



# Pre-operative virtual simulation and three-dimensional printing techniques for the surgical management of acetabular fractures

Chun-Liang Hsu<sup>1</sup> · Yu-Ching Chou<sup>2</sup> · Yuan-Ta Li<sup>1</sup> · Jia-En Chen<sup>3</sup> · Chun-Chi Hung<sup>1</sup> · Chia-Chun Wu<sup>1</sup> · Hsain-Chung Shen<sup>1</sup> · Tsu-Te Yeh<sup>1</sup> 

Received: 21 May 2018 / Accepted: 13 August 2018 / Published online: 20 August 2018  
© SICOT aisbl 2018

## Abstract

**Purpose** Surgical treatment of acetabular fractures with plate fixation is challenging for orthopaedic surgeons because of variations of the surface curvature and complex fracture patterns of the acetabulum. We present our experience with pre-operative computer-assisted virtual simulation and three-dimensional (3D) printing techniques for the surgical treatment of acetabular fractures, especially in terms of operative time and surgical outcomes.

**Methods** Twenty-nine patients with acetabular fractures treated with locking plates were included in this retrospective study (conventional locking plate fixation,  $n = 17$ ; 3D-printing-assisted precontoured locking plate fixation,  $n = 12$ ). Fracture types were classified according to the Letournel-Judet classification. Surgical duration, instrumentation time, blood loss, post-operative fracture reduction quality, and complication rates were compared between the two surgical groups.

**Results** The 3D-printing group had a significantly shorter total surgical duration and instrumentation time for fractures with posterior wall or posterior column involvement ( $222.75 \pm 48.12$  and  $35.75 \pm 9.21$  minutes, respectively;  $P < 0.05$ ) and significantly shorter instrumentation time and less blood loss for fractures with anterior column involvement ( $43.40 \pm 10.92$  minutes and  $433.33 \pm 317.28$  mL, respectively;  $P < 0.05$ ) than those in the control group. The post-operative radiological results (assessed by consensus) were similar for both groups (good/fair: 14/3 vs. 11/1;  $P = 0.622$ ). The complication rate was lower in the 3D-printing group than in the conventional group (16.67 vs. 29.41%).

**Conclusions** The 3D printing is a reliable method for treating acetabular fractures, and can reduce the surgical duration, instrumentation time, and blood loss.

**Keywords** Acetabulum fracture · Pre-operative virtual simulation · Three-dimensional (3D) printing · Precontoured

## Introduction

Three-dimensional (3D) printing was developed in the 1980s for industrial product reconstruction [1] and uses an additive

manufacturing process to precisely reconstruct an image into a real object. It has also become widely used in clinical medicine and tissue engineering. Polylactic acid is commonly used in 3D printing, with biomaterials categorized into ceramics, polymers, and composites. The application of 3D printing in tissue engineering is its ability to create complex geometries, porosities, and co-cultures of multiple cells, with the incorporation of drugs, proteins, growth factors, etc. The main aim of tissue engineering is to reconstruct functional organs from the patients' own cells; however, further research is still needed [2]. As imaging technology has improved, 3D printing can now accurately transform a computed tomography (CT) image into a real model, with the potential to revolutionize traditional operative procedures, including those for complex fractures [3].

Complex acetabular fracture surgery is a major challenge for trauma surgeons. The surgical management of acetabular

✉ Tsu-Te Yeh  
tsutey@gmail.com

<sup>1</sup> Department of Orthopaedic Surgery, Tri-Service General Hospital and National Defense Medical Center, 325, Cheng-Gong Road, Section 2, Taipei 114, Taiwan, Republic of China

<sup>2</sup> School of Public Health, National Defense Medical Center, No.161, Sec. 6, Minquan E. Rd., Neihu Dist, Taipei City 11490, Taiwan, Republic of China

<sup>3</sup> Graduate Institute of Aerospace and Undersea Medicine, Division National Defense Medical Center, No.161, Sec. 6, Minquan E. Rd., Neihu Dist, Taipei City 11490, Taiwan, Republic of China

fractures aims to obtain congruity of the articular surface and a stable joint to enable weight-bearing [4]. Anatomical reduction and stable fixation are required for ensuring excellent results, even in delayed surgery for acetabular fracture [5]. Post-traumatic arthritis is a common complication directly related to the reduction quality [6–8]. Two-dimensional (2D) and 3D CT images are widely used for pre-operative assessments (fracture pattern and classification, and surgical planning) [3, 9].

