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ORIGINAL ARTICLE

The Value of 3D Printed Models in Understanding Acetabular Fractures

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Abstract

Acetabular fractures are complex and difficult to classify. Although the Judet–Letournel classification is designed to increase the understanding of acetabular fractures, it remains prone to error when using conventional medical imaging. We hypothesize that three-dimensional (3D) printing, as a new diagnostic imaging tool, will lead to an increased understanding and knowledge of acetabular fractures and an optimal surgical approach. Digital data (DICOM) of 20 acetabular fractures were converted into 3D files [standard tessellation language (STL) data]. These STL files were used to prepare 3D prints of life-size hemipelvic models with acetabular fractures. Seven senior trauma surgeons specializing in pelvic and acetabular surgery, 5 young fellowship-trained trauma surgeons, 5 senior surgical residents, 5 junior surgical residents, and 5 interns classified 20 acetabular cases using X-ray/two-dimensional (2D) computed tomography (CT), 3D reconstructions, and 3D printed models according to the Judet–Letournel classification. Furthermore, all junior and senior surgeons were instructed to evaluate their surgical approach and the positioning of the patient during operation. Time to classify each case was recorded. Calculations were done using Fleiss' κ statistics. Only slight and fair interobserver agreements for senior surgeons ($\kappa = 0.33$) and interns ($\kappa = 0.16$) were found when using X-ray/2D CT. However, 3D printed models showed moderate and substantial interobserver agreements for senior surgeons ($\kappa = 0.59$), junior surgeons ($\kappa = 0.56$), senior surgical residents ($\kappa = 0.66$), junior surgical residents ($\kappa = 0.51$), and interns ($\kappa = 0.61$). Compared with X-ray/2D CT, the interobserver agreement regarding the surgical approach for junior surgeons using 3D printed models increased by $\kappa = 0.04$ and $\kappa = 0.23$, respectively. Except for the interns, a significant time difference for classification was found between X-ray/2D CT and 3D CT and 3D printed models for junior and senior surgical residents and junior and senior surgeons ($p < 0.001$). 3D printing is of added value in the understanding, classification, and surgical evaluation of acetabular fractures. We recommend the implementation of 3D printed models in trauma surgery training.

Keywords: 3D printing, acetabular fracture, Judet–Letournel classification, intraobserver, interobserver

Introduction

Acetabular fractures are complex injuries and are difficult to classify due to varied fracture lines in a complex three-dimensional (3D) anatomy.[1] In addition to the complex 3D anatomy, the complex surrounding tissue of nerves and blood vessels makes an optimal preoperative plan essential. The anatomy of surrounding tissues can be learned from textbooks and cadaver studies; however, the options for learning fracture patterns are

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Opposite page: Two life-size hemi-pelvic models after post-processing. *Photo credit:* Elisabeth-Tweesteden Hospital, Department of Photography and Film.

limited and thereby preoperative planning is a bottleneck to treatment.

The fracture patterns and classification of acetabular fractures have been described by Judet *et al.*[2] and Letournel.[3] High inter- and intraobserver reliability has been reported when this classification is used by surgeons treating acetabular fractures on a regular basis. However, this classification remains prone to error for inexperienced observers using conventional diagnostic imaging[4,5]; recent studies could not reproduce the high inter- and intraobserver reliability for plain radiographs alone or for plain radiographs combined with axial view computed tomography (CT) scans.[6,7] Despite this limitation, the Judet–Letournel classification still remains the most commonly used classification system for understanding acetabular fracture characteristics.[8,9]

Currently, it is generally acknowledged that the addition of CT images is essential for the treatment of acetabular fractures. The addition of 3D reconstructions (3D CT) has gained popularity in the identification of fracture patterns and education regarding acetabular fractures. Garrett *et al.*[5] found 3D CT images easier to interpret than axial CT images. The use of 3D CT resulted in achieving near anatomical reduction and reduced surgical time.[10,11] Hu *et al.*[12] found that less experienced surgeons in particular take advantage of virtual 3D planning for acetabular fractures. However, these volume-rendered models are still viewed on a two-dimensional (2D) computer monitor screen.

