

Research Article

A retrospective comparison of the conventional versus three-dimensional printed model-assisted surgery in the treatment of acetabular fractures

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Objective: The aim of this study was to compare the clinical and radiological outcomes of the conventional versus individualized three-dimensional (3D) printing model-assisted pre-contoured plate fixation in the treatment of patients with acetabular fractures.

Methods: The data from 18 consecutive patients who underwent surgery for the acetabular fractures were retrospectively analyzed. The patients were divided into two groups (9 in each): conventional and 3D printed model-assisted. The groups were then compared in terms of the duration of surgery, time of instrumentation, time of intraoperative fluoroscopy, and volume of blood loss. The quality of the fracture reduction was also evaluated postoperatively by radiography and computed tomography in both the groups. The quality of the fracture reduction was defined as good (<2 mm) or fair (>2 mm) based on the amount of displacement in the acetabulum.

Results: The conventional group included 9 patients (9 males; mean age=41.7 years; age range=16-70) with a mean follow-up of 11.9 months (range=8-15); the 3D printed model-assisted group consisted of 9 patients (9 males; mean age=46.2 years; age range=30-66) with a mean follow-up of 10.33 months (range=7-17). The average duration of surgery, mean time of instrumentation, time of intraoperative fluoroscopy, and mean volume of blood loss were 180.5±9 minutes, 36.2±3.6 minutes, 6±1 times, and 403.3±52.7 mL in the 3D printed model-assisted group, and 220±15.6 minutes, 57.4±10.65 minutes, 10.4±2.2 times, and 606.6±52.7 mL in the conventional group, respectively. Procedurally, the average duration of surgery, mean time of instrumentation, and mean time of fluoroscopy were significantly shorter, and the mean volume of blood loss was significantly lower in the 3D printed model-assisted group (p<0.05). The quality of the fracture reduction was good in 7 patients (78%) in the conventional group and 8 patients (89%) in the 3D printed model-assisted group.

Conclusion: As compared with the conventional surgery, the 3D printing model-assisted pre-contoured plate fixation technique can improve the clinical and radiological outcomes of the acetabular fractures, with shorter surgery, instrumentation, intraoperative fluoroscopy times, and blood loss.

Level of Evidence: Level III, Therapeutic study

The acetabular fractures are complex intra-articular injuries of a weight-bearing joint, which is challenging for most orthopedic surgeons especially who are not specialists in the acetabular and pelvic surgeries (1, 2). For an excellent fracture reduction, the surgeon has to know the precise anatomy and the type of fracture, fracture extent, joint congruency, step-offs or gaps in the joint surface, and entrapped osteochondral fragments that he or she deals with after the examination of the plain films and CT scans (3, 4). In addition, there is no unified anatomically correct implant to fix the variable, patient-specific fractures. The contouring plates and screw

length planning during the operative procedure may not be accurate enough and could significantly prolong the duration of surgery (5, 6).

Because of the complex anatomy, morphological variations, and limited surgical access with the fracture sites, the images are viewed on a 2D screen, which provide limited insight into the true physical configuration of the fracture and optimal surgical management that should be used (Figure 1, 2) (2, 7-11). The three-dimensional (3D) CT has much-improved imaging; however, complete understanding of the fracture lines and fragments is still difficult (10, 12).

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Another problem is the control of the reduced fragments because the visualization of the whole fragments and the joint surface is often technically impossible (13, 14).