In conventional surgery for acetabular fractures, the fixation plate is intra-operatively contoured, following temporary fixation of the fractured segments with pins or screws. This is time-consuming and unreliable, as the reduction may sometimes become displaced. Furthermore, plate contouring may be imprecise, resulting in sub-optimal reduction. However, a plate precontoured according to a 1:1 scaled 3D-printed model can be fixed, avoiding the loss of the temporary fixation, thus saving time [10, 11].

Herein, we describe a computer-assisted virtual simulation and 3D-printing technique for patients with acetabular fractures. This study aimed to compare the outcomes between patients treated for acetabular fractures with and without the use of 3D-printed models.

## Materials and methods

The medical records and radiographs of patients with acetabular fractures who underwent operative treatment at our hospital between March 2014 and February 2018 were retrospectively reviewed. Informed consent was obtained from all participants. The study was approved by our Institutional Review Board.

The exclusion criteria were as follows: age < 18 years, metastatic tumor in the acetabulum, associated brain or neurovascular injuries, ipsilateral retention of a prosthesis following total hip arthroplasty, and acetabular fractures treated with column screw fixation.

A total of 29 patients were included. Patients were classified into two groups according to the treatment received: the conventional group (treated between March 2014 and September 2016) and 3D-printing group (treated between October 2016 and February 2018). All patients underwent diagnostic radiography and CT (3-mm axial slices) for detailed pre-operative evaluation. Fracture types were classified according to the Letoumel-Judet classification [12].

## Surgical technique

All operations were performed by a single experienced trauma surgeon. In both groups, the Kocher-Langenbeck (K-L) approach was used for posterior wall or posterior column involvement. In patients with anterior column involvement, the ilioinguinal approach was used in the conventional group

and the modified Stoppa approach combined with a lateral window of the ilioinguinal approach was used in the 3D-printing group. One- or two-stage procedures were performed, depending on the fracture pattern. The number of locking plates and their position depended on the acetabular fracture pattern. The posterior wall, when involved, was fixed using a spring plate plus posterior wall buttress plate or a posterior wall buttress plate alone, depending on the comminution of the posterior wall fragment. When involved, the posterior and anterior columns were fixed using posterior and anterior column plates, respectively.

In the conventional group, a thin metal template was used to determine the shape of acetabular surface following fracture reduction, which was used to contour the locking plate during surgery. A commercial in situ plate bending instrument (Depuy Synthes, Switzerland) was used for fine plate adjustments.

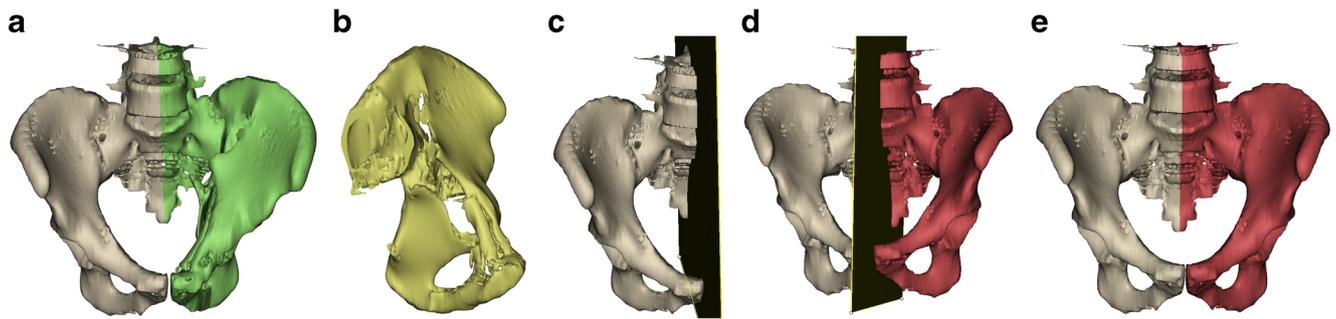
In the 3D-printing group, DICOM (Digital Imaging and Communication in Medicine) CT images were converted and imported into a medical imaging processing software (MIMICS, version 19, Belgium), which was used to process the 3D-model images (Fig. 1). The virtual hemi-pelvis model was exported in stereolithography (STL) format for 3D printing, which was performed by a fused deposition modeling apparatus (UP BOX+, Tiertime, China, or Mass Portal XD 40, Mass Portal, Latvia). The 3D-printed model was used to decide the surgical plan (including plate number, position, length, curvature, and screw position). Locking reconstruction plates were precontoured prior to surgery. The screw lengths were also measured to guide the operation (Fig. 2). In some complicated cases, a 3D-printed model of the fractured acetabulum was also acquired for pre-operative evaluation (Fig. 3). During the actual surgery, precontoured anatomic plates were applied in the designated position, following anatomical fracture reduction. All software simulation and 3D-printing procedures were performed by two orthopaedic surgeons, one of whom possessed a 3D-printing engineering license.