3D printers have become widely available and inexpensive. There are three main categories of 3D printing techniques: (1) Extrusion: fused deposition modeling (FDM) uses polylactic acid (PLA), a thermoplastic filament that is heated and extruded through an extrusion head that deposits the plastic layer by layer on a plate. FDM is the most common 3D printing technique used in desktop 3D printing. (2) Resin: a liquid resin is cured by a laser or ultraviolet light. The most common technique is called stereolithography (SLA). (3) Powder: a powdered material is melted together by a laser. Selective laser sintering is the most common technique in this category. 3D printing is an innovative technology that is been used across many medical specialties for numerous applications.[13]

The clinical use of 3D printing (rapid prototyping) in understanding and classifying acetabular fractures has been inadequately studied. In 2012, Hansen *et al.*[14] concluded that 3D pelvic models improved the ability of residents to classify acetabular fracture patterns. However, these models were standard pelvic models on which fracture patterns were created by using an oscillating saw. Last year, Manganaro *et al.*[15] concluded that patient-specific 3D printed models were promising educational tools for teaching and improving learner confidence in using the Judet–Letournel classification system. Furthermore, a couple of case series is available in which it was concluded that 3D printing can be of added value in precontouring plates for acetabular fractures.[16,17] These case series found that 3D printed models are an important advancement for better understanding fracture patterns. However, all these statements are not supported by hard metrics.

Although researchers have reported the same advantages in preoperative planning as with 3D CT,[18,19] Preece *et al.*[20] found that the use of physical models is advantageous in enhancing the visuospatial and 3D understanding of complex anatomical architecture when compared with 3D CT models. Recently, one small study measured the intra- and interobserver agreement between X-rays and 3D printed models without combining radiographs, 2D CT, and 3D CT images as commonly performed in clinical practice.[19]

Our hypothesis is that 3D printing will increase the understanding of acetabular fractures evaluated by the Judet–Letournel classification. Furthermore, we expect that extra practice in classification will lead to a better understanding of acetabular fracture patterns, complex 3D anatomy, and its surgical treatment. To our knowledge, this is the first study to investigate whether 3D printed models can be a reliable and valid way for senior residents to classify acetabular fractures. We will differentiate between several levels of training in surgery to investigate the value of implementation of 3D printed models.

In addition, until now, surgeons have based their preoperative plan of action on conventional diagnostic imaging. Will their plan of action change when classifying acetabular fractures with 3D printed models?

Methods

Study preparations

This study was exempted from the scope of the Medical Research Involving Human Subjects Act (WMO) according to our institutional ethics committee. We used the Dutch Trauma Registry to identify all acetabular fractures from the Elisabeth-TweeSteden Hospital and Isala Hospital (both are level 1 trauma centers). Two trauma surgeons from both hospitals selected 20 cases with acetabular fractures that represented fracture types as described by Judet and Letournel. Each case was evaluated using X-ray, 2D CT, 3D CT, and intraoperative findings if treated surgically. Classifying acetabular fractures according to Judet–Letournel only shows a substantial reliability when used by very experienced pelvic surgeons.[4] Because of this, we did not choose a gold standard for classification. The fractures were distributed according to the meta-analysis methodology by Giannoudis *et al.*[9] According to the opinion of both trauma surgeons, both columns, one posterior wall, three transverse posterior walls, two anterior columns posterior hemi-transverse, three T-shaped, three anterior columns, one transverse, two posterior columns, and one anterior wall type acetabular fractures were identified.

All X-rays, 2D CT, 3D CT, and 3D prints of a hemipelvis with an acetabular fracture were collected. The images were organized in *Sectra IDS7* without patient identifiers for presentation. This radiology workstation is designed to optimize the workflow and ensure quick and easy access to images integrated in our research laptop. Using a free online randomization program, all images of all cases were arranged in a random order [for example, (1) Print 10, (2) X-ray 2D CT 12, (3) Print 20, (4) 3D 11, and (5) X-ray 2D CT 17] to present to the observers. Observers were allowed to view the 2D CT slices in axial, coronal, and sagittal planes. 3D reconstructions could be turned around in two directions: horizontally and vertically. Observers were allowed to hold the 3D printed models in their hands to rotate in all directions.