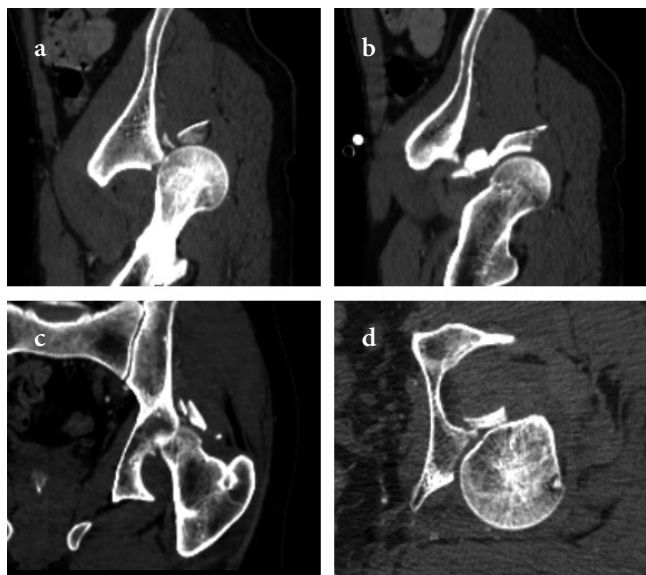


Figure 1. a-d. With the CT scans, it is possible to tell better about the fracture anatomy (complexity), the degree of comminution, and associated fracture patterns in a-d

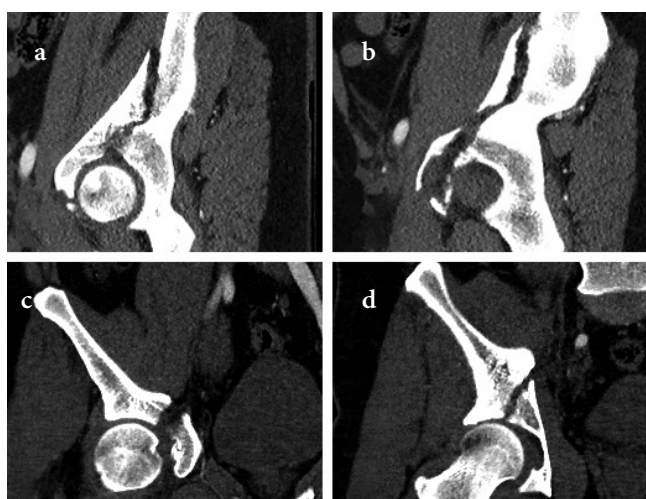


Figure 2. a-d. Preoperative CT images as broken lines in patient with acetabular fracture. The CT scan shows the complexity of the acetabular fracture and fracture line to the iliac crest in a-d

HIGHLIGHTS

- 3D models provide an insight to the patient's unique anatomy.
- Assistance of a 3D printed model during surgery decrease the duration of the operation, amount of the blood loss, fluoroscopy and instrumentation time.
- The 3D printing model-assisted pre-contoured plate fixation technique can improve the clinical and radiological outcomes of the acetabular fractures.

The 3D printing technique has been adopted in clinical orthopedics recently. It allows rapid construction of the accurate, full-scale individual fracture models so that surgeons can observe, take measurements, and even practice surgery on the models (15, 16). The surgery combined with the 3D printing technology allows the surgeons to prepare for the surgical pelvic reconstruction economically and effectively (17, 18). In recent years, with the development of digital medicine and imaging modalities, a 3D bone model of the fracture pattern can be generated to plan the position of the inter-fragmentary screws and prepare a pre-bend fixation plate to adapt to the complex orthopedics (19-21).

This study was aimed to compare the conventional surgery and 3D printing model-assisted surgery in the treatment of the acetabular fractures.

Materials and Methods

The study included 18 eligible patients (age: 16-70 years) with traumatic acetabular fractures who underwent surgery at our hospital from January 2017 to June 2018. The inclusion and exclusion criterias are listed in Table 1.

The patients were randomly divided into a conventional group (9 cases) and a 3D model-assisted group (9 cases). We used simple random sampling as the sampling method. To prevent bias in the procedure, we sequentially distributed the patients to experimental and control groups. The demographic and clinical data such as age, gender, causes of fracture, affected side, their Letournel's types, and associated trauma were recorded. During the surgery, the surgical approach, duration of surgery, blood loss, time of instrumentation, and intraoperative fluoroscopy numbers were noted.

The study was approved by the suitably constituted Ethical Committee at the Researches Department of Ege University (17-6/19) where the work was performed, and the study conforms to the Declaration of Helsinki. All patients provided written informed consent.