Wound closure was performed after checking the hip joint range of motion and confirming procedure adequacy by fluoroscopy on the iliac and obturator oblique views.

Rehabilitation was initiated one week post-operatively and included isometric quadriceps strengthening, hip passive range of motion, and non-weight bearing exercises until six weeks post-operatively. Partial weight bearing (toe walking with crutches) was permitted after the identification of partial callus formation on radiography during the outpatient follow-up. Full weight bearing was permitted after two months.

## Outcome assessment

Surgical duration, instrumentation time, blood loss, complications, and fracture reduction quality were evaluated. Surgical



**Fig. 1** Virtual simulation of the reduction maneuver for displaced fractured bones using MIMIC software. **a** Whole pelvis (white color, non-fractured hemipelvis; green color, fractured hemipelvis). **b** Isolation

of the fractured hemipelvis. **c** Determination of the midline in the sagittal plane for mirroring the non-fractured hemipelvis. **d** Hemipelvis after mirroring (red colour). **e** After merging to achieve an entire intact pelvis

duration was defined as the time from skin incision to skin closure. Instrumentation time was defined as the time to complete plate fixation, including plate configuration adjustments, screw-hole drilling, screw length measurement, and plate locking. During the operation, blood loss was collected by a suction tube connected to a suction bottle. The used gauze was weighed; this amount was added to the collected blood to estimate the total operative blood loss.

Complications analyzed included surgical site infections, neurovascular injuries, implant failure, screw penetration into the hip joint, traumatic arthritis, avascular necrosis of the femoral head, and heterotopic ossification.

Pelvic series radiographs (standard anteroposterior, inlet, outlet, and Judet views [iliac and obturator oblique views]) were used to determine the adequacy of the reduction and implant placement. All patients were examined in the outpatient department following their surgery. All follow-up radiographs were evaluated by three trauma orthopaedic surgeons, and the discrimination of the fracture reduction was determined by consensus. The quality of the fracture reduction of

the acetabulum was graded as good (0–2-mm displacement) or fair ( $\geq 2$ -mm displacement).

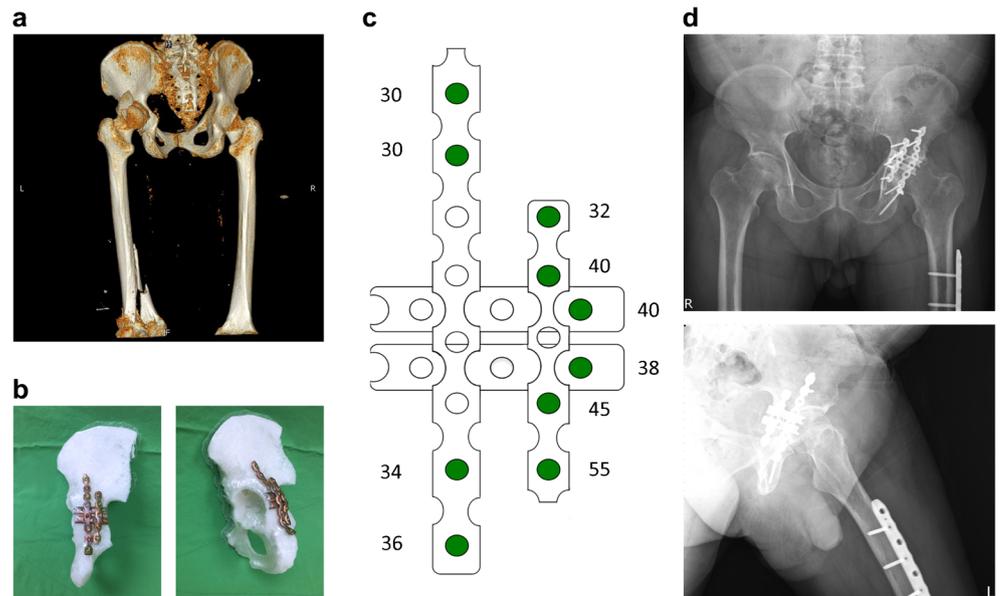
Group differences in demographic and clinical parameters were evaluated using the independent *t* test or chi-squared test. Group differences in the radiological results were evaluated using the Fisher’s exact test. *P* values  $< 0.05$  were considered statistically significant. All statistical analyses were performed using Statistical Package for the Social Sciences software (version 22.0, USA).

