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Surgical treatment of intra-articular distal radius fractures with the assistance of three-dimensional printing technique

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Abstract

Background: The aim of this study was to evaluate the effectiveness and safety of surgical treatment of intra-articular distal radius fractures (DRFs) with the assistance of three-dimensional (3D) printing technique.

Methods: Patients with intra-articular DRFs in our hospital from February 2017 to November 2018 were enrolled in this study, and were randomly assigned to 2 parallel groups to receive surgical treatment with the assistance of 3D printing technique or not. For patients in the 3D printing group, the surgical procedure was simulated with 3D physical model before surgery. Volar plate and K-wire fixation were performed in all patients. Patients in the 2 groups were compared in terms of intraoperative indexes and postoperative function.

Results: A total of 32 patients were included in our study. During surgery, mean operation time in the 3D model group was significantly lower than that in the routine group ($P<.001$). Besides, significantly less blood was lost in the 3D model group than that in the routine group ($P<.001$). Furthermore, the 3D model group had a significantly less times of intraoperative fluoroscopy than that in the routine group ($P=.002$). However, the 3D model group showed no significant difference in visual analog scale (VAS) score, the disabilities of the arm, shoulder, and hand (DASH) score, or active wrist range of motion (ROM) in comparison with the routine group ($P>.05$).

Conclusion: With the assistance of 3D printing technique, the operation time, amount of intraoperative bleeding, and times of intraoperative fluoroscopy can be reduced during the surgical treatment of intra-articular DRFs with volar plating and K-wire fixation. This technique is safe and effective, and is worth spreading in other orthopedic surgeries.

Abbreviations: 3D = three-dimensional, CT = computed tomography, DASH = the disabilities of the arm, shoulder, and hand, DRFs = distal radius fractures, ROM = active wrist range of motion, SD = standard deviation, VAS= visual analog scale.

Keywords: distal radius fracture, intra-articular, three-dimensional printing, volar locking plate

1. Introduction

Fractures of the distal radius are extremely common, which account for the largest portion of orthopedic fractures.[1] In 2007, Medicare cost 170 million dollar in distal radius fracture-related payments.[2] According to whether the fracture line involves the articular surface or not, distal radius fractures (DRFs) can be divided into extra-articular fractures and intra-articular fractures.[3] In recent years, people in large cities have had greater exposure to high-energy trauma, meanwhile the number of intra-articular fractures has increased significantly. For patients with extra-articular fractures, closed reduction and cast immobilization was the first choice.[4,5] As intra-articular DRFs often had fragments displacement >2 mm, and are commonly accompanied by multi-fragments in the articular surface, surgical treatment is required by most cases.[6]

Over the last decade, volar plating has become the best choice for many surgeons in the treatment of DRFs,[7] but volar locking plates alone may fail to stabilize small fragment as it is too distal and not connected to any larger fragments. On the other hand, although K-wire alone cannot stabilize the fracture tightly, but it could conveniently fix small fragment. The combination of volar plating and K-wire is a good choice for intra-articular DRFs, but preoperative or intraoperative planning for identification and fixation of fragments is necessary.[8]

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In recent years, with the in-depth application of computer-aided technology and three-dimensional (3D) printing technique in the field of orthopedics, great changes have taken place from virtual simulation to realistic simulation.[9,10] Through the 3D printing model, clinicians can optimize the surgical design and simulate surgery, which helps to reduce the operative complications and ensure a successful operation.[11–13]

As the reduction process of intra-articular DRFs requires accurate identification of the fragment and articular surface, we tried to use 3D printing technique for preoperative planning and surgery simulation. We compared 3D printing assisted surgery to the routine surgery, and aimed to verify the effectiveness and safety of this new method in the treatment of intra-articular DRFs.

2. Methods

2.1. General information

Patients with intra-articular DRFs in our hospital from February 2017 to November 2018 were enrolled in this study. Inclusion criteria were adult patients (between 18 years and 65 years) with intra-articular DRFs, including both simple and comminuted fractures, requiring volar plate and K-wire fixation. Exclusion criteria included a multiply injured patient, treatment beginning later than 7 days after injury, an open fracture, a previous fracture of the distal radius, accompanied by neurovascular injury, or lack of informed consent.

Patients were randomly assigned to 2 parallel groups, initially at a 1:1 ratio, to receive surgical treatment with the assistance of 3D printing technique or not. Randomization was carried out with use of sequentially numbered, opaque, sealed envelopes. Patients were blinded to the grouping results. All surgeries were performed by the same surgeon. The ethics committee of the Third Hospital of Hebei Medical University approved this research on December 11, 2016 (IRB-2016-12-02), and written informed consents were acquired from all patients.