Table 1. The inclusion and exclusion criteria

The inclusion criteria	The exclusion criteria
Fresh closed, unilateral acetabular fracture	Bilateral acetabular fracture
Normal non fractured contralateral acetabulum anatomy	Previous acetabular surgery
Complete CT images	Pathological fractures Open fractures Pelvic deformity Severe soft tissue injuries

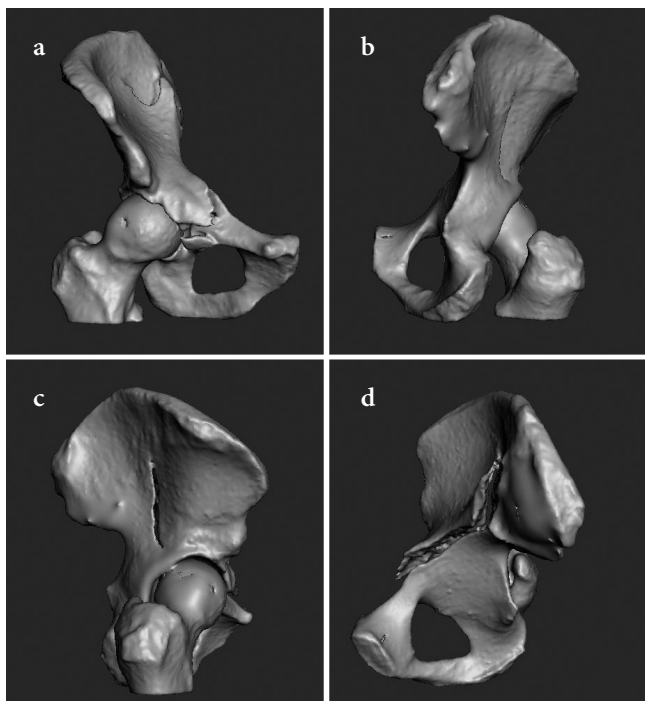


Figure 3. a-d. In 3D reconstructed images, the broken lines can be rotated all around. By looking at the anterior and posterior views, we can see the fracture line of the acetabular fracture to the iliac crest in a-d

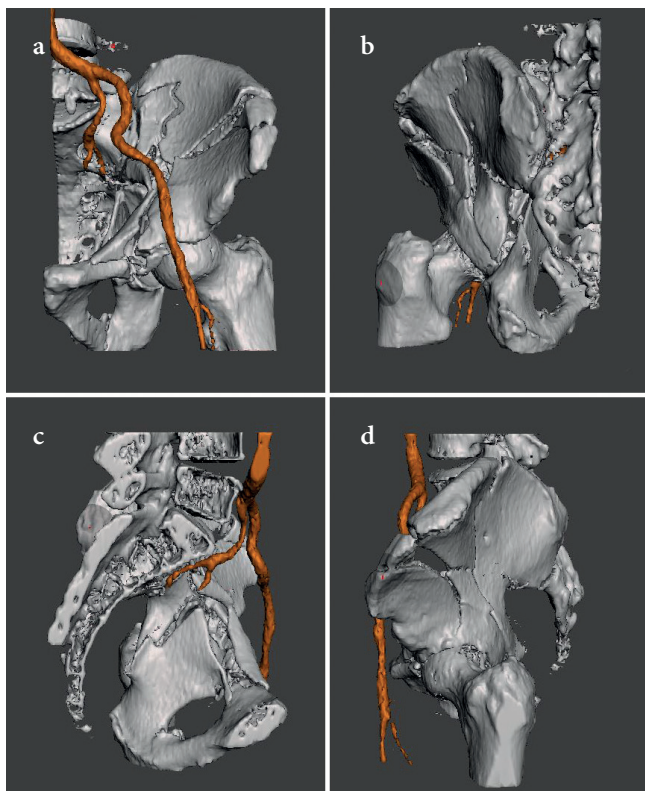


Figure 4. a-d. Tracking fracture lines can also be examined with femoral arteries. Also, with the help of the software program by removing the femoral head from the fractured acetabulum, we can directly see inside the acetabulum in a-d

