European Journal of Trauma and Emergency Surgery (2022) 48:1255–1261
https://doi.org/10.1007/s00068-021-01617-z

ORIGINAL ARTICLE

Virtual planning on contralateral hemipelvis for posteriorly fixed acetabular fractures

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Received: 8 May 2020 / Accepted: 5 February 2021 / Published online: 8 March 2021

Abstract

Background Open reduction and internal fixation is a standard treatment for displaced acetabular fractures using 3.5 mm reconstruction plates contoured intra-operatively. This process is difficult and time consuming hence resulting in increased surgical morbidity. Virtual surgical planning is now being commonly used worldwide to aid in management of such complex problems. Patient-specific reconstruction plate pre contoured using virtual surgical planning on contralateral intact hemipelvis will be helpful in achieving better surgical outcomes. Also, it has an added advantage of considerably reducing the time and effort spent in virtual pre-operative planning process.

Methodology This study was performed in 30 patients with acetabulum fracture who were fixed posteriorly via Kocher-Langenbeck approach. Virtual planning was done on contralateral hemipelvis to prepare patient-specific pre-contoured plates and mirrored to the fractured side. The time required for virtual planning on fractured and normal side was recorded and compared. The efficiency of plates so prepared were accessed in terms of outcome variables like duration of surgery, blood loss, reduction obtained on X-ray as well as CT Scan.

Result Time required for virtual planning was more on fractured side and lesser when it was done using normal hemipelvis with mean values of 81.83 (sd = 28.02) min and 15.67 (sd = 6.12) min, respectively. Values of blood loss, duration of surgery and reduction as accessed on X-ray and CT scan were comparable or even better than compared to other studies.

Conclusion Contralateral normal pelvis can be used for virtual preoperative planning making the whole process easier and less time consuming.

Keywords Acetabular fracture · Normal hemipelvis · Virtual planning · Pre contoured plate

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Abbreviations

DICOM	Digital imaging and communications in medicine
STL	Stereolithography
PLA	Polylactic acid
CT	Computed Tomography
3D	3 Dimensional
MIMICS	Materialise Interactive Medical Image Control System

Introduction

Management of acetabular fractures is one of the major challenges faced by trauma surgeons since the beginning. Incidence of acetabular fractures in USA and western Europe is around 30 patients per million annually [1]. Exact epidemiological data related to incidence in Indian population is not available. There are very limited number of indications for conservative management of acetabular fractures such as minimally displaced (< 2 mm) fractures, medical contraindication to surgery, local soft tissue factors etc. Displaced fractures of acetabulum or those involving the weight bearing dome necessitate an anatomic articular reduction for obtaining good functional outcome. Achieving the same is very difficult due to complex bony anatomy along-with restricted direct visualization of articular surface because of soft tissue constraint. There is a need to devise an accurate method of fixing acetabular fractures which is easy, less time consuming and requires less effort.

With the advancements in image processing and computer technology, virtual planning software and rapid prototyping technology have revolutionized medical science. With its various applications in the form of medical models, customized implants, customized prosthesis, medical appliances/devices, 3D-printed scaffolds, bioprinted tissues and organs and 3D-printed organs, it has improved surgical outcomes not just in orthopaedics but other fields as well. Pelvi-acetabular surgeries being one of the most difficult have found the most ardent use of this technology. In the last 2 decades various authors have published their results proving the same beyond doubt. The main limitations preventing the widespread use of this technology are time consumed in preparing a 3D model virtually and printing the same, technical expertise needed to operate the software and the increased cost involved in the use of software as well as the 3D printer. The two studies conducted by Maini et al. [2, 3] have found virtual planning and 3D printing to be a powerful tool in increasing the surgeon's understanding of acetabular fractures thus improving surgical outcome. We have been using virtual preoperative planning routinely for managing acetabular fractures. In this study we have utilized our experience with the use of virtual planning to overcome the above mentioned demerits.

The best template to reconstruct the anatomy of acetabulum would be the intact contralateral hemi-pelvis. Patient specific reconstruction plate, if constructed pre-operatively by doing virtual surgical planning on opposite intact pelvis, will be useful to respect the patient-specific morphology. Also, it has an added advantage of considerably reducing the time and effort spent in virtual reduction of fractured acetabulum which is one of the major constraints involved in using this technology. These plate templates should be more accurate than the other means of contouring the plates thus reducing the surgical invasiveness, as well as simplifying the surgical procedure.