## Results

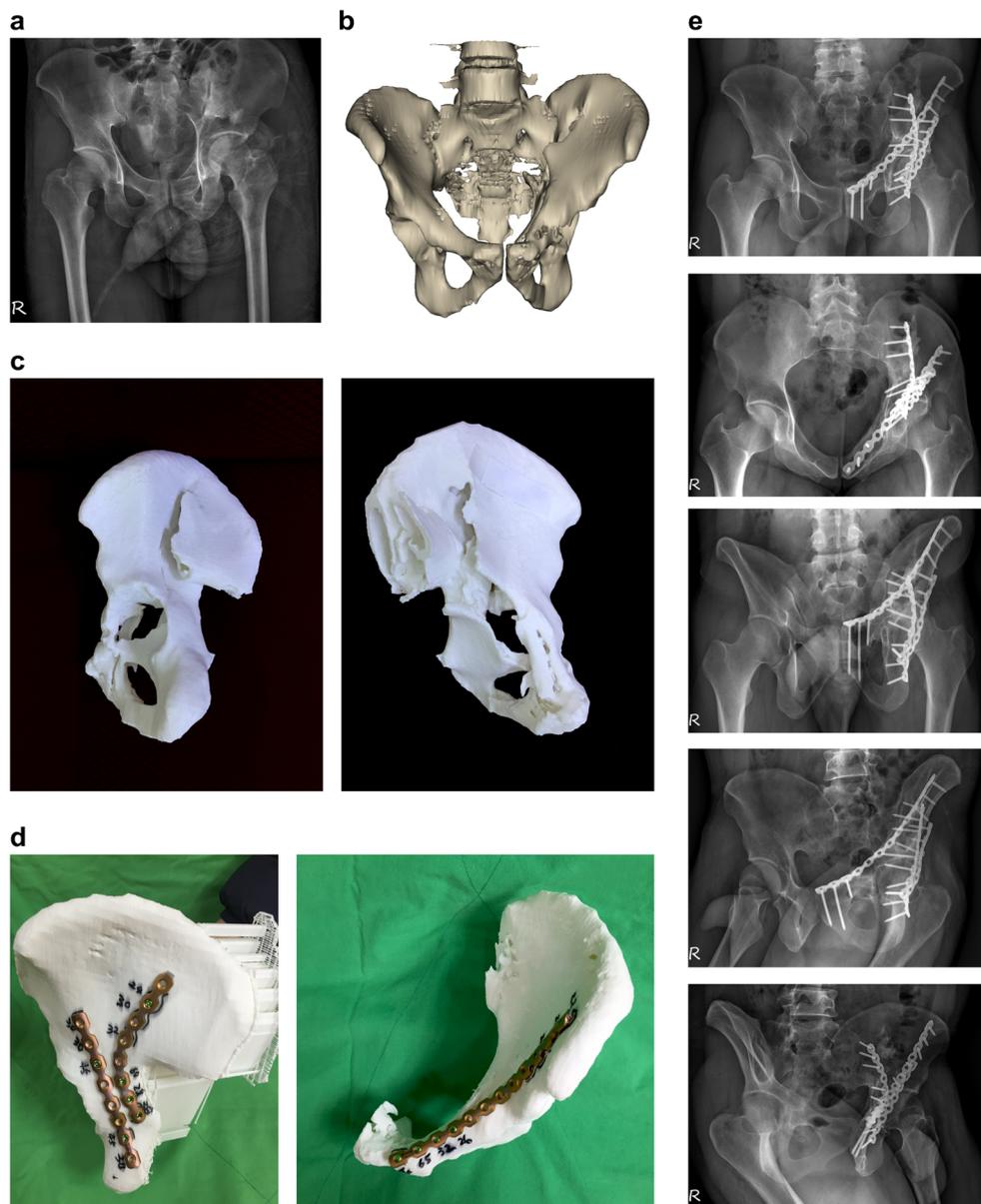
### Demographic and clinical characteristics

The mean age, mean body mass index (BMI), and fracture classification are summarized according to group in Table 1. Overall, the two groups were comparable in terms of their demographics ( $P > 0.05$ ) (Table 1). Additionally, there were no significant between-group differences in clinical

**Fig. 2** Images of a posterior wall fracture in a 63-year-old male. **a** Pre-operative 3D computed tomography demonstrates posterior dislocation of the left hip, comminuted fracture of the posterior wall of the acetabulum, and distal femur fracture. **b** The 3D model with two precontoured spring plate overlapped by a posterior wall buttress plate and posterior column plate. **c** Schematic diagram used as a guide for the operation, with numbers denoting the screw length. **d** Post-operative follow-up radiography (anteroposterior and lateral views) at 10 months



