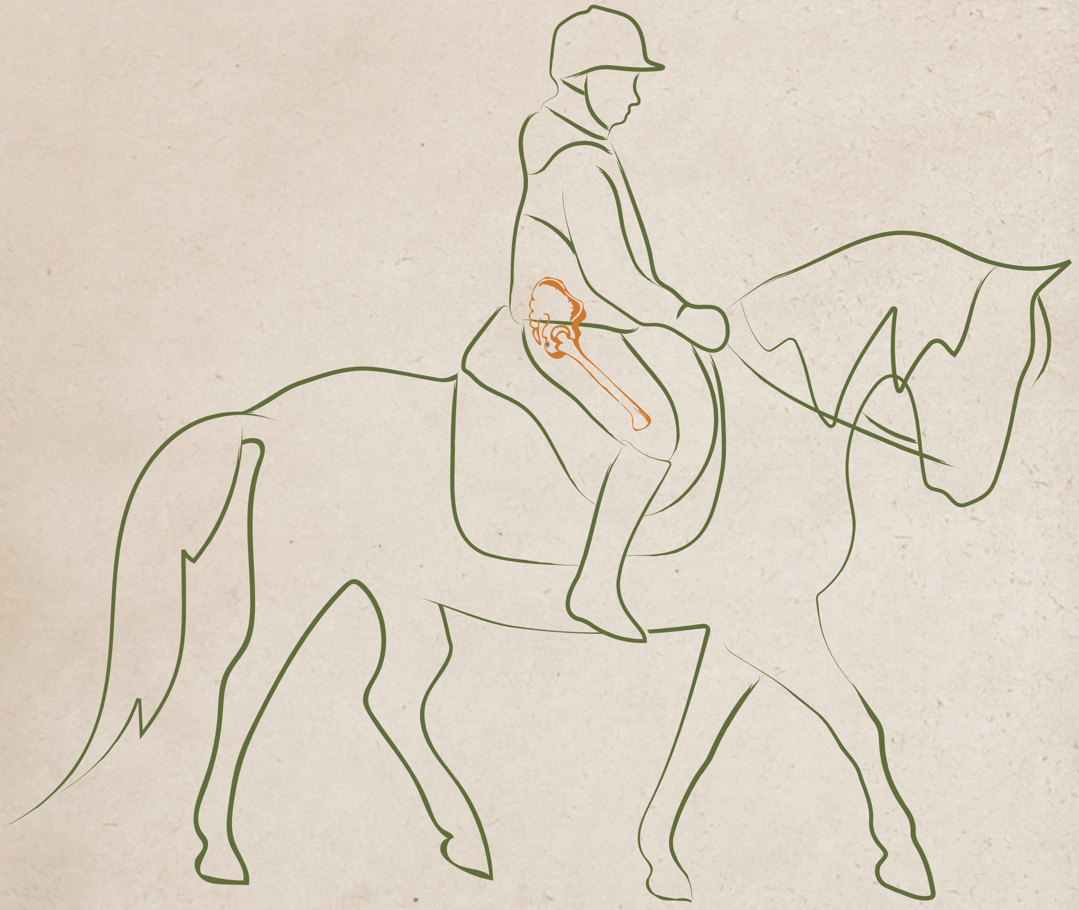
3D INTERACTIVE MODEL



CHAPTER 8

Feasibility of imaging-based 3D models to design patient-specific osteosynthesis plates and drilling guides

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ABSTRACT

Importance

In acetabular fracture surgery, achieving an optimal reconstruction of the articular surface decreases the risk of osteoarthritis and the subsequent need for total hip arthroplasty. Unfortunately, no "one-size-fits-all" osteosynthesis plate is available due to differences in fracture patterns and variations in pelvic anatomy. The current osteosynthesis plates need to be manually contoured intraoperatively, often resulting in inadequate reduction and fixation of the fractured segments.

Objective

A novel concept of fast-track three-dimensional (3D) virtual surgical planning and patient-specific osteosynthesis for complex acetabular fracture surgery is introduced.

Design

We report an experimental study on the use of patient-specific osteosynthesis plates for 10 patients who underwent acetabular fracture surgery. 3D models were created based on CT data, fractures were virtually reduced and implant positions were discussed in a multidisciplinary team of clinicians and engineers. Patient-specific osteosynthesis plates with drilling guides were designed, produced, sterilized and clinically applied within 4 days.

Setting

A tertiary university-affiliated referral center and level-1 trauma center.

Participants

Consecutive patients needing operative treatment for a displaced associated type acetabular fracture between 2017 and 2018.

Interventions/Exposures

Development and clinical implementation of personalized fracture surgery.

Main Outcomes and Measures

The primary outcome was the quality of the reduction on the postoperative CT scan. The secondary outcomes were accuracy of the screw placement and clinical outcome using patient-reported outcome measures.

Results

Ten patients (median age 63 years) with an acetabular fracture were included. The median preoperative gap was 20 mm (IQR: 15-22 mm) and the step-off was 5 mm (IQR: 3-11 mm). Postoperatively, the median gap reduced to 3 mm (IQR: 2-5 mm; P=0.005) and the step-off to 0 mm (IQR: 0-2 mm; P=0.01) indicating good fracture reduction. The median difference in screw direction between the planning and actual surgery was only 7.1 degrees (IQR: 7-8 degrees). All patients retained their native hip and reported good physical functioning at follow-up.

Conclusion and Relevance

3D virtual surgical planning, manufacturing and clinical application of patient-specific osteosynthesis plates and drilling guides is feasible and yields good clinical outcomes. Fast-track personalized surgery opens a new era for the treatment of complex injuries.