Creating life-size patient-specific 3D model

The CT images (Discovery St PET/CT scanner, General Electric, Milwaukee, WI, USA, 1.0 mm slice spacing) were processed in the Digital Imaging and Communications in Medicine (DICOM) format. Their segmentation needed to be performed manually in all slices in all three planes (Figure 3. a-d, Figure 4. a-d, Figure 5. a, b). The patient groups were treated with their life-size models preoperatively with the fracture line (Figure 6. a-d, Figure 7. a, b). The model of the pelvis was exported in the STL format for 3D printing. The mean time required for successful 3D reconstruction was 100 min.

The reduction methods for the fractured bones included segmentation, split, mirror, and reposition techniques in the software depending on the fracture patterns. After moving

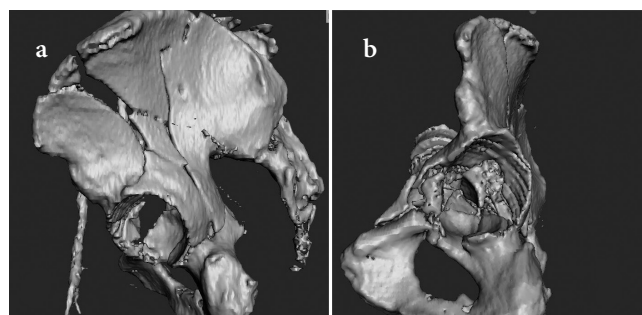


Figure 5. a, b. Using the splitting process, the femur was erased and acetabulum was isolated in a-b

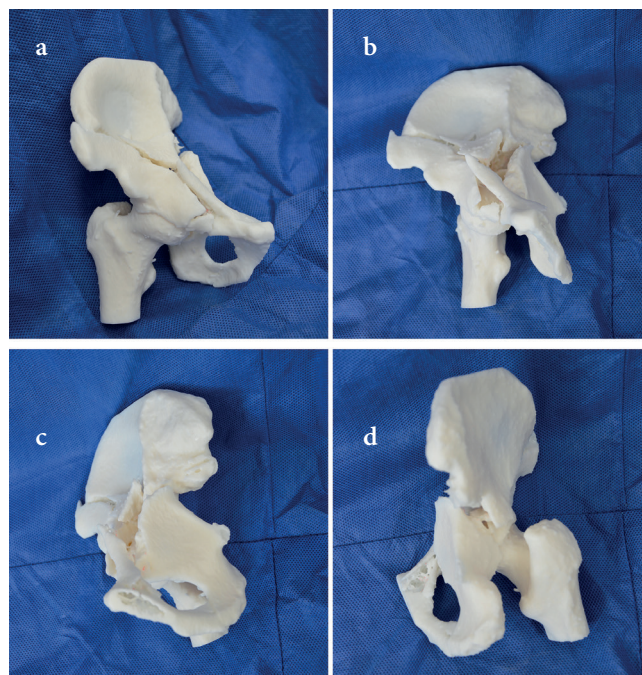


Figure 6. a-d. In 3D model, we can directly see the displacement, comminuted parts, the position of the acetabular fracture, and also the iliac crest. It helps with the planning for the surgery. First the iliac crest fracture is fixed and then the acetabular fracture is fixed in a-d

and rotating the pelvis and determining the characteristics of the fractures, the presurgical algorithms were prepared by the orthopedic and 3D modelling team. Using the splitting process, the bilateral femurs were erased, the acetabulum appeared, and the pelvis was isolated (Figure 5. a, b, Figure 7b).