**Fig. 3** Images of acetabular fracture of both columns combined with pelvic iliac wing fracture in a 23-year-old male. **a** Pre-operative radiography (anteroposterior view). **b** The 3D reconstructed computed tomography images. **c** The 3D-printing model prior to virtual reduction for pre-operative evaluation. **d** The 3D-printing model following reduction by MIMIC software, fixed with precontoured plates (posterior wall buttress plate, posterior column plate extended to the iliac wing, and anterior column plate). **e** Post-operative follow-up radiograms at 1 year (pelvic anteroposterior, inlet, outlet, and Judet views)



characteristics ( $P > 0.05$ ; Table 1). The mean follow-up duration was 14.4 months (range 3–43 months), and no patient was lost to follow-up.

### Clinical outcomes

Table 2 summarizes the clinical outcomes. For fractures with posterior wall or column involvement, the surgical duration and instrumentation time were significantly shorter in the 3D-printing group than in the conventional group ( $P < 0.05$ ; Table 2). For fractures with anterior column involvement, the instrumentation time was shorter and blood loss was less in the 3D-printing group than in the conventional group ( $P < 0.05$ ; Table 2). No other significant between-group differences were observed.

### Discussion

For acetabular fractures, the anatomical restoration of the joint congruity of weight-bearing domes and experienced surgeon's technique results in better outcomes and a lower risk of post-traumatic arthritis [6–8, 13]. A thorough pre-operative evaluation of the fracture pattern is important for management. However, plain radiograms or axial CT scan images do not provide an adequate assessment, as the surgeon must evaluate deformed fracture geometry based on 2D images. Fortunately, standardized 3D CT scanner reconstructions can increase the accuracy of acetabular fracture classification [14]. In the present study, acetabular fracture classification utilized the Letournel-Judet classification system (a widely used classification system for acetabular fractures) and was based on the

**Table 1** Demographic and clinical characteristics

	Conventional group ( <i>n</i> = 17)	3D-printing group ( <i>n</i> = 12)	<i>P</i> value
Age (years), mean ± SD	38.24 ± 16.39	36.75 ± 16.39	0.812 <sup>a</sup>
Sex, <i>n</i>			0.622 <sup>b</sup>
Male	14	11	
Female	3	1	
BMI (kg/m <sup>2</sup> ), mean ± SD	25.76 ± 3.38	26.17 ± 6.10	0.822 <sup>a</sup>
Classification, <i>n</i>			0.863 <sup>b</sup>
Post. wall	5	3	
Post. column	0	1	
Transverse	0	1	
Both column	4	2	
Transverse + post. wall	2	2	
Post. column + post. wall	1	1	
n/a, T-shaped + post. wall	4	1	
n/a, both columns + post. wall	1	1	
Injured side, <i>n</i>			0.251 <sup>b</sup>
Right	8	9	
Left	9	3	
Post. wall involvement, <i>n</i>	13	8	0.683 <sup>b</sup>
Post. column involvement, <i>n</i>	12	9	1.000 <sup>b</sup>
Ant. column involvement, <i>n</i>	11	7	1.000 <sup>b</sup>
Associated hip dislocation, <i>n</i> (%)	7 (41.2)	7 (58.3)	0.594 <sup>a</sup>
Associated femoral head fracture, <i>n</i> (%)	4 (23.5)	2 (16.7)	1.000 <sup>b</sup>
Associated pelvic injury, <i>n</i> (%)	2 (11.8)	2 (16.7)	1.000 <sup>b</sup>
Days (from inj. to first stage op), mean ± SD	2.82 ± 2.27	3.17 ± 2.29	0.693 <sup>a</sup>
Days (from inj. to second stage op), mean ± SD	7.50 ± 1.97 ( <i>n</i> = 6)	11.80 ± 5.17 ( <i>n</i> = 5)	0.140 <sup>a</sup>
No. of post. wall spring plate, <i>n</i>			1.000 <sup>b</sup>
0	8	6	
1	5	4	
2	4	2	
No. of post. wall buttress plate, <i>n</i>	17	12	n/a
No. of post. column plate, <i>n</i>			1.000 <sup>b</sup>
0	2	2	
1	15	10	
No. of ant. column plate, <i>n</i>			0.646 <sup>b</sup>
0	11	6	
1	4	5	
2	2	1	
Approach method, <i>n</i>			0.471 <sup>b</sup>
Kocher-Langenbeck	11	6	
Kocher-Langenbeck + ant.	6	6	

*n/a* not applicable, cannot be classified by the Letournel-Judet classification; *transverse type* both column type and *T-shaped* fractures were defined as both anterior and posterior column involvement in our study, *BMI* body mass index, *post.* posterior, *ant.* anterior, *inj.* injury, *op* operation, *no.* number, *n* patient number

<sup>a</sup> Independent *t* test or chi-squared test

<sup>b</sup> Fisher's exact test

3D image in the MIMICS software. The present study results provide further support for previous studies suggesting that the use of a computerized virtual planning system in

acetabular fracture surgery is a valuable tool for surgeons to better understand the fracture pattern and formulate an appropriate pre-operative plan [15].