INTRODUCTION

The overall incidence of acetabular fractures is estimated as 5-8 per 100,000 people per year, which accounts for roughly 60,000 injured individuals annually in Europe [1,2]. A pelvic injury can have major consequences for physical functioning, participating in social activities and the ability to work. Acetabular fracture treatment consists of either nonoperative treatment (56% of the patients), open reduction and internal fixation (38% of the patients) or primary total hip arthroplasty (THA, 6% of the patients) [3].

Achieving an optimal reconstruction of the articular surface improves the functional outcome and decreases the risk of progressive osteoarthritis and the subsequent need for THA [4–6] but this is particularly challenging for associated type (more complex) fractures with substantial displacement [7–9]. Postoperative CT analysis of acetabular fractures demonstrated inadequate reductions in up to 53% of the cases [9]. Thirty-six percent of the patients with an inadequate reduction eventually need a conversion to THA in comparison to only 10% of those with an adequate reduction [9].

Despite the progress in surgical techniques and osteosynthesis plates, even experienced surgeons often fail to achieve adequate reconstruction of the fractured acetabulum [9]. Currently, the conventional osteosynthesis plates often require multiple intra-operative contouring manoeuvres, to fit the individual pelvis reasonably. Moreover, the optimal screw positions, with good purchase, might be hard to determine and verify with fluoroscopy. Unfortunately, a uniform osteosynthesis plate that fits the shape of each pelvis, covers all the fracture patterns and holds the surgically reduced fracture fragments perfectly in place, does not exist.

We developed an innovative surgical procedure for acetabular fractures by using 3D virtual surgical planning and patient-specific pelvic osteosynthesis plates with drilling guides [10]. We hypothesized that this new personalized approach would result in optimal osteosynthesis plate fitting, accurate screw placements and adequate fracture reductions. The patient-specific osteosynthesis plates, tailored to both the shape of the pelvis and the fracture type, can be applied to repair accurately one of the most challenging fracture types in orthopedic trauma surgery. The aim of this study, therefore, was to assess whether such a personalized approach is feasible, leading to accurate reconstruction of associated type acetabular fractures.

METHODS

Patients

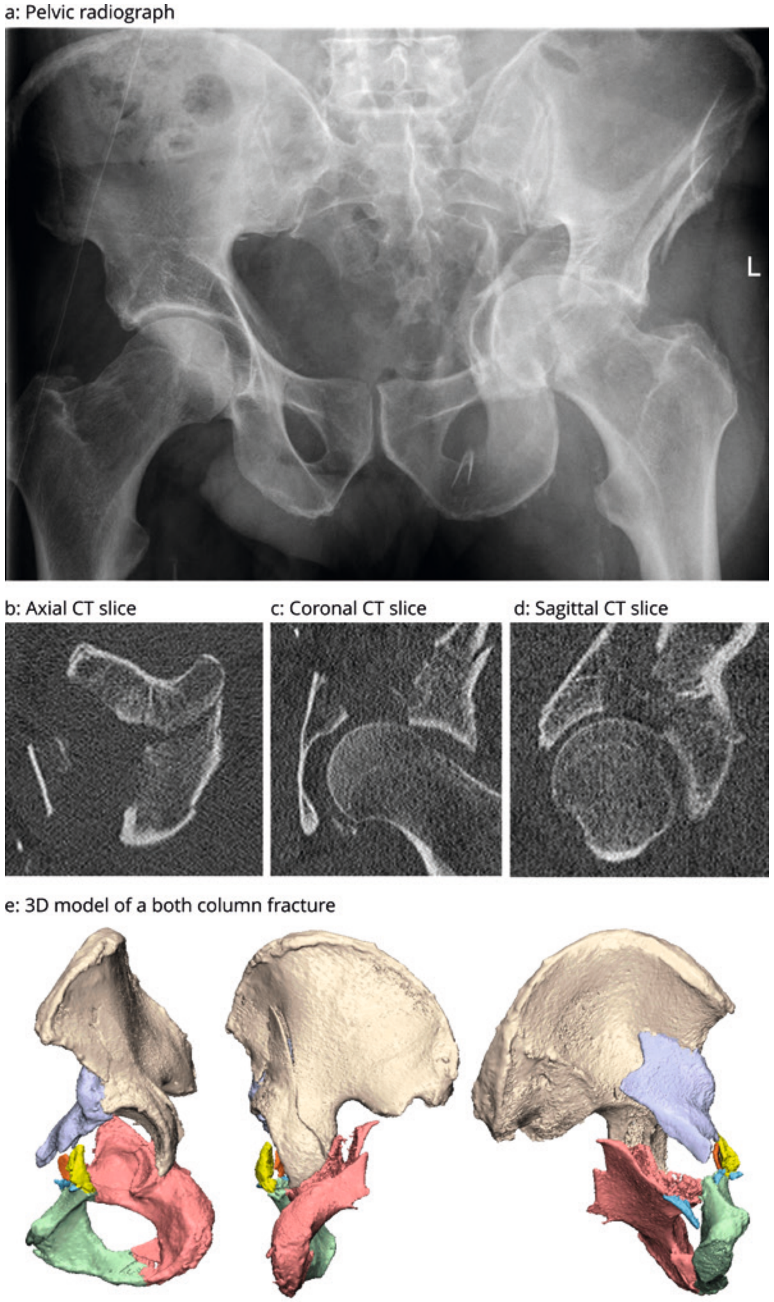
Eligibility criteria were patients who sustained a displaced unilateral associated type acetabular fracture [11,12] and requiring surgical treatment. All consecutive patients with comminuted, displaced T-shaped or both column acetabular fracture types between 2017 and 2018 were included. Ten patients were treated with patient-specific osteosynthesis plates according to the procedures (eFigure 1 in the Supplement) described in the following sections. Approval was obtained from our hospital's Institutional Review Board (2016.234) and informed consent was obtained from all patients.