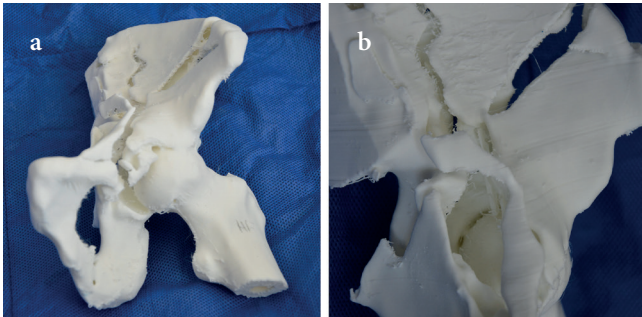


Figure 7. a, b. All the effects of trauma created on the life-size model are revealed. The 3D print model helps with the complete understanding of the fracture lines and fragments before planning and during the surgery. Especially during the surgery to decide the implantation type for the iliac crest fracture and surgical approach for the acetabular fracture in a-b



Figure 8. a-d. The fixation implant can be pre-contoured according to the 3D patient-specific mirrored pelvis model in a-d

3D models

We used the manipulated 3D image to print a patient-specific pelvis model that had the same size (1:1 model) (Formlabs Inc. 35 Medford St. Suite 201, Somerville, MA, USA) and geometric features as the patient's acetabulum (Figure 6-8). In the 3D printing group, we used the mirror imaging technique where the normal side acetabulum was printed into a real-size fracture side acetabulum model that was likely to be similar to the acetabulum before the injury; it was used to make the preoperative design and simulate the operation *in vitro*. The length of the plates planned to be placed with the help of the mirror image of the intact acetabulum and pelvis was determined before the operation (Figure 8). The preoperative planning of the internal fixation, including the screw positions, orientation, plate location, and number and intervals of screws were studied to determine the 3D life-size models.

Acetabular surgery

All the surgeries were performed by the same surgeon. We used DePuy Synthes (Goshen Parkway West Chester, PA, USA) 3.5 mm reconstruction plate. In the 3D model-assisted group, all the plates were contoured and fixed to the mirror image 3D models (non fractured acetabulum) before surgery. In this way, the size, shape of the plate, and number and size of the screws were determined; a sterilization process for these plates and screws before surgery was done (Figure 8). During the surgery, the correct reduction of the fragments by fluoroscopy evaluation and fitting of the pre-operative contoured plate according to a mirror image of the uninjured half of the pelvis were done.

Postoperative rehabilitation

The rehabilitation was initiated one week post-operatively. The hip passive range of motion, isometric quadriceps

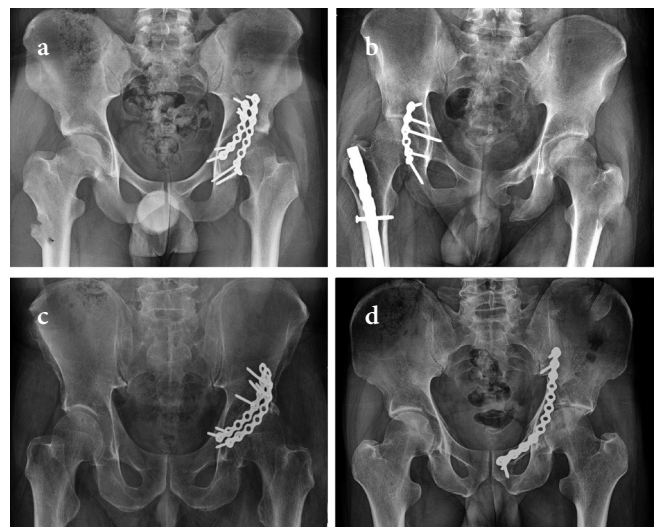


Figure 9. a-d. Postoperative X ray shows how to evaluate the condition of the reduction, implant placement, and fracture healing in a-d

Table 2. Details of the patients such as the age, gender, causes of fracture, affected side, Letournel types, imaging findings, and operative details of acetabular fractures