Hence in our study we aim to assess efficacy and accuracy of plates pre-contoured using plate templates virtually designed on contralateral hemipelvis for acetabular fracture fixation.

Materials and methods

In this quasi-experimental study, 30 patients who came to either orthopaedic emergency or outpatient department in our institution (tertiary level hospital attached to medical college) between September 2016 to April 2018 were included. Patients aged between 18 and 60 years with displaced acetabular fractures with intra-articular displacement of > = 3 mm requiring posterior fixation only via kocher-langenbeck approach were included in the study to maintain homogeneity of data. Open fractures of the acetabulum, Associated Morel-Lavallee lesion, bilateral acetabular fractures or any disease affecting the morphology of contra-lateral pelvis were excluded from this study. Also, any fracture needing anterior fixation was excluded from the study. After haemo-dynamic stabilization of all the patients, series of plain radiographs (AP and Judet views) and non-contrast computed tomography (NCCT) scans with 1 mm axial cuts were obtained. NCCT scans in DICOM format were imported in the MIMIC software (Mimics Innovation Suite by Materialise NV, Belgium, version 17.0) and following the methodology as described by Maini et al. [3]. Firstly, "thresholding" was done in which bone is selected by separating from surrounding soft tissue based on density. In this step, a colour is given to the part selected, which is called as a "mask" in technical term. Further steps involved are described below:

1) Plate template planned on contra-lateral intact hemipelvis: After thresholding, "calculate 3D" command was run to make a virtual 3D model of the pelvis (Fig. 1). The virtual 3D model was then exported into another software Materialise 3-Matic (version 9.0). Further, plate templates were designed on contra-lateral pelvis as required based on the fracture pattern. These plate templates were then mirrored from contra-lateral to fractured side by "mirror" command using "mid-plane" as reference (Fig. 2). These plate templates were then exported as STL format files. Time required in completing these steps was noted.
2) Designing plate template on fractured side: Here, after "thresholding", next step performed was "segmentation". "Segmentation" is the step in which fracture fragments are separated in various slices of CT using "edit mask" and "region growing" commands. Then a virtual 3D model of each separated fracture fragment was made while maintaining their spatial relationships. Fracture was assessed and further steps were carried out in 3-Matic software. Virtual reduction was done followed by designing desired plate templates, which were exported as STL files. Here also, Time required in completing these steps was noted.

After this, the plate templates based on contra-lateral hemipelvis were 3D printed using poly-lactic acid (PLA) material in a Fused Deposition Modelling (FDM) 3D printer. These 3D-printed plate templates were then utilized as reference to perform contouring of 3.5 mm reconstruction plates one day before the surgery (pre-bending). The pre-bending was done manually by senior surgeon (L.M) using conventional plate benders. The pre-bent plates were then autoclaved and used for fixation in the surgery (Fig. 3).

Factors assessed in the study:

Pre-operative period: 1. Time required in designing plate templates based on contra-lateral hemipelvis. 2. Time required to in designing plate templates based on fractured hemi-pelvis.

During surgery: 1. Duration of surgery 2. Blood loss 3. Any requirement of re-contouring of pre-bent plates.

Post-operative period: 1. Reduction on AP and Judet plain radiographs (Matta and Merit criteria [4]) 2. Assessment of reduction in post-operative CT scan performed between 5 and 7 post-operative days: Post-operative gap at fracture site was noted in articular region. Also, difference in fracture gap was noted between pre and post-operative CT scans (Fig. 4).

To eliminate any bias, all surgeries were performed by the same operating surgeon (L.M) and designing of plate was done by same 2 surgeons in each case (L.M and G.A).

Statistical evaluation

The data was entered in excel sheet and SPSS 22.0 software was used for assessment. Mann Whitney *U* test and independent *t*-test were used to assess and compare quantitative parameters i.e. intraoperative blood loss and intraoperative time. Chi square test was used for comparing and assessing post-operative reduction and *p*-value (< 0.05) was considered as significant.