3D surgical planning

Each patient's CT data (≤ 1 mm slices, spatial resolution of 0.5-0.6 mm) was used to create a 3D model (Figure 1) with Mimics Medical 19.0 software (Materialise, Leuven, Belgium). A pre-set threshold for bone was used for automatic segmentation of all the fracture fragments. Each fracture fragment was assigned a different color and reduced to its anatomical position by using translational and rotational tools in the planning software. The contralateral hemipelvis was mirrored and used as a template to verify the accuracy of the virtual fracture reduction [13].

Patient-specific osteosynthesis plate design

Patient-specific osteosynthesis plates tailored from the virtually reduced 3D fracture model, to achieve optimal support and stable internal fixation of fracture fragments, were designed within a day after hospital admission. First, the optimal screw trajectories in relation to the fracture fragments were predetermined in the 3D fracture model. Subsequently, the patient-specific titanium osteosynthesis plates were designed with 3-Matic 11.0 (Materialise, Leuven, Belgium), Solidworks professional 2017 (Dassault Systèmes Solidworks Corp., Waltham, MA, USA) and Geomagic for Solidworks (3D systems, Rock Hill, SC, USA) software programs. All the screw lengths were predetermined as part of the preoperative planning. Drilling guides were designed to translate the virtual planning towards the surgical procedure and to redirect the drill bit as well as the screws in the right direction (Figure 2). The guides were provided with additional bone supporting extensions that enabled a perioperative visual check for correct placement. In addition, the guides were supplied with holes for k-wire fixation once the correct position was achieved. The synthetic guides were designed to envelope the osteosynthesis plate and to allow insertion of a stainless-steel drill sleeve while drilling the screw pilot holes. The surgical plan, screw trajectories and osteosynthesis plate design were discussed in a multidisciplinary meeting with pelvic surgeons, technical physicians and engineers.


a: Pelvic radiograph

b: Axial CT slice

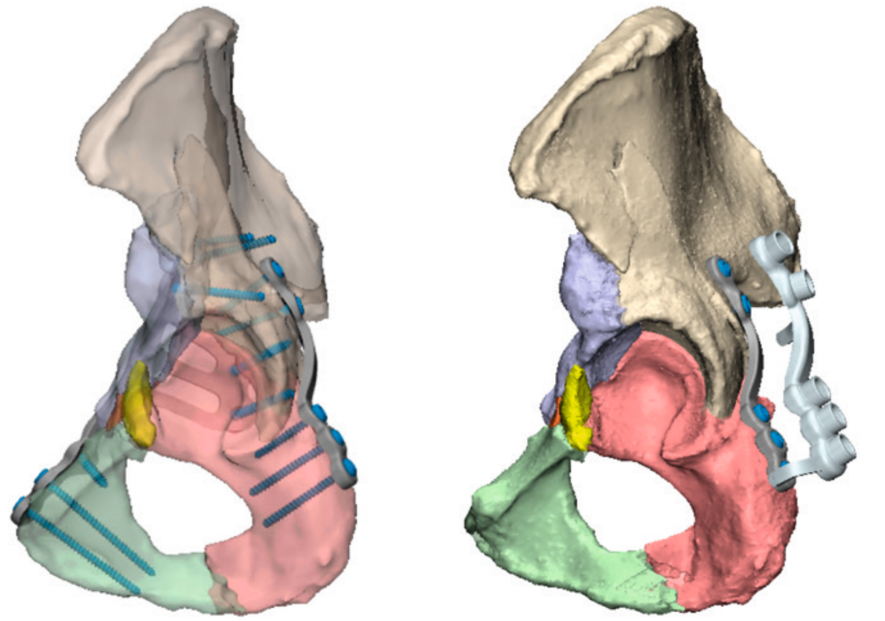
c: Coronal CT slice

d: Sagittal CT slice

e: 3D model of a both column fracture

Figure 1: Preoperative situation. Pelvic radiograph, CT scan (axial, coronal, sagittal CT slices) and 3-D model from patient 5, who had fallen from a height and sustained an associated-type both-column fracture. The fracture caused medial protrusion of the femoral head and severe displacement of the anterior as well as the posterior column. This patient was treated with patient-specific osteosynthesis plates.

a: 3D surgical planning of the posterior plate b: application of the posterior plate by using a drilling guide



c: 3D surgical planning of the anterior plate d: application of the anterior plate by using a drilling guide

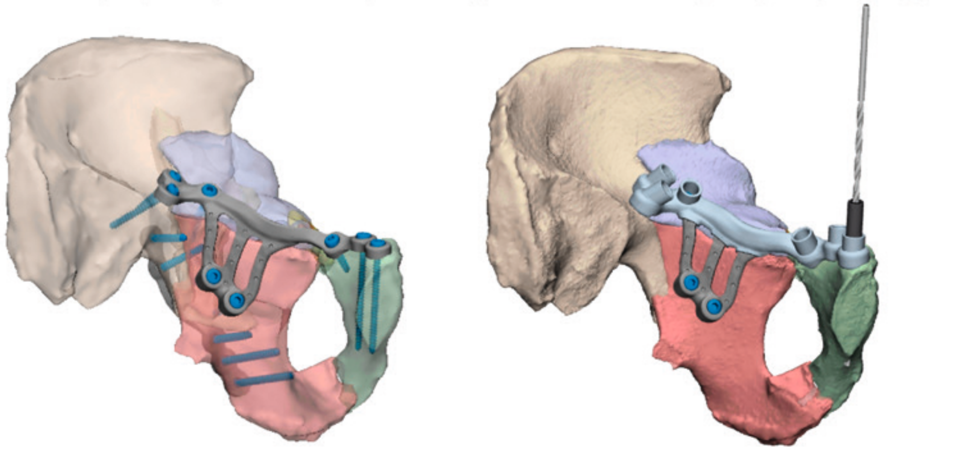


Figure 2: 3-D Virtual surgical planning. These images represent the preoperative planning, osteosynthesis plate designs, and drilling guides for patient 5, who underwent an associated-type both-column fracture operation. Our plan was to first perform a Kocher-Langenbeck approach, reduce the posterior column with a collinear reduction clamp and apply the patient-specific posterior plate (A). The proximal screws in the posterior plate were aimed at the ilium (cream-colored fragment) by using the drilling guide (B) to not compromise the reduction of the anterior column (purple fragment). After reduction and fixation of the posterior column, the wound was closed, and an additional anterior intrapelvic approach was performed. The anterior column was stabilized with a patient-specific anterior plate (C), which provided optimal support along the quadrilateral surface (red fragment). The screws in the anterior plate were aimed in the right direction by the drilling guide placed temporarily on top of the osteosynthesis plate (D).