Case-Gender-Age-Side	Injury	Letournel Classification	Associated Trauma	Surgical Approach	Operation			Intraoperative Fluoroscopy - n	Follow-up - Month	Post-op X-ray Good:0-2 mm
					Time - Min.	Blood Loss -mL	Instrumentation Time - Min.			
Patients with Conventional Therapy										
BI-Male-61-R	Fall	Posterior wall	Head Trauma	Kocher- Langenbeck	195	550	52	9	9	G
CN-Male-19-L	Traffic accident	Posterior wall	-	Kocher- Langenbeck	210	620	55	10	14	G
EA-Male-16-R	Traffic accident	T-shaped	Femur and Cruris Fractures	Kocher- Langenbeck	205	610	42	8	15	G
FD-Male-46-L	Traffic accident	Posterior column	-	Kocher- Langenbeck	225	640	48	9	8	G
HK-Male-34-L	Traffic accident	Transverse	Humerus Fracture	Kocher- Langenbeck	220	570	62	14	14	G
IU-Male-34-R	Fall	T-shaped	Femur Fracture	Kocher- Langenbeck	235	650	71	13	14	G
MI-Male-25-L	Fall	Transverse + posterior wall	Pubic Separation	Kocher- Langenbeck	230	640	73	12	11	F
NE-Male-70-R	Traffic accident	Both columns	Costal Fracture	Ilioinguinal	245	670	64	11	12	F
SO-Male-70-L	Traffic accident	Anterior column	Scapula and							
Spine Fracture	Ilioinguinal	215	510	50	8	10	G			
Statistical detail					220±15.6 (195-245)	606.6±52.67 (510-670)	57.4±10.65 (42-73)	10.4±2.2 (8-14)	11.9±2.5 (8-15)	78%

Table 2. Details of the patients such as the age, gender, causes of fracture, affected side, Letournel types, imaging findings, and operative details of acetabular fractures (Continued)

Case-Gender-Age-Side	Injury	Letournel Classification	Associated Trauma	Surgical Approach	Operation			Post-op		
					Time - Min.	Blood Loss -mL	Instrumentation Time - Min.	Intraoperative Fluoroscopy - n	Follow-up - Month	X-ray Good:0-2 mm
Patients with Three Dimensional Model-assisted Therapy										
AS-Male-53-L	Fall	Transverse	Cruris Fractures	Ilioinguinal	185	380	36	5	10	G
ME-Male-51-L	Traffic accident	Posterior wall	-	Kocher- Langenbeck	170	350	38	6	10	G
CK-Male-38-L	Traffic accident	Posterior column	-	Kocher- Langenbeck	175	410	32	6	13	G
YK-Male-50-R	Fall	Transverse	-	Ilioinguinal	190	430	40	7	15	G
HC-Male-35-L	Traffic accident	Anterior column	Tibia plateau Fracture	Ilioinguinal	195	510	37	5	15	G
HF-Male-66-R	Traffic accident	Both columns	Costal+ Humerus Fractures	Ilioinguinal	185	450	41	6	8	F
MS-Male-30-L	Traffic accident	Posterior column + Posterior wall	Costal Fractures	Kocher- Langenbeck	175	380	38	7	7	G
MI-Male-60-R	Fall	Transverse	Radial Fractures	Kocher- Langenbeck	170	370	30	5	7	G
MA-Male-33-L	Fall	Transverse	Forearm Fractures	Kocher- Langenbeck	180	350	34	7	8	G
Statistical detail					180.5±9* (170-190)	403.3±52.67* (350-510)	36.2±3.6* (30-41)	6±0.86* (5-7)	10.33±3.2 (7-17)	89%

*Statistically significant p<0.05
G: Good; F: Fair

strengthening, and non-weight bearing exercises were used until six weeks post-operatively. The partial weight bearing was permitted after the identification of the partial callus formation on radiography. The full weight bearing was permitted after two months.

Follow-up

To demonstrate the position and orientation of the implants post surgery, the postoperative X-ray and CT scans were acquired 48 h following the surgery if the general condition of the patient was suitable. The patients were followed up in the outpatient clinic by radiographs (pelvic anteroposterior radiograph, inlet, outlet, and Judet radiographs) that were taken at certain intervals and it was decided that the quality of the fracture reduction and the adequacy of the implant placement be obtained with these radiographs (Figure 9). The fracture reduction quality was defined as good and fair according to whether the radiograms were less than 2 mm in displacement in the acetabulum.