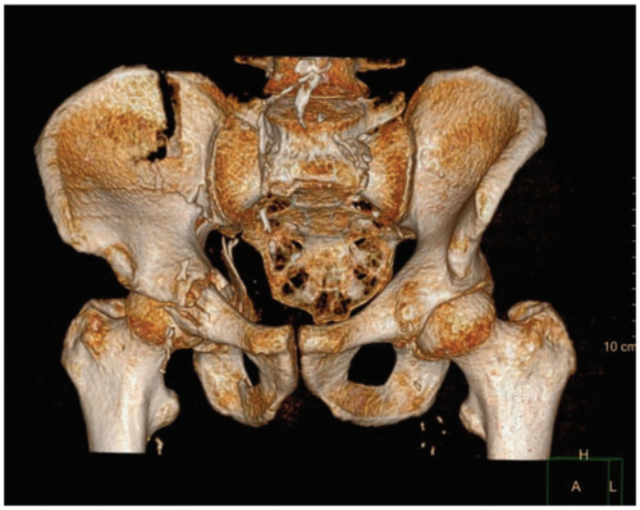

FIG. 1. 3D CT of pelvis. 3D, three-dimensional; CT, computed tomography. Color images available online at www.liebertpub.com/3dp

FIG. 3. Hemipelvic model after postprocessing. Color images available online at www.liebertpub.com/3dp

Process of creating 3D prints from DICOM data

The process of converting digital imaging and communications in medicine (DICOM)-format data into standard tessellation language (STL) format and 3D print is divided into several parts: (1) image acquisition, (2) image postprocessing, and (3) 3D printing.[13]

Image acquisition. The Elisabeth-TweeSteden Hospital and Isala clinics used acetabular CTs for data acquisition, namely, a *Siemens Somatom Definition AS 64-slice CT* and a *Philips iCT 256 slice*, respectively. A slice thickness of 1 mm or less was used. Soft reconstruction filters were applied to minimalize image noise of soft tissue. Raw data of acetabular images were saved in a DICOM format.

Image postprocessing. In both hospitals, DICOM data of acetabular fractures were saved in a picture archiving and communication system (PACS). *Philips Intellispace Portal* software was used for converting and volume rendering DICOM data into 3D CT (Fig. 1). Using the thresholding technique, bone was differentiated from surrounding soft tissue. The femur was digitally removed to enhance intra-articular fracture visualization, and the healthy side of the pelvis was removed to reduce printing time. The 3D reconstruction of a hemipelvis was saved as an STL file. *Philips Intellispace Portal* was integrated into the PACS of the Elisabeth-TweeSteden Hospital.

We used open-source programs to manipulate the STL file. In *Meshlab*, errors such as holes were fixed, and global smoothing was applied. In *Simplify 3D*, the design of an added support and a raft was performed to hold the parts of the printed acetabular model in place.

FIG. 2. Hemipelvic model before postprocessing. Color images available online at www.liebertpub.com/3dp

3D printing. FDM print technology is considered simple to use and environmentally friendly. These printers offer an attractive price–performance combination. Although SLA printers produce higher resolution objects, it is more expensive, is slower in creating large models, and remains a laborious process. Since the thickness of the DICOM data was 0.6–1 mm, print layers of 0.2 mm were sufficient. The FDM technique is capable of printing this layer thickness.

The Elisabeth-TweeSteden Hospital has unlimited access to a Makerbot Replicator Z18, a high-end consumer FDM 3D printer with a large build volume, which is especially important for printing pelvic models.

In *Simplify 3D*, the following process settings were utilized: extruder temperature, 215°C; chamber temperature, 24°C; primary layer height, 0.2 mm; infill, 2% (the outer side of the bone consists of cortical bone; therefore, the model supports itself, and less infill can be used); support infill, 20%; and maximum overhang without support, 60%. Finally, a digital preview of the print was made, and the building time and material costs were calculated. The STL file was converted into G-code to prepare the file for the 3D printer. The hemipelvic models with acetabular fractures were printed on a scale of 1:1. After printing, the models required postprocessing to remove the support and raft (Figs. 2 and 3).