2.2. Preoperative preparation

All patients were required to perform a 1.0 mm computed tomography (CT) scan (Germany Siemens Somatom Sensation 64) of both the injured and contralateral sides, and the data were kept in the DICOM format. For patients in the 3D printing group, the editing function of Mimisc18.0 (Materialise, Belgium) was used to design the 3D model. The design data were saved as STL format and sent to 3D printer, and the 3D physical fracture model was fabricated as exact 1:1 (Fig. 1).

According to the 3D physical fracture model and the mirrored contralateral model, the process of the operation was simulated, which including the sequence of reduction, the specific placement of the K-wire, the selection and pre-bending of the volar plate, and the placement of appropriate screws.

2.3. Surgical treatment

After brachial plexus anesthesia, the wrist was placed on the operating table. A pneumatic tourniquet was applied on the

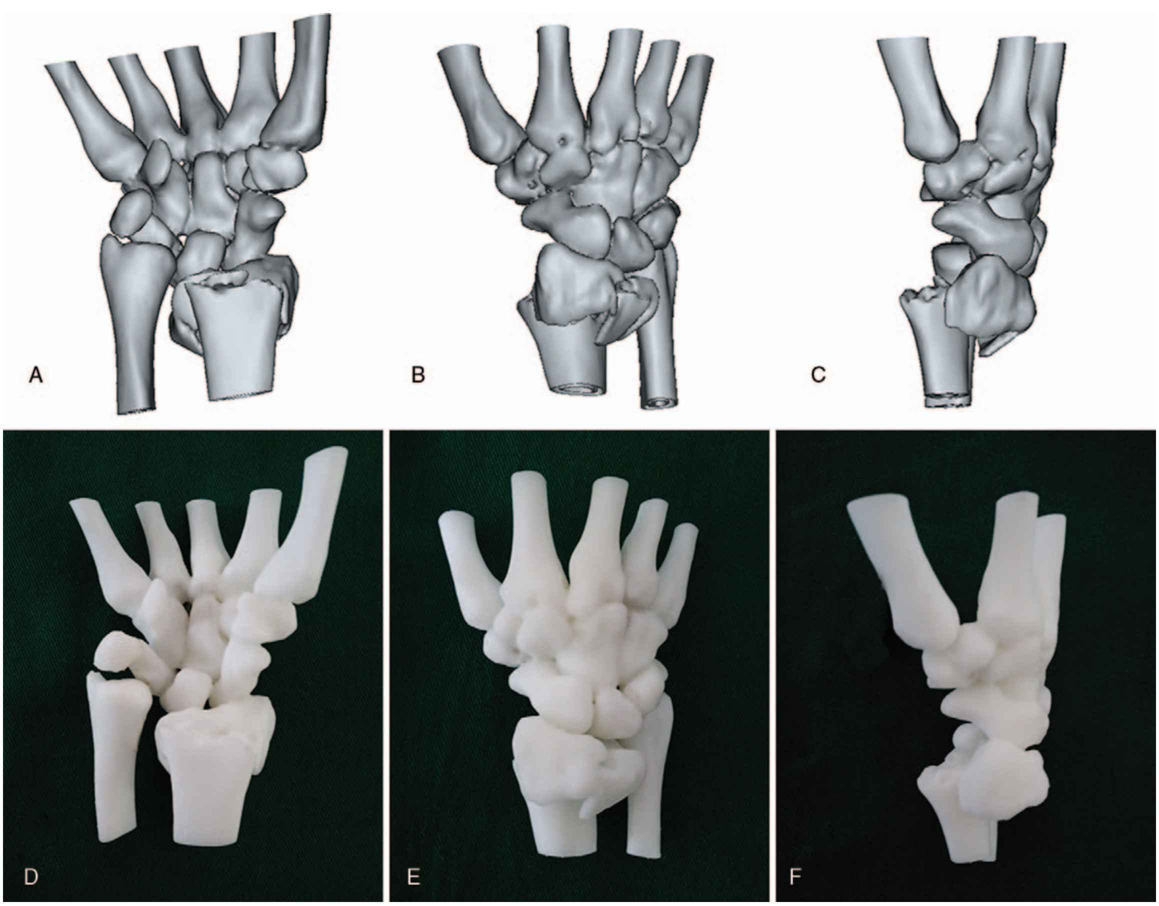

Figure 1. Images of the distal radius from different visual angle. A–C, the 3D digital model; D–F, the 3D printing model. 3D = three-dimensional.

upper arm and inflated at 250 mmHg. The incision was made between the flexor carpi radialis and radial artery. The pronator quadratus was cut off and elevated from the distal radius. After the fragment was identified and exposed with traction, the reduction was performed and fixed with K-wire first, and direct visualization and x-ray fluoroscopy confirmed adequate reduction. Then the volar plate was inserted into the fracture site and fixed with screws. The fixation was completed after intraoperative x-ray fluoroscopy displayed good reduction. Following saline irrigation, the pronator quadratus was repaired, and the wound was closed and dressed. After that, a volar brace was applied.