Statistical analysis

The data were analyzed using the Student's unpaired t test, chi-squared test, and Friedman test. $p < 0.05$ was considered statistically significant. The data are given as mean \pm standard deviation. The statistical analyses were performed using the Statistical Package for Social Sciences, version 25.0 software (IBM SPSS Corp.; Armonk, NY, USA).

Results

There were no statistical differences in sex, age, classification of fracture, cause of injury, side of injured acetabulum, and duration of follow-up in the two groups. In the 3D assisted-model group, the duration of surgery, volume of intraoperative blood loss, time of instrumentation, and time of intraoperative fluoroscopy were significantly less than that in the conventional group ($p < 0.05$) (Table 2).

The fracture reduction quality was good in 7 patients (78%) in the conventional group and 8 patients (89%) in the 3D group (Table 2).

Although 3 patients in the 3D group who received reduction during surgery were controlled by fluoroscopy, the plates obtained with the mirrored images and models in the initial placement were not found to be fully seated over the fracture lines. In these 3 patients, the reductions were reevaluated and corrected during the surgery.

No serious postoperative complications, including infections, neurovascular injuries, erosion of the soft tissues overlying the implant, and deep venous thrombosis occurred during the follow up.

Discussion

The acetabular fractures are serious intraarticular fractures resulting from high-energy injuries. Approximately 80% of the acetabular fractures are the result of high-velocity injuries such as motor vehicle collisions, whereas 10% of them are the result of low-velocity injuries sustained by elderly individuals who fall (1-4). When a force is applied along the long axis of the femoral neck with the hip in external rotation, an anterior fracture may result, and the internal rotation may result in a posterior fracture (7-11). This difficulty is compounded by the need to apply a radiographically based classification system in which the acetabular fractures are described as though one were looking at the acetabulum from the lateral side (Figure 1, 2), to 3D imaging examinations such as personalized model (Figures 3. a-d, 4. a-d, 5. a,b, 6. a-d, 7. a,b, 8. a-d) (17, 18).

The surgical treatment principles for the displaced acetabular fractures include an anatomic reduction of the articular surface with the stable fixations to restore the biomechanical characteristics of the acetabula and achieve early postoperative rehabilitation. The anterior column acetabular fractures can be divided into those in the articular region and the ones in the non-articular region (22, 23). The articular region fragments contain the areas of the acetabulum and quadrilateral plate, which must be anatomically reduced. The pubic and iliac fragments from the non-articular region do not require anatomical reduction as indirect reduction and bridge-plating can be applied (8, 16). The anterior approaches such as the ilioinguinal and Stoppa approaches are always employed to treat the pelvic and acetabular fractures (7, 24). Stable fixation could be achieved by placing a plate along the superior border of the arcuate line through this approach. However, difficulties in the reduction and fixator placement with this approach at the area of the quadrilateral surface limit its application (25, 26). The risk of blood vessels injuries, especially the Corona Mortis, is also a major concern with this approach. The Stoppa approach allows a wide view of the inner surface of the pelvis, which could provide direct visual of the quadrilateral surface, anterior column, and arcuate line. The common surgical complications associated with the dissection of the deep tissue include peritoneal injury, iliac vessel injury, and femoral nerve injury (24).

Cimerman et al. reported favorable results in the pre-operative planning of the acetabular fracture reduction in using a commercially available tool such as CAD software (4). Citak et al. and Shen et al. worked to develop a pre-operative reconstruction system for the unilateral pelvic and acetabular fracture reduction and internal fixation surgery using computer graphics and augmented reality technique to simplify the surgical procedure (14, 26). Duncan et al., Maini et al., and Zeng et al. also carried out 3D printing of the fractured hemipelvis for pre-contouring of the plates and concluded that the patient-specific pre-contoured plate made using the

3D model is a better implant than the intra-operatively contoured plate (17, 26, 27).