Osteosynthesis plate production process

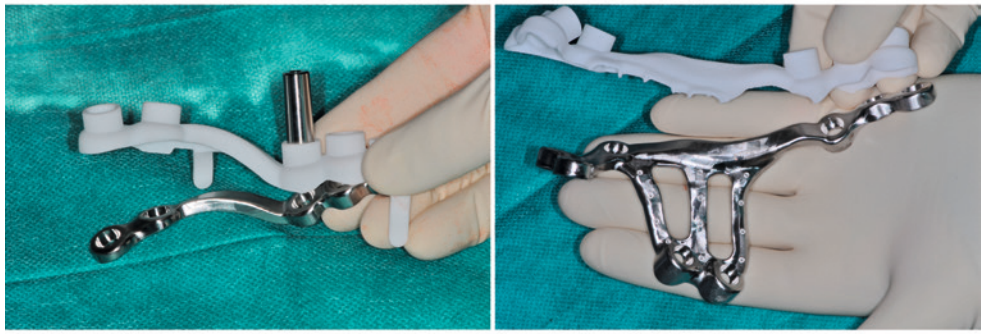
The self-designed patient-specific osteosynthesis plates were manufactured by a regional medical company (Witec Medical B.V., Stadskanaal, the Netherlands) within 3 days for each case. The osteosynthesis plate was milled out of a medical grade titanium alloy by a 5-axis milling machine. The drilling guides were 3D laser-printed from medical certified polyamide powder (by Oceanz, Ede, the Netherlands). The osteosynthesis plates and guides were prepared for surgery with a routine 134 °C autoclave steam sterilization process.

Surgical procedure

All the patients were operated according to the standard of care by two trauma surgeons, each with > 5 years of experience in pelvic surgery, which avoids bias of the results due to differences in operative skills between surgeons. The fracture pattern and amount of displacement were decisive for the surgical approach. The most suitable approach (anterior intrapelvic approach with or without a lateral window, Kocher-Langenbeck, or a combined approach, respectively) was left to the treating surgeon and discussed before designing the osteosynthesis plate. After exposing the fractures, standard tools were used to perform fracture reduction during which patient-specific osteosynthesis plates were applied to put and/or keep the fracture fragments in place. The drilling guides with additional bone supporting extensions, which enabled visual checks when positioning the osteosynthesis plate, were placed on top of the osteosynthesis plate (Figure 3). Intraoperative fluoroscopy was used to verify that the osteosynthesis plate was positioned according to the preoperative 3D planning. A drill sleeve was inserted into the cylinders of the guide to aim the drill bit correctly. After drilling, the drill sleeve was removed and screws, with a predetermined length, were inserted one by one into their proper trajectory. After inserting the last screw, the fracture reduction and osteosynthesis material were checked with fluoroscopy. The drill guide was removed from the osteosynthesis plate and all wounds were closed in layers.

a: Posterior plate with drilling guide and drill sleeve

b: Anterior plate with drilling guide



c: Application of the posterior plate

d: Application of the anterior plate

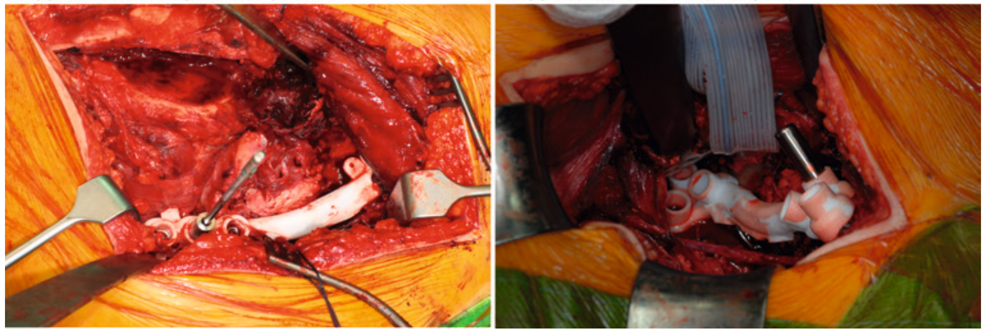
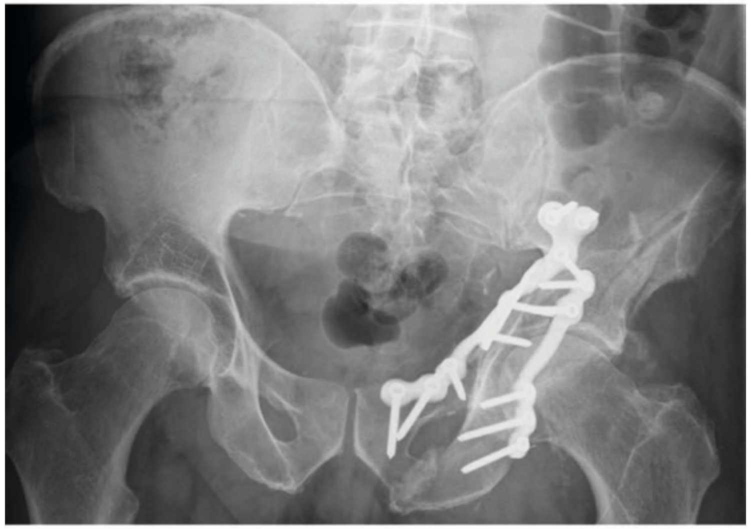