Intra- and interobserver agreement

Seven senior trauma surgeons from several level 1 trauma centers in the Netherlands, experienced in the field of pelvic- and acetabular surgery, were instructed to complete three tasks:

1. Classify acetabular fractures on X-ray/2D CT, 3D CT, and 3D printed models according to the Judet–Letournel classification.
2. Evaluate their surgical approach for every acetabular fracture on X-ray/2D CT/3D CT and reassess for a potential change to their surgical approach when classifying with 3D printed models.
3. Determine the positioning of the patient during operation: supine, prone, lateral, supine/prone, or lateral/prone.

These tasks were also completed by five young fellowship-trained trauma surgeons. Five senior surgical residents (postgraduate years 5–6, specialization in trauma surgery), five junior surgical residents (postgraduate years 1–2), and five surgical interns were only asked to complete the first task. The time needed to complete the tasks was noted. Participants were informed that each of Judet–Letournel's fracture pattern could be represented once, more than once, or not at all. Surgical approaches were defined according to the principles of the AO foundation [(modified) Stoppa, ilioinguinal, Kocher–Langenbeck, (extended) iliofemoral, Trochanter flip, and/or pararectal].[21] The opinions of all observers on the different classification modalities were collected.

After 2 months, all observers were asked to classify the acetabular fractures on all modalities presented in a random order. This score was used to compare with the first ''classification round'' and calculate a potential learning curve for classifying acetabular fractures.

Data analysis

Descriptive statistics were calculated to provide an overview of the print process settings. A paired samples *t* test was used to compare the calculated printing time and real print time. One-way analysis of variance with a *post hoc* Bonferroni test was used to calculate the time all observers needed to classify 20 cases. A paired samples *t* test was used to calculate the difference in time between the first and second rounds of measurement. A level of significance of $\alpha = 0.05$ was used.

Observer data were analyzed and expressed in terms of intra- and interobserver agreement. Calculation was done using Fleiss' κ statistics. Fleiss' κ calculates the agreement between a fixed number of observers when assigning categorical ratings to a number of items or classifying items.[22] We interpreted the multirater κ statistics as follows: values of 0.01–0.20 indicate slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and >0.80, good agreement.[23]

IBM SPSS Statistics 24 was used for statistical analysis. The Fleiss' κ calculator was taken from an open-access Microsoft Excel spreadsheet.[24] Calculations were performed using 95% confidence intervals (CIs).

Results

Twenty 3D printed hemipelvic models with acetabular fractures were manufactured using a *Makerbot Replicator Z18 Printer*. The mean weight of the models was 129.5 g [standard deviation (SD) 26.5]. The mean weight of the support and raft was 111.8 g (SD 54.5), 46% of the total weight. The mean printing time was 32.6 h (SD 11.5). The mean material (PLA) cost per hemipelvic model was €11.5 (SD 2.4) or $12.9 (SD 2.7).

Classification

The interobserver agreement for interns improved from slight to fair to substantial when acetabular fractures were classified by X-ray/2D CT, 3D CT, and 3D printed models, respectively. The κ values of X-ray/2D CT, 3D CT, and 3D printed models for junior surgical residents were 0.19, 0.37,

TABLE 1. CLASSIFICATION OF INTEROBSERVER AGREEMENTS

Classification	*2D, κ (95% CI)*	*3D, κ (95% CI)*	*Print, κ (95% CI)*
Overall	0.19 (0.18–0.19)	0.34 (0.33–0.35)	0.47 (0.46–0.47)
Senior surgeon	0.33 (0.30–0.35)	0.42 (0.39–0.44)	0.59 (0.57–0.62)
Junior surgeon	0.18 (0.15–0.21)	0.43 (0.40–0.47)	0.56 (0.52–0.60)
Senior surgical resident	0.17 (0.14–0.21)	0.43 (0.40–0.46)	0.66 (0.62–0.69)
Junior surgical resident	0.19 (0.16–0.23)	0.37 (0.34–0.40)	0.51 (0.47–0.54)
Intern	0.16 (0.12–0.19)	0.38 (0.35–0.41)	0.61 (0.57–0.64)