**Table 2** Clinical outcomes

	Conventional group ( <i>n</i> = 17)	3D-printing group ( <i>n</i> = 12)	<i>P</i> value
Software time (min), mean ± SD	–	11.08 ± 1.44	n/a
3D-printing time (min), mean ± SD	–	615.25 ± 23.14	n/a
Post. plate precontouring time (min), mean ± SD	–	41.67 ± 14.64	n/a
Ant. plate precontouring time (min), mean ± SD	–	23.08 ± 25.69	n/a
Post. wall or column involvement			
Surgical duration (min), mean ± SD	259.76 ± 46.50	222.75 ± 48.12	0.047 <sup>a</sup>
Instrumentation time (min), mean ± SD	67.35 ± 10.80	35.75 ± 9.21	0.001 <sup>a</sup>
Blood loss (mL), mean ± SD	866.47 ± 550.33	845.83 ± 681.06	0.929 <sup>a</sup>
Ant. column involvement			
Surgical duration (min), mean ± SD	274.17 ± 80.95	199.00 ± 50.29	0.082 <sup>a</sup>
Instrumentation time (min), mean ± SD	99.00 ± 15.41	43.40 ± 10.92	0.001 <sup>a</sup>
Blood loss (mL), mean ± SD	958.33 ± 427.10	433.33 ± 317.28	0.036 <sup>a</sup>
Post-operative X-ray film, <i>n</i>			0.622 <sup>b</sup>
Good (0–2-mm displacement)	14	11	
Fair (≥ 2-mm displacement)	3	1	
Complication, <i>n</i>			
No	12	10	
Yes	5	2	
AVN of FH	0	1	
Heterotopic ossification	1	0	
Sciatic nerve injury	1	0	
Superior gluteal artery injury	0	1	
Traumatic arthritis	3	0	

*Post.* posterior, *n* patient number, *AVN of FH* avascular necrosis of femoral head, *n/a* not applicable

<sup>a</sup> Independent *t* test or chi-squared test

<sup>b</sup> Fisher's exact test

There are several advantages to surgical planning aided by the use of virtual simulation and 3D-printed models. These include a better delineation of the complex acetabular fracture pattern, simulation of the fracture reduction, choice of plate position and quantity, plate precontouring, and screw length estimation on a 1:1 scale fracture model. Martelli et al. concluded that the use of 3D printing in surgery can improve pre-operative planning and accuracy, save time in the operating room, and decrease risk and complications. However, the authors also mentioned that most surgeons do not have the specific skills required to utilize the 3D software, requiring cooperation with outside engineers [16]. Our team included one orthopedic surgeon with a 3D-printing engineering license and familiarity with fracture pattern and software management. Thus, we could handle every step ourselves.

Hu et al. also concluded that computer-assisted virtual surgical procedures are useful in surgical planning [17]. Upex et al. reported one case of an acetabular both-column fracture treated with a plate precontoured on a 3D-printed model [18]. Mirroring of the non-fractured acetabulum to obtain a

“normal acetabulum” on the injured side is a simple method. However, in cases of bilateral acetabular fractures, fracture reduction should be performed via the manual repositioning technique using the software; there were no such cases in the present study. Maini et al. used 3D printing and patient-specific precontoured plates in their pre-operative planning for acetabular fractures [19], with fracture reduction simulated on a 3D-printed model of the fractured acetabulum. It is our opinion that precontouring the plate on a fracture model is difficult. Therefore, we used the more efficient method of precontouring the plate following software-based fracture reduction.

Indirect reduction using anatomical plates has been widely used for other fractures. In combined acetabular and pelvic fractures, such a reduction is difficult. Patient-specific anatomical plates precontoured using a 3D-printed model, as in the present study, may enable indirect reduction.