Figure 3: Intraoperative situation. Intraoperative images of the patient-specific posterior and anterior osteosynthesis plates used to treat the acetabular fracture of patient 5. A, posterior plate, including the drilling guide and drill sleeve. B, anterior plate, including the drilling guide. C, intraoperative reduction of the posterior column through a Kocher-Langenbeck approach by using a collinear clamp and the subsequent application of the posterior plate with the corresponding drilling guide. D, application of the anterior plate by using an anterior intrapelvic approach.

Postoperative CT evaluation

A postoperative CT scan (≤ 1 mm slice thickness) was performed in order to evaluate the accuracy of the acetabular reconstruction and screw positioning (Figure 4). Two experienced trauma surgeons, who were blinded for patient data, assessed the quality of the reduction by measuring the greatest residual gap and/or step-off displacement at the acetabular dome on the postoperative CT scan in any of the axial, sagittal, or coronal plane views according to a standardized method [14]. The quality of the reduction was graded according to Matta's criteria and the newly proposed CT-based criteria [8,15,16].

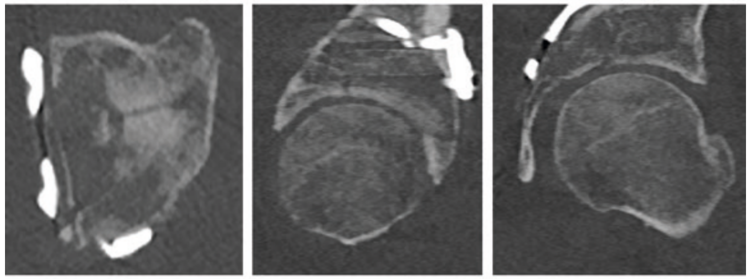
a: Patient-specific osteosynthesis plates



b: Reconstruction of the acetabulum (axial view)

c: Reconstruction of the acetabulum (coronal view)

d: Reconstruction of the acetabulum (sagittal view)



e: 3D model of the reconstructed acetabulum

f: Osteosynthesis plates and screws

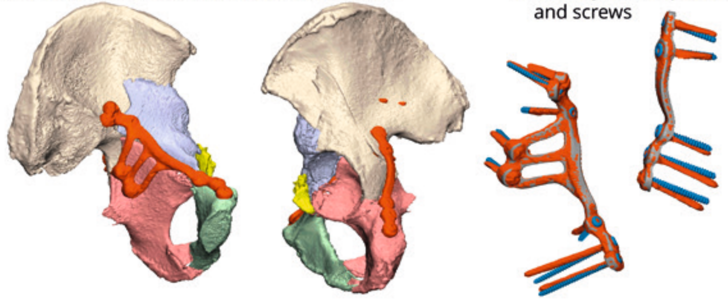


Figure 4: Postoperative situation. Patient-specific osteosynthesis plates were placed in patient 5 according to the preoperative plan. A postoperative computed tomography (CT) scan demonstrated good reconstruction of the fractured acetabulum. The gap was reduced from 28 mm before the operation to 5 mm after the operation. The step-off was reduced from 15 mm before the operation to 2 mm after the operation. A 3-dimensional (3-D) model, generated from the postoperative CT data, demonstrated an accurate surgical reconstruction of the fractured acetabulum (bottom left and middle). The osteosynthesis plates and screws, retrieved from the postoperative CT scan (orange), were digitally matched with the preoperative planning (grey and blue, F). The matched osteosynthesis plates demonstrated that all screws had been inserted accurately with only a median deviation of 6.8 degrees between the preoperative planning and the actual execution. The patient recovered uneventfully and returned to work after 6 months of rehabilitation. At the 1-year follow-up, the patient had no complaints about the hip, with no pain or physical impairment.

Furthermore, the postoperative CT data was used to create a 3D model of the reconstructed pelvis, which was matched, using surface-based matching, with the preoperative 3D surgical planning in order to assess how accurately the preoperative plan had been executed (Figure 4). The deviation in screw direction (degrees) between the pre- and postoperative 3D model was determined for each screw. Additionally, differences in screw lengths (mm) between the preoperative planning and postoperative situation were calculated, in order to assess the feasibility of using pre-planned screw lengths and, thereby, of saving some operation time.

Clinical follow-up

All the patients were followed-up at 3 months and one year. The patient-reported outcomes were assessed at the time of admission (pre-injury score) and during both visits with the validated Short Musculoskeletal Function Assessment (SMFA) questionnaire. The SMFA evaluates the functional status of a patient with various musculoskeletal disorders and injuries. It consists of 46 items regarding physical function of the extremities, daily activities, as well as mental and/or emotional problems. The SMFA scores may vary from 0 to 100, with a higher score indicating a poorer function [17,18]. Also, returned to work was recorded. All complications were monitored during the follow-up.

Statistical analysis

The Wilcoxon signed rank test was used to assess differences between the pre- and postoperative gap and step-off by using SPSS (version 23, IBM, Chicago, IL, USA). Moreover, the paired samples Wilcoxon signed rank test was used to assess differences between the pre-injury, 3 month and one-year patient-reported outcome scores (SMFA indices). The Spearman correlation coefficient was used to assess correlations between the postoperative reduction (e.g. gaps and step-offs) and clinical outcome (SMFA).