Learning curve of interobserver agreements

Learning curve	*2D, κ*	*3D, κ*	*Print, κ*
Overall	0.04	0.01	0.01
Senior surgeon	0.03	0.08	0.06
Junior surgeon	0.16	0.05	0.04
Senior surgical resident	0.05	–0.09	–0.17
Junior surgical resident	–0.01	–0.01	0.16
Intern	0.05	0.08	–0.02

Difference in κ between first round and second round of observations.
2D, two-dimensional; 3D, three-dimensional; CI, confidence interval.

Table 2. Time to Classify 20 Acetabular Fracture Cases Per Modality

Time	2D	3D	Print	p
Overall, minutes (SD)†	27.59 (18.74)	10.77 (4.97)	9.25 (3.22)	0.000
Senior surgeon*	21.42 (7.61)	8.32 (3.49)	9.19 (2.5)	0.000
Junior surgeon*	30.14 (10.21)	10.64 (3.50)	10.20 (3.12)	0.000
Senior surgical resident*	28.30 (6.81)	14.47 (4.42)	10.07 (5.30)	0.000
Junior surgical resident*	21.43 (2.62)	9.19 (3.88)	9.63 (3.17)	0.000
Intern	38.41 (40.41)	11.55 (7.55)	7.18 (1.55)	0.096
p	0.578	0.311	0.607	

Note: One-way analysis of variance (ANOVA). *Post hoc* multiple comparisons Bonferroni.

†Difference between 2D CT and 3D CT/print: $p < 0.000$. Difference between 3D and print: $p = 1.000$.

*Difference between 2D CT and 3D CT/print: $p < 0.01$.

CT, computed tomography; SD, standard deviation.

and 0.51, respectively. Senior surgical residents obtained κ values of 0.17, 0.43, and 0.66 when viewed by X-ray/2D CT, 3D CT, and 3D printed models, respectively. The κ values of junior and senior surgeons were 0.18 and 0.33 when viewed by X-ray and 2D CT, 0.43 and 0.42 when viewed by 3D CT, and 0.56 and 0.59 when viewed by 3D printed models, respectively. In general, the 3D printed model κ values of all groups approached each other when compared with X-ray/2D CT and 3D CT (Table 1).

The overall κ values for interobserver agreement for the classification of 20 acetabular fracture cases were 0.19 (95% CI: 0.18–0.19) when only X-ray and 2D CT were viewed, 0.34 (95% CI: 0.33–0.35) when only 3D CT was viewed, and 0.47 (95% CI: 0.46–0.47) when only 3D printed models were viewed (Table 1).

The time to classify 20 cases of each modality was recorded (Table 2). Except for the interns, a significant time difference between X-ray/2D CT and 3D CT and 3D printed models was found for junior and senior surgical residents and junior and senior surgeons ($p < 0.001$). However, there was no significant time difference between 3D CT and 3D printed models ($p = 1.00$).

The same significant time difference was found when all observer groups were combined. No significant time difference was found between the groups of observers per modality: X-ray/2D CT ($p = 0.58$), 3D CT ($p = 0.31$), and 3D printed models ($p = 0.61$).

The potential learning curve for acetabular fractures is given in Table 1; it shows the difference in κ values between the first and second rounds (after 2 months) of measurement.

Junior surgeons obtained the best learning curve when only X-ray and 2D CT were viewed ($\kappa = 0.36$), whereas senior surgeons and interns both scored 0.08 higher when only 3D CT data were viewed. Junior surgical residents obtained the best learning curve when only 3D printed models were viewed ($\kappa = 0.67$). Overall, slightly higher κ values for X-ray/2D CT, 3D CT, and 3D printed models compared with the first classification round were found, at 0.23, 0.35, and 0.48, respectively.

The difference in time between the first and second rounds of observation to complete the sets of acetabular cases was recorded. Overall, observers needed less time to complete the second round of acetabular cases when compared with the first round (Table 3). Significant differences were found for all modalities: X-ray/2D CT ($p = 0.01$), 3D CT ($p = 0.00$), and 3D printed models ($p = 0.00$).