Inadvertent intra-articular screw penetration can lead to wearing of the hip joint cartilage and pain during motion and weight bearing, and is an important cause of poor clinical

outcomes despite accurate fracture reduction and fixation. The obturator oblique and iliac oblique/outlet views afford the most accurate position of an anterior column acetabular screw [20]. The 3D navigation-guide percutaneous screw provides a safe and effective method in most pelvi-acetabular fractures [21]. However, the implant itself may mask a penetrating screw, or ambiguous fluoroscopy images may render it difficult to precisely determine the screw condition. Pre-operative screw position and length can be determined on a 3D model to help prevent screw penetration into the hip joint, as in the present study. We could acquire accurate information regarding the correct screw direction and required screw length. However, it should be noted that although we recorded every screw length measured from precontour plates fixed onto the 3D models, we did not compare the screw length discrepancy between the simulation and actual surgery.

In the present study, the total surgical time was significantly shorter in the 3D-printing group than in the conventional group for patients with posterior wall or posterior column involvement. This difference is mainly attributed to the use of a precontoured plate, which significantly decreased the instrumentation time. A biomechanical study revealed fixation using a reconstruction plate, and compression screws placed lateral to the screws may address acetabular posterior wall fracture in a more appropriate manner than techniques using only plates or screws [22]. Fixation with a single spring plate is not stable for large posterior wall fractures. A spring plate overlapped by a posterior wall buttress plate is known to improve fixation strength [23, 24]. However, buttress plates are difficult to bend to a precise curvature during an operation; designing precontoured plates using 3D-printed models is easier and significantly shortens the instrumentation time. In the present study, the mean time to precontour a posterior plate was more than that for an anterior plate. Precontouring the posterior plate to match the posterior acetabulum wall is difficult because of the double curvature made by the posterior acetabulum and ischial tuberosity. Precontouring the anterior plate is relatively easy, as the only curvature is the curvature of the anterior column.

We used an ilioinguinal approach to expose the fracture site and contour the plate intra-operatively in the conventional surgery group for cases with anterior column involvement (anterior column, transverse type, both columns, and T-shaped fractures). This resulted in considerable soft tissue dissection and haemorrhage. In the 3D-printing group, we used a precontoured anterior column plate and a minimally invasive method. This resulted in less blood loss and reduced instrumentation time. Although the surgical duration was shorter in the 3D-printing group than in the conventional, the difference failed to reach significance.

Unique customized anatomical plates can be contoured using a 3D-printing method. Further, the fit of the plate during the operation indicates the reduction quality. However, in the

present study, there were no significant group differences in the post-operative radiographic results. Both groups had satisfactory results, even though the procedure was accomplished more efficiently in the 3D-printing group.

The complications observed in our study population (traumatic arthritis of the hip, sciatic nerve injury, heterotopic ossification, avascular necrosis of the femoral head, and superior gluteal artery injury) were either related to the injury or the surgical technique. No complications were secondary to the use of 3D printing or the precontoured plate technique.

The present study has some limitations. First, some fracture patterns cannot be classified by the Letournel-Judet classification system; several studies have explored the possibility of a more comprehensive system [25]. Second, the measurement of post-operative residual displacement may be more accurate on CT scans than on plain radiograms. However, in the health care system of our country, most medical expenses are paid by the National Health Insurance, and are strictly controlled by the medial claims review system. Although pre-operative CT examinations are allowed for complex fractures, routine post-operative CT examinations are not indicated for follow-up. Since we relied on plain radiograms, we attempted to minimize inter-observer bias by ensuring that three trauma surgeons reviewed all post-operative radiograms. Third, the dispersion in the follow-up duration (3–43 months) may introduce a bias effect in the observed complications. Finally, the study was retrospective in nature, with a relatively small sample size due to the rarity of acetabular fractures. This may limit the reliability and generalizability of our results.

Thus, our study demonstrates that virtual simulation and 3D-printing techniques are useful, especially for fractures involving the posterior column of the acetabulum. Further prospective randomized-controlled blinded trials with long-term follow-up may provide further insights into the role of these techniques in the management of acetabular fractures.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of our Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## References

1. Gross BC, Erkal JL, Lockwood SY, Chen C, Spence DM (2014) Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences. *Anal Chem* 86:3240–3253