Results

Elementary fracture group comprised of 14 cases—10 posterior wall, 1 posterior column and 3 transverse fracture types. Associated fracture group comprised of 16 cases—5 posterior column with posterior wall, 3 transverse with posterior wall, 4 t type, 1 anterior wall with posterior hemi-transverse and 3 bi-columnar fracture types.

Mean duration of surgery for all the 30 cases was 89.8 (sd = 22.2) min. The duration of surgery for simple fracture types (78.5 min) was less than that for associated fracture types (99.81 min). Mean blood loss was found to be 411.67 (sd = 106.41) ml. The mean blood loss for simple fracture types (367.85 ml) was less than that for associated fracture types (450 ml) and on applying Mann Whitney *U* test it was found that difference in blood loss of two groups was statistically significant ($p < 0.05$). Subjective outcomes like number of patients requiring blood transfusion and fall in haemoglobin level postoperatively were also taken into consideration.

As seen in Table 1 there was significant difference in post-operative reduction on x-ray between elementary and associated fracture types. Post-operative reduction on CT was mean displacement of 3.17 (sd = 3.39) mm. Mean displacement of associated fracture group being greater than that of elementary fracture group, this difference was found to be statistically insignificant. On analysis, difference in reduction on pre-op and post-op CT was mean displacement of 15.95 (sd = 9.18) mm. The mean displacement for simple fracture types was more than that for associated fracture types.

Time required for virtual pre-operative planning was more when reduction of fracture fragments was done and lesser when it was not done with mean values of 81.83 (sd = 28.02) min and 15.67 (sd = 6.12) min respectively. Time required for pre-operative planning in elementary and associated fracture types on fractured side was 62.14 (sd = 16.37) min and 99.06 (sd = 24.65) min respectively and planning on contralateral side was 15.35 (sd = 5.36) min and 15.96 (sd = 6.88) min respectively. These findings suggest

Table 1 Table showing values of reduction on X-ray and CT scan

	Total (30)	Elementary (14)	Associated (16)
Reduction on X-ray			
Anatomical	21 (70%)	13 (92.86%)	7 (43.75%)
Imperfect	8 (27%)	1 (7.14%)	8 (50%)
Poor	1 (3%)	0	1 (6.25%)
Reduction on CT scan			
Mean displacement (in mm) ± S.D	3.17 ± 3.39	2.16 ± 0.74	4.06 ± 4.74
Mean difference in displacement (in mm) ± S.D	15.95 ± 9.18	18.75 ± 9.39	13.5 ± 8.54

S.D. standard deviation

that there is considerable reduction in time needed for pre-operative planning irrespective of fracture morphology.

In 2 cases out of 30 re-contouring of plates was needed due to some change in plan intra-operatively regarding the placement of plates in view of difficulties like bone loss etc. In rest cases pre-contoured plates were matching pelvis morphology accurately.

Discussion

Intra-operative contouring of recon plates for acetabular fracture fixation increases significant surgical time and morbidity. Average time spent in intra-operative contouring of plates has been reported to be 20 min per plate by Shen et al. [5], 9 min per plate by Maini et al. [2] and 4.4 min per plate by Maini et al. [3] Pre-operative planning for pre contouring of recon plates has been done in various studies in past reporting decreased intraoperative duration and better surgical outcomes. Upex et al. reported time savings at 30 min [6]. Although in all studies pre-operative planning was a time-consuming process with a learning curve. In our study, we intended to simplify the virtual pre-operating planning process and make it less time consuming by designing plate template on contralateral hemipelvis.

Symmetrical nature of human morphology has been utilized earlier in various studies with satisfactory outcomes. Coward et al. [7] described an automated technique that creates a mirror imaged wax model of an ear to reconstruct the lost contralateral side. Kang et al. [8] in 2019 published a study where he used real size 3D models of fractured tibia and normal tibia created by mirroring of contralateral side. In a study done by Hannen et al. [9] in 2005 plates were created for reconstruction in tumour deformed mandibles with original contour using mirrored contralateral normal side. Upex et al. [6] published a case report in 2016 in which they used the similar technique for pre contouring of both anterior and posterior column plates for acetabular fracture fixation and experienced significant reduction in surgical duration. Hsu et al. [10] in 2018 published a study comprising of 29 acetabular fracture patients in which they used a 1:1 scaled 3D-printed model of the pelvis which was created by mirroring the contralateral normal side to the fractured side and published favourable results.