Surgical approach

Table 4 shows that junior surgeons obtained κ values of 0.04, 0.16, and 0.23 when viewing X-ray/2D CT, 3D CT, and 3D printed models, respectively. The κ values of senior surgeons were 0.26, 0.24, and 0.31 when viewing X-ray/2D CT, 3D CT, and 3D printed models, respectively.

The overall κ values for interobserver agreement for the surgical approach were only slight and fair for all modalities. The reassessment of agreement regarding the surgical approach is also shown in Table 4; it shows the difference in κ values between the first and second rounds of measurement. Senior surgeons slightly agreed more on 3D CT ($\kappa = 0.26$), whereas the junior surgeons slightly agreed more on 3D printing ($\kappa = 0.25$).

Positioning of the patient

Table 5 shows that both senior and junior surgeons agreed the most on the positioning of the patient with help of a 3D printed model, at $\kappa = 0.31$ and $\kappa = 0.28$, respectively. The overall κ values for interobserver agreement for positioning of the patient were fair on all modalities. The second round of observations did not show large improvements in the agreement.

Prone or lateral positioning could be the preference of the treating surgeon. To rule this out, both positions of the patient were taken together to calculate new interobserver agreement,

Table 3. Difference in Time Between First Round and Second Round of Observations

Difference	2D	p	3D	p	Print	p
Overall, minutes (SD)	−8.73 (−16.36)	0.013	−3.55 (−4.17)	0.000	−3.45 (−3.28)	0.000
Senior surgeon	−8.38 (−6.33)	0.013	−2.52 (−2.81)	0.056	−4.70 (−2.68)	0.004
Junior surgeon	−12.91 (−10.53)	0.091	−3.11) (−2.70)	0.105	−3.41 (−4.00)	0.129
Senior surgical resident	0.85 (−15.74)	0.910	−3.22 (−5.58)	0.267	−4.14 (−3.01)	0.037
Junior surgical resident	−3.23 (−5.48)	0.324	−4.13 (−2.63)	0.113	−3.38 (−2.34)	0.032
Intern	−19.84 (−29.60)	0.208	−5.36 (−6.44)	0.136	−1.10 (−4.28)	0.595

Paired-samples *t* test.

Table 4. Interobserver Agreements for the Surgical Approach

Surgical approach	*2D, κ (95% CI)*	*3D, κ (95% CI)*	*Print, κ (95% CI)*
Overall	0.16 (0.13 to 0.19)	0.23 (0.20–0.26)	0.30 (0.26–0.33)
Senior surgeon	0.26 (0.20 to 0.32)	0.24 (0.18–0.30)	0.31 (0.24–0.37)
Junior surgeon	0.04 (–0.02 to 0.11)	0.16 (0.09–0.23)	0.23 (—)
Learning curve of the surgical approach			
Learning curve	*2D, κ*	*3D, κ*	*Print, κ*
Overall	–0.01	–0.04	–0.03
Senior surgeon	–0.06	0.02	–0.06
Junior surgeon	–0.03	–0.11	0.02

Difference in κ between first round and second round of observations.

Table 5. Positioning of the Patient

Positioning	*2D, κ (95% CI)*	*3D, κ (95% CI)*	*Print, κ (95% CI)*
Overall	0.23 (0.19–0.27)	0.28 (0.24–0.31)	0.31 (0.27–0.34)
Senior surgeon	0.30 (0.23–0.36)	0.31 (0.24–0.37)	0.31 (0.25–0.37)
Junior surgeon	0.16 (0.06–0.25)	0.21 (0.11–0.30)	0.28 (0.18–0.38)
Positioning	*2D, κ*	*3D, κ*	*Print, κ*
Overall	0.09	0.01	0.07
Senior surgeon	0.05	0.06	0.07
Junior surgeon	0.04	–0.05	0.01

as given in Table 6. This table gives higher interobserver agreement than in Table 5, which gives the initial analysis.