Upex et al. reported that one possibility is to generate a model of the uninjured half of a fractured pelvis with 3D printing, and then pre-contour the fixation plates preoperatively on this model (9). Maini et al. reported that reduced blood loss (100 mL less), surgical time (12 min less), and better post-operative reduction were observed in cases than that in the controls (19). In the study by Hun et al., the patients treated with virtual simulation had significantly shorter internal fixation times, shorter surgery duration, and less blood loss (57 min, 70 min, and 274 mL, respectively; $p < 0.05$) than that in the patients in the conventional surgery group (7).

The great consistence of the implant positions and orientations applied in the actual surgery with the pre-operation designs and the efficient restoration of the acetabular fractures provide convincing evidence that the 3D printing technique in preoperative planning allows for superior acetabular surgery management, improving the surgeon's efficiency in the operating room, shortening the operative times, and reducing the exposure to radiation. Therefore, the 3D reconstructions of the fracture anatomy are necessary for visualizing the fractures, determining the fracture type, and choosing a proper surgical approach (28-32).

In this study, we tested the 3D printing technology assisted with surgical procedure assessment for the preoperative planning of the acetabular fracture reduction. We found that the preoperative planning using the personalized 3D model can be completed in a day. Although limited in number of series, we believe the patient specific models help considerably in understanding the difficult acetabular fractures with the models that were reduced either anatomically or satisfactorily in the pre-operative planning stage (Figure 6-8). The personalized model can help the orthopedist to make an individual, accurate, and reasonable surgical plan for the patients. The options for the reduction and fixation of the fracture include extensive surgical approaches with the possibility of morbidities such as infection, blood loss, and wound complications. However, 3D models guide the surgery, has the advantage of low infection rate, minimal blood loss, and fewer wound complications.

The recently adopted 3D printing method allows rapid and accurate construction of a full-scale individual model, which can facilitate the visualization of the fracture pattern and complex pelvic anatomy prior to the surgery. The surgeons with the 3D modelling team can determine the best sequential reduction procedures. They can choose the appropriate surgical incision and approach. The implants can be pre-contoured according to the 3D patient-specific pelvis model, and the screw length could be estimated pre-operatively, which decreases the risks of implant-related complications (Figure 8). Moreover, the precontoured plate can serve as actu-

al shape of the anatomy and during the surgery, it can help to evaluate the fracture reduction by accommodating to the reduced fracture surface. These 3D printing techniques that have been successfully used in the orthopaedic surgeries can improve the surgeon's efficiency, shorten the surgical duration, and reduce the iatrogenic complications (Table 2). The basic treatment principles for the displaced acetabular fractures include the anatomic reconstruction of the articular surface to restore its biomechanical characteristics and stable fixation to allow immediate postoperative exercising.

Some limitations could be noted in this study. It was a randomized-non-controlled blinded study and focused on the peri-operative results rather than the longterm clinical outcomes. A larger patient population is needed to further assess its clinical application.

In conclusion, this technique can significantly improve the outcome of the acetabular fracture surgery via providing a better pre-operation plan, and a training platform for the residents and surgical teams to completely understand the surgical procedures.

Ethics Committee Approval: Ethics committee approval was received for this study from the Researches Ethics Committee of Ege University (17-6/19).

Informed Consent: Written informed consent was obtained from the patients.

Author Contributions: Concept - A.M.Ö., K.A., F.G.; Design - A.M.Ö., F.G., M.A.Ö.; Supervision - A.M.Ö., K.A., F.G., M.A.Ö.; Resources - A.M.Ö., O.S., S.Ş., M.A.Ö.; Materials - A.M.Ö., O.S., S.Ş.; Data Collection and/or Processing - A.M.Ö., O.S., M.A.Ö.; Analysis and/or Interpretation - A.M.Ö., K.A., F.G., O.S., M.A.Ö.; Literature Search - A.M.Ö., F.G., O.S.; Writing Manuscript - A.M.Ö., K.A., F.G., O.S., S.Ş., M.A.Ö.; Critical Review - A.M.Ö., K.A.

Conflict of Interest: The authors have no conflicts of interest to declare.

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