In all such studies utilizing the technique of virtual planning and rapid prototyping a full size (1:1) 3D-printed model of the hemipelvis was used for pre-contouring of plates. Time and cost involved in the same can not be ignored. In our methodology, we printed plate template based on contralateral hemipelvis instead of entire 3D model thus decreasing the time and cost significantly. Although with improvement in rapid prototyping technology, time needed for 3D printing of full-sized pelvis model has been reduced to around 24hrs as reported in recent studies [6]. Not just the time and cost; by eliminating the steps of segmentation, the whole process becomes far easier thus making it more accessible to people who are hesitant to use the technology because of the technical expertise needed.

Steps of segmentation and reduction involved in preparing a 3D model of the patient's pelvis can be bypassed by performing virtual planning on contralateral normal pelvis after mirroring it to the fractured side. Mean segmentation time has been reported to be between 38.7 and 130 min in various studies.

Our results also indicated clearly that there is considerable reduction in time spent in pre-operative virtual work up if planning is done on contralateral normal pelvis and that this time is not affected by complexity of the fracture pattern.

Not many authors have published their results reporting duration of surgery and blood loss in various studies available in literature. Few authors have used both ilio-inguinal and kocher-langenbeck approaches and results are not reported separately making the data inhomogeneous and thus difficult to compare with the results in our study. Mayo et al. [11] in 1994 reported mean duration of surgery of 3.2 h and blood loss of 420 ml after use of kocher-langenbeck approach alone in 58 patients. Similarly, in a study by Maini et al. [3] in 2017 values reported were 96 min and 443.75 ml respectively with a sample size of 16. On comparing mean values of duration of surgery and blood loss for elementary and associated fracture types there was statistically significant difference between the 2 groups suggesting that a longer time is needed resulting in increased blood loss for fixation of associated fracture types.

Our results of post-operative fracture reduction accessed on X-ray are comparable to other studies reported in literature as shown in Table 2. On comparing mean displacement on pre-op and post-op CT between elementary and associated fracture types difference in both the cases was found to be statistically insignificant, hence, implying that final reduction achieved and the displacement reduced by the use of implant is not affected by the complexity of fracture. However, use of pre-bent plates does aid in achievement of more accurate reduction. On applying Pearson coefficient to see the relationship of delay in surgery with post-op CT reduction and pre-post operative displacement difference, this relationship was found to be very weak with Pearson coefficient < 0.1. Hence, it can be implied from above data

Table 2 Table showing reduction on X-ray in various studies with the use of Kocher-Langenbeck approach

S. No	Study	Study characteristic	Reduction on X-ray (in percentage)		
			Anatomical (%)	Imperfect (%)	Poor (%)
1	Pantazopoulous et al. [12]	52 posterior wall fractures	80.77	19.2	0
3	Moed et al. [13]	100 posterior wall fractures	97	3	0
5	Mitsionis et al. [14]	19 posterior hip dislocation with posterior wall	78.95	15.79	5.26
7	Pascarella et al. [1, 15]	121 posterior wall	95	5	–
9	Maini et al. [3]	16 all fracture types	50	31.25	18.75

that neither complexity of fracture nor delay in surgery up to 21 days have significant effect on fracture reducibility.

This technique cannot be used in a patient with bilateral acetabular fracture. A limitation of this study was a small sample size hence affecting the precision of the data obtained and the reliability of the inference. Another limitation is the cost involved in acquisition of virtual planning software currently available in the market. We are trying to explore and find out software which are cost effective and user friendly.

Further prospective randomized-controlled trials with large sample size and focussing on specific fracture types or approaches may ascertain the role of this technique in the management of acetabular fractures. Also, subsequent studies using this technique can help in designing of anatomical plate configuration with pre decided screw trajectories for acetabular fracture fixation in specific populations. Similar technique can be a basis for future research exploring the morphological symmetry of human anatomy for preoperative planning at various different limb segments.

Conclusion

In our study we found that contralateral hemipelvis can be used for virtual preoperative planning of acetabular fractures making the whole process easier and less time consuming.