Overall impressions of the observers

The opinions of all observers regarding the different classification modalities were structured and are given in Table 7. Observers found X-ray/2D CT to be most detailed. 3D CT was able to give a quick overview; however, this modality was not ''real 3D.'' 3D printed models gave a ''natural'' 3D view; however, small details were melted together.

Discussion

In contrast to previous studies about the role of 2D CT, 3D CT, and 3D printed models in classifying acetabular fractures, we also investigated the interobserver agreement regarding the surgical approach and the time needed to classify the acetabular fractures. This study shows the added value of 3D printed models in classifying acetabular fractures and evaluating the surgical approach. The highest κ values were obtained when acetabular fractures were classified with the usage of 3D printed models. Interns, residents, and junior surgeons showed greater improvement in agreement from X-ray/2D CT/3D reconstructions to 3D printing than the senior surgeons, with the greatest benefit from 3D printing found in interns. Moreover, a reduction in time to classify the acetabular fractures was seen when viewed by 3D printed models.

Classifying acetabular fractures

Several studies only investigated the role of 2D CT and 3D CT among different groups with varying levels of experience in classifying acetabular fractures.[5] The outcomes differed from those of our study due to a rapid change in the quality of CT data and improvement in high-resolution 3D images,[25] other medical specialists (radiologists), or less instructed observers, creating a greater chance of agreement.[6]

A comparison between 3D printed models and 3D CT was not found in the literature. All groups of observers benefited from 3D printed models when compared with 3D CT. A reason could be that 3D reconstructions are normally seen on a 2D screen, which gives no actual 3D view. On the one hand, it could be possible that the limitation in rotating the 3D reconstruction led to less understanding of the fracture patterns. On the other hand, even the most experienced surgeons obtained much higher κ values in 3D printing ($\kappa = 0.59$) than in 3D reconstructions ($\kappa = 0.42$). In our opinion, this finding confirms that 3D printing is superior than 3D reconstructions.

Only one study compared conventional diagnostics with 3D printing to classify acetabular fractures. We found lower κ values for senior and junior surgeons in our study than in the single former study.[19] It could be that we included more observers per subgroup, creating a greater chance of disagreement.

Preparation time and costs of a 3D print

In our opinion, 3D printed models should be ready quickly, ensuring enough time for decent surgical preparation. Our models were prepared in less than one-and-a-half days. Although acetabular fractures should be surgically treated as soon as possible to diminish fracture pain and stabilize the hip joint, as a result of concomitant injuries, patients are usually surgically treated within 1 week, ensuring enough time to prepare a 3D printed hemipelvis and decent surgical preparation. Taking into account the higher agreement for classification when compared with 2D CT and 3D reconstructions, the benefits outweigh the disadvantages of the extra time needed to prepare a 3D print.

Table 6. Positioning of the Patient: Preference of Lateral or Prone Combined

Positioning without preference	*2D, κ (95% CI)*	*3D, κ (95% CI)*	*Print, κ (95% CI)*
Overall	0.33 (0.28–0.38)	0.44 (0.39–0.48)	0.44 (0.40–0.49)
Senior surgeon	0.40 (0.32–0.48)	0.47 (0.39–0.55)	0.43 (0.35–0.51)
Junior surgeon	0.27 (0.15–0.40)	0.40 (0.28–0.52)	0.47 (0.35–0.59)

Table 7. Summarized Comments of All Observers on the Different Modalities

X-ray/2D CT	Most detailed, fissure fractures visible as well. However, the relevance of this finding is questioned.
3D CT	Quick overview. The model can only be turned one-way at the time. No actual 3D view, because the model is shown on a 2D screen.
3D printing	''Natural'' 3D view. The model can be rotated in all directions. Small details are melted together.

To make the 3D print process cost efficient, development and operating costs should be as low as possible. Our *Makerbot Replicator Z18 Printer* cost us €7900 ($8860). This investment refunded itself in <18 life-size hemipelvic models when we compare our 3D printing process with the outsourced production of 3D printed models.[19] We developed a robust and low-cost workflow that allows the creation and design of complex anatomic models using free open-source and in-hospital software, without the need for technical support. Other benefits of a basic in-hospital 3D printing laboratory are that DICOM files of patients do not have to be sent away by mail and that 3D printing will be accessible 24/7 instead of during office hours when managed by other parties.