RESULTS

Demographics

Ten patients, nine males and one female, with a median age of 63 years (range 46-79) who sustained an associated both column fracture or a T-shaped fracture, were included. A total of 15 patient-specific osteosynthesis plates were used. Five patients were treated with only an anterior plate, the other five patients received an additional posterior plate (Table 1).

Surgical procedure

The osteosynthesis plates and drilling guides were designed, fabricated and sterilized within 4 days (Video 1: Patient-specific osteosynthesis workflow. A compilation of the 3D surgical planning, patient-specific osteosynthesis plate development and surgical procedure. https://edhub.ama-assn.org/jn-learning/video-player/18585889). They all fit well and did not need additional bending manoeuvres during the operation. All the patient-specific osteosynthesis plates were a good reference for the reduction and functioned as a guide for fracture reduction. Only three out of 95 screws that were preoperatively planned could not be placed during surgery due to the narrow space and the presence of soft tissues deep in the pelvis, which hampered the predetermined drilling angle. None of the screws penetrated into the hip joint or caused soft tissue injuries.

Table 1: Patient characteristics.

Patient	Age	Gender	Trauma mechanism	Fracture type	Surgical approach	Osteosynthesis plates
1	40s	Male	Fell of bicycle	Both column	AIP + LW + KL + TF	Ant + post
2	60s	Male	Fell of bicycle	T-shaped	AIP + KL	Ant + post
3	60s	Male	Fall from height	Both column	AIP + LW	Ant
4	70s	Male	Fell of scooter	Both column	AIP + LW	Ant
5	60s	Male	Fall from height	Both column	AIP + KL	Ant + post
6	40s	Male	Fell of bicycle	Both column	AIP	Ant
7	40s	Male	Fell of bicycle	Both column	AIP	Ant
8	60s	Male	Fall from height	Both column	AIP	Ant
9	70s	Male	Fall from height	T-shaped	AIP + KL	Ant + post
10	70s	Female	Fell of bicycle	Both column	AIP + KL	Ant + post

AIP anterior intra-pelvic; LW lateral window; KL Kocher-Langenbeck; TF trochanter flip; ant anterior; post posterior

Postoperative CT evaluation

Initially, the median preoperative gap was 20 mm (IQR: 15-22 mm) and the step-off was 5 mm (IQR: 3-11 mm) (eTable 1 in the Supplement). After patient-specific osteosynthesis plate surgery, the median gap on the postoperative CT scan was reduced to 3 mm (IQR: 2-5 mm; P=0.005) and the step-off to 0 mm (IQR: 0-2 mm; P=0.01). According to CT-based criteria, the reduction was graded as perfect in 3 out of 10 patients and good in 7 out of 10 patients [15]. The pre- and postoperative axial CT slices at the acetabular dome are presented in eFigure 2 in the Supplement.

A total of 95 screws were placed by using a drilling guide. Per patient, the median number of anterior and posterior screws was 6.5 (IQR: 6-7) and 6 (IQR: 5-7) respectively. The median difference between the planned screw length and the actual screw length was 1.7 mm (IQR: 1-3 mm) and between the planned and actual screw direction was 7.1 degrees (IQR: 7-8 degrees), which is within the safe zone for using personalized acetabular fracture surgery with confidence in clinical practice.

Clinical follow-up

All the patients had retained their native hip at the one-year follow-up. The median pre-injury Short Musculoskeletal Function Assessment (SMFA) function index was initially 7 out of 100 (IQR: 2-9), indicating good physical functioning (eTable 2 in the Supplement). Three months after surgery it was 29 (IQR: 22-35) and improved to 9 (IQR: 5-27) at the one-year follow-up (P=0.04), indicating good physical functioning. The median pre-injury SMFA lower extremities index was initially 1 out of 100 (IQR: 0-8), then 32 (IQR: 28-38) three months after surgery and improved to 6 (IQR: 3-19) at the one-year follow-up (P=0.05). There was no significant correlation between the SMFA indices at one year and the postoperative gap and step-off. At the one-year follow-up, six out of ten patients reported almost the same level of physical functioning as pre-injury according to the SMFA questionnaire (eTable 2 in the Supplement). Four patients reported some decrease in physical function at the one-year follow-up despite an accurate operative reconstruction of the fractured acetabulum. These patients were elderly, respectively 79-, 62-, 74- and 70-years of age, with some comorbidity and pre-existing functional impairment. Two of these patients reported better physical functioning at three months than at one year, due to a progression in secondary arthrosis as seen on the radiographs. Five of the ten patients returned to the same level of work as pre-injury. Two patients partially returned to work and three patients were already retired. One patient had a complication and needed readmission due to a deep wound infection requiring multiple washouts and antibiotic treatment after which he recovered, and the fracture healed. In one patient the osteosynthesis plate was removed after one year on the patient's request.

DISCUSSION

This study demonstrates that the application of 3D surgical planning and patient-specific osteosynthesis plates, combined with drilling guides, is feasible and allows for accurate operative reconstruction of complex acetabular fractures within 4 days post-trauma. The application of patient-specific osteosynthesis plates and drilling guides provides the possibility to execute the preoperative plan and to attain the predetermined osteosynthesis plate and screw positions, resulting in accurate reconstruction of the articular surface and good functional patient recovery.