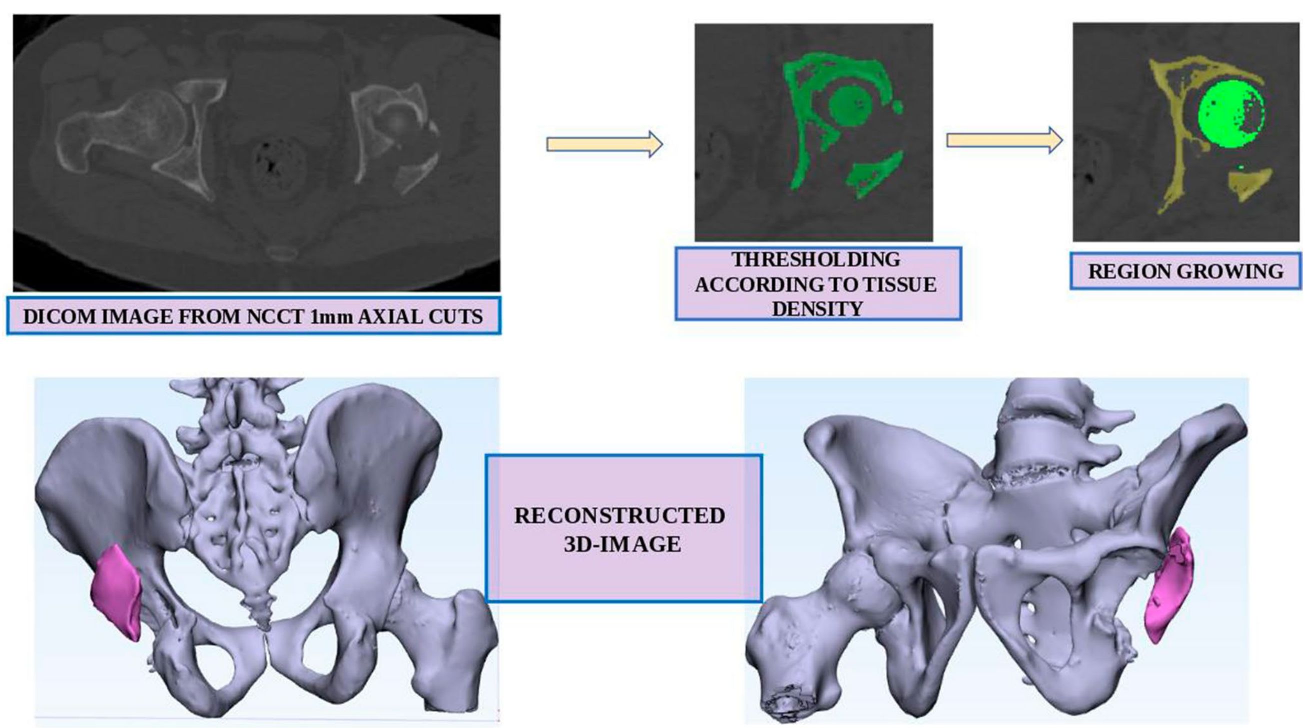

Fig. 1 3D model reconstructed from DICOM images of NCCT 1 mm axial cuts of patient's pelvis