Surgical approach and time needed to classify acetabular fractures

Although an improvement in agreement on surgical approach was seen with 3D printing, only slight and fair agreements were found on all modalities. The reason could be the preference of the surgeon. In our study, too many surgical approaches were available to obtain high κ values. Nevertheless, junior surgeons had the greatest benefit from 3D printed models for the type of surgical approach when compared with the senior surgeons.

The same trend in agreement was seen for the positioning of the patient. Although 3D printed models appeared to have the highest agreement, only slight and fair agreements were found. Junior surgeons had the greatest benefit from 3D printed models for the positioning of the patient when compared with senior surgeons. We hypothesized that prone or lateral positioning would be particularly likely to cause disagreement because of the personal preference of the surgeon. The reanalysis results yielded higher κ values, but these values are still not higher than moderate agreement. This finding indicates that acetabular surgery is still a more experienced-based surgery instead of evidence-based surgery.

Significant time reduction was seen when comparing X-ray/2D CT with the other modalities. However, no significant time difference was seen between 3D CT and 3D printed models. There is no need to scroll through images in both modalities. Taking into account the benefit of higher interobserver values for 3D printing, we prefer 3D printed models.

Definition of experienced observers

Beaulé *et al.*[4] divided surgeons into three groups with varying levels of experience and concluded that 2D CT was not essential for the classification of acetabular fractures. The definition of an ''experienced surgeon'' is not known and differs by country.[5–7,25] The Dutch Trauma Society (NVT) has set a minimum of 20 surgical treated acetabular and/or pelvic ring fractures per hospital annually to improve the trauma care and outcome of these severely injured patients.[26] In 2016, 42 patients presented themselves with an acetabular fracture (without associated pelvic ring fracture) in our level 1 trauma center. Twenty-two patients were surgically treated, distributed over two senior trauma surgeons, and both surgeons had >10 years of experience in treating acetabular fractures. It is interesting to note that our ''experienced surgeons'' seem to belong to ''less experienced'' according to the study of Beaulé *et al.*[4] This means that ''experienced'' is not a universal term and should be specified in each study.

Limitations

This study has some limitations. We did not set a ''gold standard'' for the classification of acetabular fractures. Currently, it is common to determine the gold standard by the intraoperative findings. However, this can be challenging in acetabular surgery, especially for fracture approaches without access to fracture lines on the other column. To the best of our knowledge, there has not been a study that reached good agreement (κ > 0.80) in the classification of acetabular fractures.[4–7] Therefore, the accuracy of the original diagnosis could be questioned.

Another limitation was the different quality of the CT scans. Because of the study's retrospective design, there was no consistent acetabular CT protocol. Although we think that the quality of the included CT scans was good enough, small differences in slice thickness or reconstruction filters were seen. All observers took the CT sets in the same format, equalizing the results. Furthermore, it could be possible that there are inaccuracies between the printed models and 2D/3D CT.[13] Although an earlier study showed that the accuracy of 3D printed models is mostly influenced by the scan parameters and not by the process of converting CT data into 3D prints,[27] observers noted melted details on the 3D printed models. These melted details make it difficult to identify fracture patterns sometimes and may cause lower κ values in the classification of acetabular fractures. However, we are not sure whether these melted fissure fractures are clinically relevant for surgical and conservative treatment. We do not think the agreement regarding the surgical approach and positioning of the patient was affected by these melted details. A new study is needed to investigate the accuracy of a 3D printed model compared with CT, 3D reconstructions and the human bone.

Two recent literature reviews analyzed all articles about 3D printing.[28,29]

There is a need for a randomized controlled trial to test several aspects of 3D printing in acetabular fractures, such as the cost effectiveness, reduced operation time and blood loss by prebending plates, decreased length of hospital stay, patient satisfaction, and health-related quality of life.

Conclusion

In conclusion, this study shows that 3D printing is of added value in understanding acetabular fractures. The implementation of 3D printed models in the trauma surgery training is recommended. Furthermore, 3D printed models can be used for teaching medical students.

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