2. Jammalamadaka U, Tappa K (2018) Recent advances in biomaterials for 3D printing and tissue engineering. *J Funct Biomater* 9:E22
3. Cimerman M, Kristan A (2007) Preoperative planning in pelvic and acetabular surgery: the value of advanced computerised planning modules. *Injury* 38:442–449
4. 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* 78:1632–1645
5. Gao YS, Zhou ZB, Tang MJ, Yu XW, Chen S, Zhang CQ, Sun YQ (2015) Late surgery for acetabular fractures in a Chinese level I trauma Centre: surgical experience and outcomes. *Int Orthop* 39:1865–1871
6. Marsh JL, Buckwalter J, Gelberman R, Dirschl D, Olson S, Brown T, Llinias A (2002) Articular fractures: does an anatomic reduction really change the result? *J Bone Joint Surg Am* 84-A:1259–1271
7. Ragnarsson B, Mjöberg B (1992) Arthrosis after surgically treated acetabular fractures. *Acta Orthop Scand* 63:511–514
8. Brown TD, Johnston RC, Saltzman CL, Marsh JL, Buckwalter JA (2006) Posttraumatic osteoarthritis: a first estimate of incidence, prevalence, and burden of disease. *J Orthop Trauma* 20:739–744
9. Munjal S, Leopold SS, Kormreich D, Shott S, Finn HA (2000) CT-generated 3-dimensional models for complex acetabular reconstruction. *J Arthroplast* 15:644–653
10. Fuller SM, Butz DR, Vevang CB, Makhlof MV (2014) Application of 3-dimensional printing in hand surgery for production of a novel bone reduction clamp. *J Hand Surg* 39:1840–1845
11. Rankin TM, Giovinco NA, Cucher DJ, Watts G, Hurwitz B, Armstrong DG (2014) 3D printing surgical instruments: are we there yet? *J Surg Res* 189:193–197
12. Judet R, Judet J, Letoumel E (1964) Fractures of the acetabulum: classification and surgical approaches for open reduction. Preliminary report. *J Bone Joint Surg Am* 46:1615–1646
13. Boudissa M, Ruatti S, Kerschbaumer G, Milaire M, Merloz P, Tonetti J (2016) Part 2: outcome of acetabular fractures and associated prognostic factors—a ten-year retrospective study of one hundred and fifty-six operated cases with open reduction and internal fixation. *Int Orthop* 40:2151–2156
14. Sebaaly A, Riouallon G, Zaraa M, Upex P, Marteau V, Jouffroy P (2018) Standardized three dimensional computerised tomography scanner reconstructions increase the accuracy of acetabular fracture classification. *Int Orthop* 42:1957–1965
15. Wang H, Wang F, Newman S, Lin Y, Chen X, Xu L, Wang Q (2016) Application of an innovative computerized virtual planning system in acetabular fracture surgery: a feasibility study. *Injury* 47:1698–1701
16. Martelli N, Serrano C, van den Brink H, Pineau J, Prognon P, Borget I, El Batti S (2016) Advantages and disadvantages of 3-dimensional printing in surgery: a systematic review. *Surgery* 159:1485–1500
17. Hu Y, Li H, Qiao G, Liu H, Ji A, Ye F (2011) Computer-assisted virtual surgical procedure for acetabular fractures based on real CT data. *Injury* 42:1121–1124
18. Upex P, Jouffroy P, Riouallon G (2017) Application of 3D printing for treating fractures of both columns of the acetabulum: benefit of pre-contouring plates on the mirrored healthy pelvis. *Orthop Traumatol Surg Res* 103:331–334
19. Maini L, Sharma A, Jha S, Sharma A, Tiwari A (2018) Three-dimensional printing and patient-specific pre-contoured plate: future of acetabulum fracture fixation? *Eur J Trauma Emerg Surg* 44:215–224
20. Guimarães JAM, Martin MP 3rd, da Silva FR, Duarte MEL, Cavalcanti ADS, Machado JAP, Mauffrey C, Rojas D (2018) The obturator oblique and iliac oblique/outlet views predict most accurately the adequate position of an anterior column acetabular screw. *Int Orthop*. <https://doi.org/10.1007/s00264-018-3989-5>
21. Chui KH, Chan CCD, Ip KC, Lee KB, Li W (2018) Three-dimensional navigation-guided percutaneous screw fixation for nondisplaced and displaced pelvis-acetabular fractures in a major trauma Centre. *Int Orthop* 42:1387–1395
22. Wu X (2018) A biomechanical comparison of different fixation techniques for fractures of the acetabular posterior wall. *Int Orthop* 42:673–679
23. Richter H, Hutson JJ, Zych G (2004) The use of spring plates in the internal fixation of acetabular fractures. *J Orthop Trauma* 18:179–181
24. Lee C, Johnson EE (2018) Use of spring plates in fixation of comminuted posterior wall acetabular fractures. *J Orthop Trauma* 32:S55–S59
25. Hutt JR, Ortega-Briones A, Daurka JS, Bircher MD, Rickman MS (2015) The ongoing relevance of acetabular fracture classification. *Bone Joint J* 97-B:1139–1143