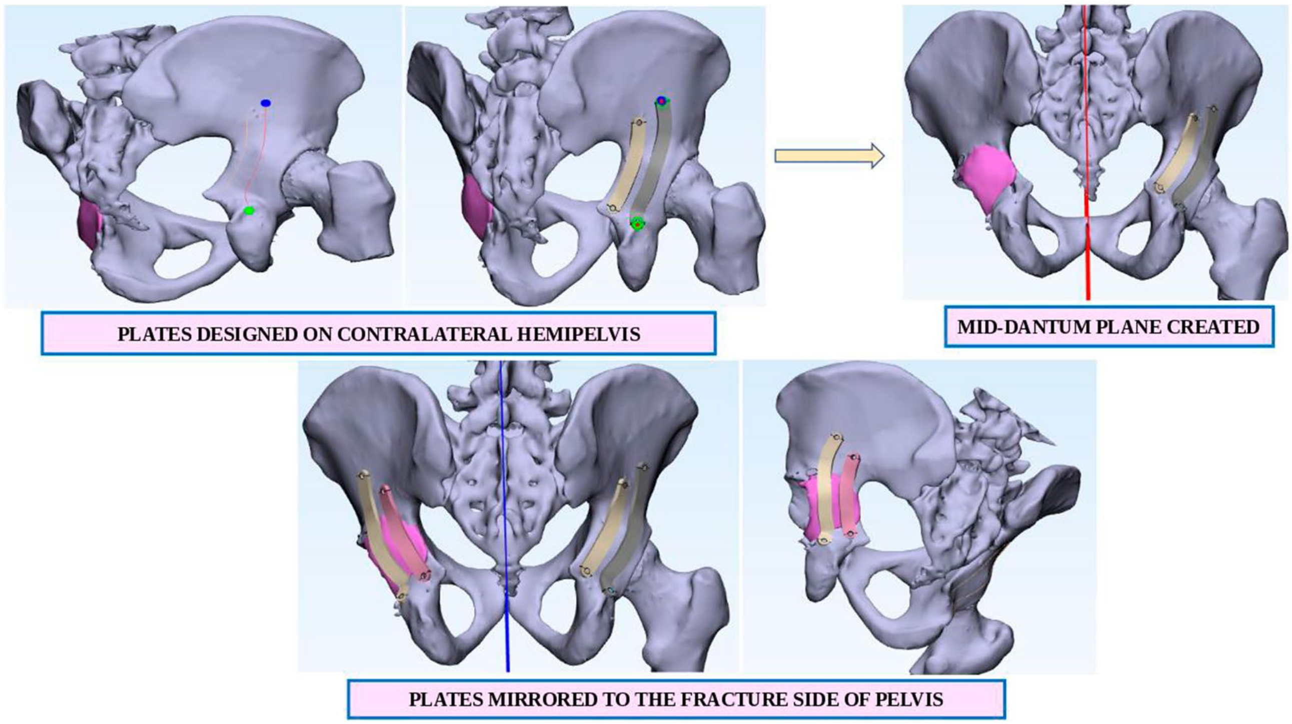

Fig. 2 Plates designed on contralateral normal hemipelvis and mirrored to the fractured side