3D virtual models allow the surgeon to gain more insight into the fracture pattern and treatment strategy [19]. Moreover, 3D printed pelvic models are used as a template for fitting and pre-contouring conventional osteosynthesis plates before the actual surgery [19–22]. Several case series indicate that the use of 3D printed models in pelvic surgery can result in reduced blood loss and shorter operation time [23–27]. Although the reported use of pre-bent plates, adapted to printed 3D models, show some benefits, little data is available on whether 3D printed models improve the quality of the reduction [23,24]. Our additional efforts in producing patient-specific osteosynthesis plates, with drilling guides, allowed for good alignment of the plate and screws to fit the fracture and shape variations of the pelvis, and using the plates as a reference led to good fracture reductions. A study comparing 3D printed model contouring and patient-specific osteosynthesis plates should reveal the indications for use per case. Few preliminary reports about the clinical application of patient-specific osteosynthesis plates for pelvic fracture surgery are available so far. Wang et al. described the manufacturing of customized pelvic plates by using selective laser melting technology for 3D metal printing and applied them to only three clinical cases [28]. They did not investigate the accuracy of the fracture reduction or follow-up the patients. Xu et al. used custom-made locking plates milled out of titanium on 24 consecutive patients with acetabular fractures, but did not use drilling guides as in our series. They reported some advantages, including the avoidance of intra-operative plate contouring, low risk of intra-articular screw penetration, low rate of osteosynthesis plate failure and early mobilization of the patient [29]. The main drawbacks of their series were the relatively long time that was required to produce the osteosynthesis plates (6.9±2.2 days) and the required technical demands. The study lacked a description of the performed placement accuracy but the potential benefits are in line with our experiences. We managed to speed up the whole process, which provides opportunities for applying personalized fracture care on a larger scale in orthopedic trauma surgery. Yet, it is not possible to compare the current surgery results to theirs in terms of fracture reduction quality because of the differences in fracture types (severely displaced both column fractures in our series versus all types of fractures in their series) and differences in imaging modalities used for postoperative assessment (CT scan versus X-ray).

Our techniques have some benefits for surgery. Firstly, a review of the 3D surgical planning by multidisciplinary team provides a moment of consultation and the possibility to discuss the optimal surgical approach, features of the osteosynthesis plate and screw positions, thus following the principle of "Plan your operation – and operate your plan!" [30]. Secondly, guided screw placement enables tailoring the screw positions to the fracture reduction strategy. For instance, one patient sustained a severely displaced both column fracture and needed a combined approach with a posterior as well as an anterior plate. The screws in the posterior plate were guided away from the anterior column and hence did not interfere with the reduction of the anterior column in the second phase of the operation. Also, the anterior plate was tailored to the fracture line in the ilium, which avoided an extra lateral window approach. Regarding another patient, the drilling guide was used to aim a lag screw through the anterior plate in order to indirectly reduce and fixate a large posterior wall fragment; screw accuracy planning was crucial here. Overall, the patient-specific osteosynthesis plates with guided screw insertion optimized fixation abilities and avoided additional surgical approaches in several cases.

Limitations

A possible limitation of this study is that these advanced technologies are not applicable yet in all hospitals. We realize that these innovative techniques require sufficient resources, including the availability of dedicated engineers, validated software packages and collaborative osteosynthesis plate production facilities. The cost for designing and producing the osteosynthesis plates was not part of this feasibility study. There is no selection bias, because in order to challenge our innovative personalized approach the most complex acetabular fractures were eligible for this study. A potential confounding factor however could be the experience of the surgeon. Therefore, the surgical procedures in this case series were performed by the same team. Another potential bias could be that the CT-based gap and step-off measurements are prone to intra- and inter-observer variability [31]. Therefore, measurements were performed in consensus by two experienced surgeons, who were blinded for patient data.

Future perspectives

Over the next few years, we will work on increasing the efficiency of personalized fracture care. If software applications and advanced technologies contribute to more efficient and precise surgery, to the benefit of the patient by improving physical functioning for years, it would be worthwhile to explore the general applicability further in the near future. A follow-up study is needed which compares patient-specific osteosynthesis with conventional osteosynthesis.

CONCLUSIONS

In conclusion, we developed and implemented a patient-specific multi-disciplinary workflow for acetabular fracture surgery, which made it possible to reconstruct the acetabulum accurately and fixate the fracture fragments with a custom-made osteosynthesis plate, resulting in good one-year clinical outcome. Moreover, none of the osteosynthesis plates required intraoperative contouring manoeuvres and all the screws could be placed accurately using the drilling guides.

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SUPPLEMENTS

eTable 1: The pre- and postoperative displacement.

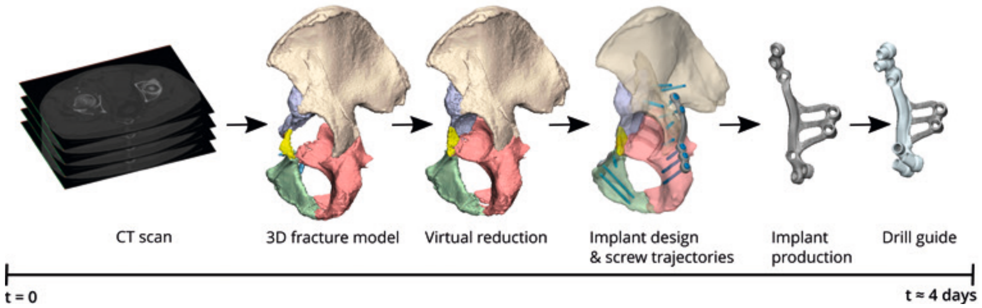
Patient	Measurement	Preoperative	Postoperative
1	Gap Step-off	21 mm 0 mm	2 mm 0 mm
2	Gap Step-off	22 mm 12 mm	3 mm 0 mm
3	Gap Step-off	19 mm 4 mm	5 mm 2 mm
4	Gap Step-off	21 mm 3 mm	3 mm 0 mm
5	Gap Step-off	28 mm 15 mm	5 mm 2 mm
6	Gap Step-off	7 mm 0 mm	2 mm 0 mm
7	Gap Step-off	9 mm 5 mm	3 mm 0 mm
8	Gap Step-off	14 mm 4 mm	5 mm 2 mm
9	Gap Step-off	23 mm 12 mm	4 mm 0 mm
10	Gap Step-off	16 mm 8 mm	2 mm 0 mm
Overall (Median, IQR)	Gap* Step-off*	20 [15-22] mm 5 [3-11] mm	3 [2-5] mm 0 [0-2] mm

*: Significant improvement of the postoperative gap (P = 0.005) and step-off (P = 0.01).