2.4. Postoperative treatment

The broad-spectrum antibiotics were applied for 24 hours after operation. The exercise of metacarpophalangeal joints and elbow joint begun the first day postoperatively. The volar brace was removed 1 month after surgery, and active and passive motion of the wrist were begun. Routine follow-up examinations were performed at 1-, 2-, 3-, and 6 months postoperatively. At each visit, patients were asked to perform x-ray tests. At the 6-month follow-up, additional clinical assessment was performed.

2.5. Evaluation indexes

Three values were recorded during surgery, including operation time, amount of intraoperative bleeding, and times of intraoperative fluoroscopy. Operation time was defined as the time from skin incision to suture. As no aspirator was used during surgery, intraoperative bleeding was calculated as the amount of liquid absorbed by gauze. We weighed the preoperative and postoperative gauze by electronic balance, and the difference was approximately equal to intraoperative bleeding. Times of intraoperative fluoroscopy were counted after incision and before closing the wound.

After surgery, the incidence of complications, such as superficial wound infection, deep wound infection, iatrogenic neurological symptoms, tendon damage, loss of reduction, and fixation failure were recorded in both groups.

We further analyzed the postoperative outcomes at the 6 months follow-up, including the visual analog scale (VAS) during wrist movement, the Disabilities of the Arm, Shoulder and Hand (DASH) score,[14] and active wrist range of motion (ROM). The VAS score was a numerical rating scale with 0 being no pain and 10 being the worst pain imaginable. Active wrist ROM included the following motions: flexion, extension, radial deviation, ulnar deviation, pronation, and supination.

2.6. Statistical analysis

Qualitative variables were summarized as numbers and percentages, and quantitative variables were summarized as mean ± standard deviation (SD). The chi-squared test or Fisher exact test were used for qualitative variables, and the independent sample *t* test or the Mann–Whitney *U* test was used for quantitative variables. *P* value <.05 was considered to be statistically significant. All of the data analyses were performed with the Statistical Package for Social Sciences software (version 18.0; SPSS Inc., Chicago, IL).

3. Results

A total of 32 patients were included in our study, including 19 male and 13 female patients, with mean age of 42.0 ± 5.9 years. There were 16 patients in each group. No significant differences in age, sex, and fracture types were observed between the 2 groups (Table 1). One patient in the routine group was lost at the 6 months follow-up. The clinical data of the other 31 patients were complete.

Table 1

The basic data of patients with intra-articular distal radius fractures.

	3D model group	Routine group	*P* value
Patients (n)	16	16	
Age, yr	41.1 ± 6.4	42.8 ± 5.1	.41
Gender			
Male	10	9	.72
Female	6	7	
Dominant extremity fracture			
Yes	7	6	.72
No	9	10	
AO classification			
Type B	4	5	.69
Type C	12	11	
Associated ulnar styloid process fracture			
Yes	3	5	.41
No	13	11	
VAS score	3.7 ± 1.3	4.2 ± 1.4	.30
DASH score	68.0 ± 9.6	71.5 ± 10.0	.32

DASH = the disabilities of the arm, shoulder, and hand, VAS = the visual analog scale.

The surgical data are shown in Table 2. Mean operation time in the 3D model group was 51.4 ± 6.8 minutes, which was significantly lower than that in the routine group (63.5 ± 5.9 minutes; $P < .001$). Besides, significantly less blood was lost in the 3D model group (52.3 ± 9.9 mL) than that in the routine group (74.2 ± 10.3 mL, $P < .001$). Furthermore, the 3D model group had a significantly less times of intraoperative fluoroscopy (4.2 ± 1.3 times) than that in the routine group (5.6 ± 1.1 times; $P = .002$).

The 3D model group showed no significant difference in VAS score, DASH score, or active wrist ROM in comparison with the routine group ($P > .05$, Table 3). One patient in the routine group experienced superficial wound infection, and one patient in each group showed loss of reduction, which required no surgical interference. No iatrogenic neurological symptoms or other complications were observed in both groups.

4. Discussion

The current study revealed that the operation time, amount of intraoperative bleeding, and times of intraoperative fluoroscopy in the 3D model group were significantly less in comparison with the routine group. Meanwhile, the incidence of postoperative complications in the 3D model group was not increased. The

Table 2

The comparison of intraoperative parameters in patients with intra-articular distal radius fractures.

	3D model group	Routine group	*P* value
Patients (n)	16	16	
Operation time, min	51.4 ± 6.8	63.5 ± 5.9	<.001
Intraoperative bleeding, ml	52.3 ± 9.9	74.2 ± 10.3	<.001
Times of intraoperative fluoroscopy (n)	4.2 ± 1.3	5.6 ± 1.1	.002

Table 3

The comparison of function and active wrist ROM in patients with distal radius fractures at 6 months follow-up.