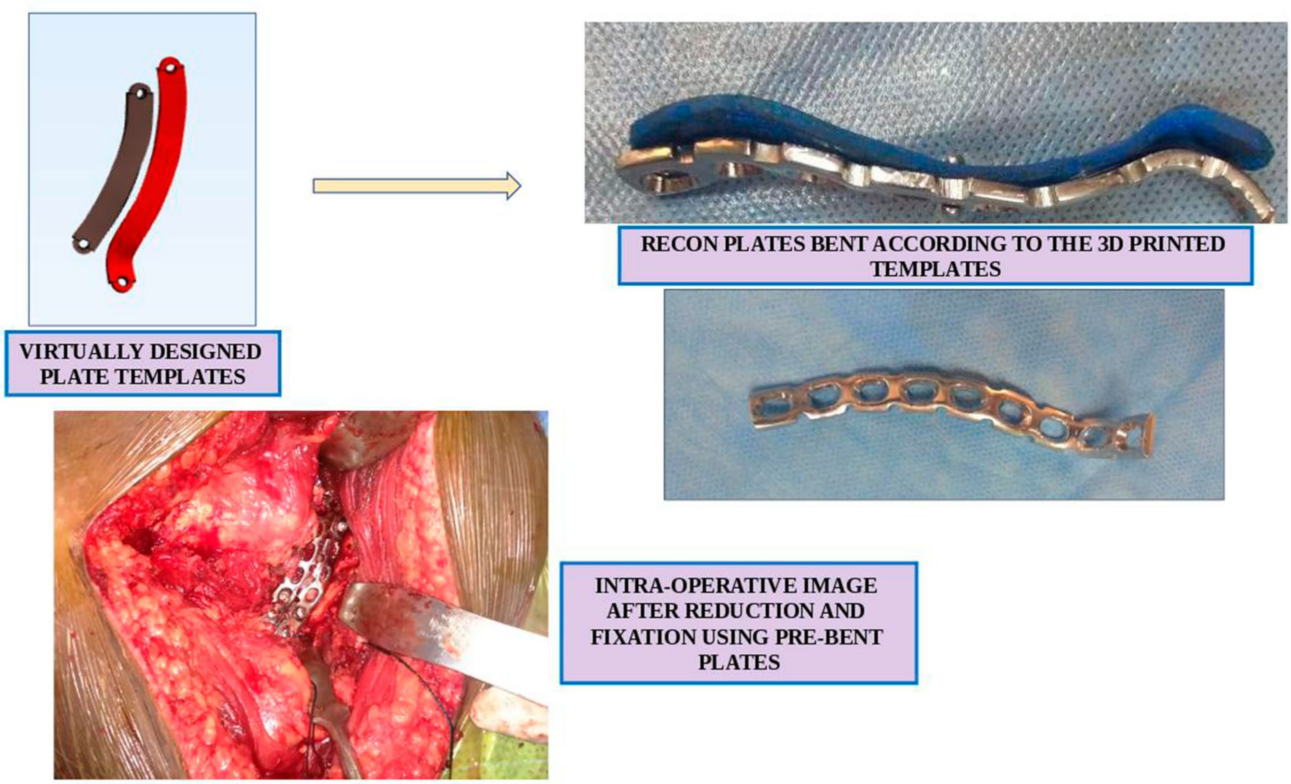

Fig. 3 Plates bent according to the 3D-printed template and used for intra-operative fixation

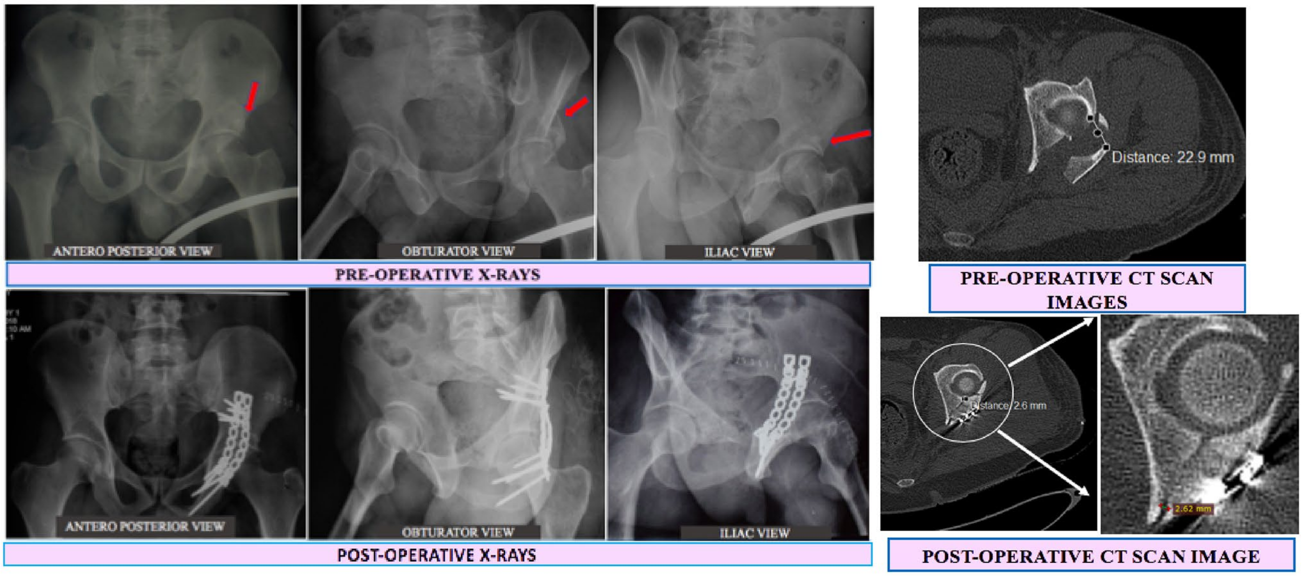

Fig. 4 Pre-op and post-op x-ray and CT scan images

Authors' contributions GA: conceptualization, methodology, software. AM: data curation, writing—original draft preparation. TV: visualization, investigation. LM: supervision. RK: writing—reviewing and editing. AM: writing—reviewing and editing.

Funding This study has been approved by the appropriate ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Compliance with ethical standards

Consent for publication The patients have given their informed consent to be a part of the study.

Competing interests The author(s) declare that they have no competing interests.

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