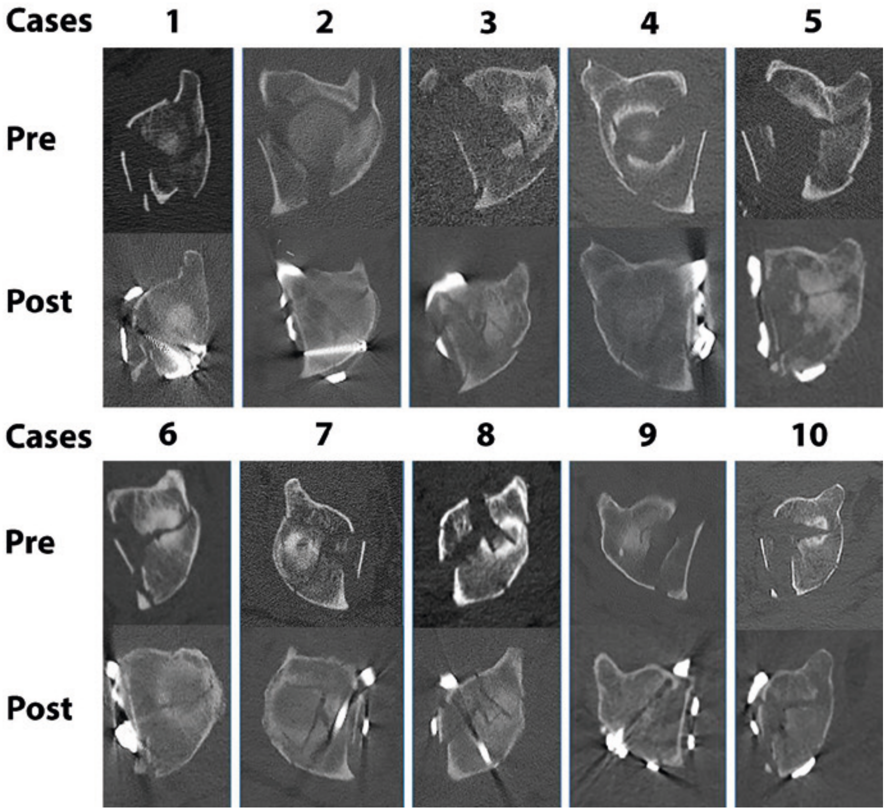
eTable 2: Clinical outcome assessed by the SMFA questionnaire pre-injury, at three months of follow-up and at one year of follow-up.

Patient	SMFA	Pre-injury	Three months follow-up	One year follow-up
1	Function Index	0.0	3.7	0.0
	Bother Index	0.0	0.0	0.0
	Lower Extremities	0.0	4.2	0.0
2	Function Index	7.4	20.6	10.3
	Bother Index	0.0	31.3	16.7
	Lower Extremities	2.1	18.8	6.3
3	Function Index	0.0	5.1	2.9
	Bother Index	0.0	2.1	2.1
	Lower Extremities	0.0	4.2	2.1
4	Function Index	18.4	43.4	30.1
	Bother Index	18.8	45.8	35.4
	Lower Extremities	12.5	47.9	20.8
5	Function Index	6.6	30.1	3.7
	Bother Index	4.2	37.5	0.0
	Lower Extremities	0.0	29.2	0.0
6	Function Index	7.4	33.1	8.1
	Bother Index	4.2	37.5	12.5
	Lower Extremities	6.3	33.3	6.3
7	Function Index	0.0	36.0	7.4
	Bother Index	0.0	33.3	10.4
	Lower Extremities	0.0	37.5	12.5
8	Function Index	15.4	35.3	40.4
	Bother Index	12.5	35.4	45.8
	Lower Extremities	14.6	37.5	43.8
9	Function Index	8.8	28.7	36.0
	Bother Index	10.4	27.1	50.0
	Lower Extremities	8.3	31.3	43.8
10	Function Index	8.1	27.2	19.1
	Bother Index	41.7	31.1	29.2
	Lower Extremities	0.0	20.8	6.3
Overall	Function Index	7.4 (2-9)	29.4 (22-35) *	9.2 (5-27) **
(Median, IQR)	Bother Index	4.2 (0-12)	32.3 (28-38)	14.6 (4-34)**
	Lower Extremities	1.0 (0-8)	30.3 (19-38) ***	6.3 (3-19)

The SMFA scores may vary from 0 to 100, with a higher score indicating a poorer function.
*: Significant improvement in scores at one year compared to the scores at three months (P=0.04).
**: Significant difference between pre-injury and one year scores (P=0.02).
***: Significant improvement in scores at one year compared to the scores at three months (P=0.05).



eFigure 1: Timeline of the workflow. Workflow regarding the design and production of a patient-specific pelvic osteosynthesis plate tailored to the fracture type. A 3D model is generated from the CT data and the displaced fracture fragments are virtually reduced. The contralateral intact hemipelvis is used as a mirrored template in order to verify the accuracy of the reduction. The reduced 3D fracture model can be used to design and produce a patient-specific plate (milled titanium). A drilling guide (3D printed), designed to fit on top of the plate, is used to aim the screws in the right direction during surgery.



eFigure 2: Pre- and postoperative CT scans. A comparison of the pre- and postoperative axial CT slices at the acetabular dome of all ten patients treated with patient-specific osteosynthesis plates. All the patients had multiple fracture lines and substantial displacement in multiple directions at the acetabular dome on the preoperative CT scan. After surgery, all the fractures were accurately reduced and fixated with patient-specific osteosynthesis plates.