	3D model group	Routine group	*P* value
Patients (n)	16	15	
VAS score	0.9±0.2	0.9±0.3	.91
DASH score	23.8±8.1	24.5±7.0	.80
Active wrist ROM			
Flexion, °	69.3±5.5	68.4±7.2	.70
Extension, °	61.2±9.8	62.1±11.1	.81
Radial deviation, °	24.8±5.1	23.2±4.9	.38
Ulnar deviation, °	22.0±6.9	19.8±5.8	.35
Pronation, °	78.0±14.5	78.4±13.1	.94
Supination, °	82.0±12.1	79.9±16.3	.69

3D=three-dimensional, DASH=the disabilities of the arm, shoulder, and hand, ROM=active wrist range of motion, VAS=visual analog scale.

above results indicate that the 3D printing technique can facilitate surgical treatment of intra-articular DRFs without increase adverse events. The main reason is that the 3D printing technique can help to optimize the surgical procedure before operation and improve the accuracy and safety of K-wire implantation, which simplify the surgical procedures and save more time.[13]

The distal radius has an irregular bone shape and provides articular surfaces for wrist joint. Surgical treatment can better reduce the anatomical structure of distal radius, and is a preferred choice for clinicians, but surgical treatment of intra-articular DRFs is confronted with an apparent difficult, that is the restoration of fragment displacement in the articular surface.[15] According to Schreiner et al,[16] surgeons are limited by uncertain factors such as the angle of the fracture line or overlapping fracture patches, which often leads to long operation time, excessive blood loss, and uneven joint surface, resulting in increased incidence of postoperative complications. For surgeons who tried to improve the quality of surgery and to facilitate the procedures, multi-angle and all-round observation is necessary before specific surgical plan is developed.

With the development of CT technique, clinicians can conduct 3D image analysis for complex fractures. Although 3D CT volume roaming technology plus coronal and sagittal planes reconstructions provide good modeling for preoperative planning, its application is usually restricted by complicated fractures and it is impossible to simulate the surgical process practically or conveniently. In recent years, 3D printing technology has been widely used in the medical field. This technology became feasible and accessible in orthopedic surgery as it allows surgeons to combine imagination with practical 1:1 solid model of real bone.[17] Before surgery, surgeons can observe the fracture line, broken bone fragments, and their positional relation using a 3D model, and simulate the surgical operation to determine the type and size of the implants for internal fixation. Therefore, 3D printing technology can make the diagnosis as well as the surgical procedure more directly visible, realistic, and specific, helping to plan a complex surgical procedure and allowing a simulation of a personalized surgery to be performed.[18] Although software preoperative planning could also simulate reduction and fixation, but it is not practical and has limited ability in choosing suitable internal plate for patients.

Intra-articular fractures of the distal radius are commonly accompanied by multi-fragments in the articular surface.[19] If not identified and recognized preoperatively or intraoperatively, volar locking plates alone may fail to stabilize the fragments as they are too distal and not connected to any larger fragments. The combination of volar plating and K-wire is a good choice for intra-articular DRFs.[8] This procedure uses the volar plating to fix major fracture fragments and applied K-wire fixation to capture and stabilize small fracture fragments. Thus, preoperative planning for identification and fixation of fragments is necessary.

Three-dimensional printing technique is a bridge between CT images and realistic clinical operation.[20] Prior to a complex surgery, surgeons can observe the anatomical structure of the fracture using a 3D printed prototype, and simulate surgery to determine the size of the implants for internal fixation. With the assistance of 3D printing technology, surgeons know exactly how to reset the displacement, how to fix small fragment with K-wire, and what length of screws and size of plates are required, which significantly reduce operation time, blood loss, and times of intraoperative fluoroscopy. After surgery, patients get good postoperative function and wrist ROM without increased complications.

An apparent limitation of this study is that the sample size is small and all surgeries were performed by a single surgeon. The results remain to be tested by more surgical teams in some larger populations, which will be the focus of our future research. In addition, there are still several other limitations when applying 3D printing technique. First of all, high-quality CT images are necessary because accurate data are required, but the 3D printing process uses software to deal with the data, which cannot eliminate errors and will certainly decrease authenticity of the model. Secondly, the data creating the model of bones and soft tissues are derived from different images. Combining all these structures into one model is of great value, but we cannot meet that requirement yet. Finally, printing a solid model of the bone may require several hours, which limit the widespread of this technology in emergency surgery.

In summary, with the assistance of 3D printing technique, the operation time, amount of intraoperative bleeding, and times of intraoperative fluoroscopy can be reduced during the surgical treatment of intra-articular DRFs with volar plating and K-wire fixation. The main reason is that the 3D printing technology can optimize the surgical plan. This technique is safe and effective, and is worth spreading in other orthopedic surgeries.

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