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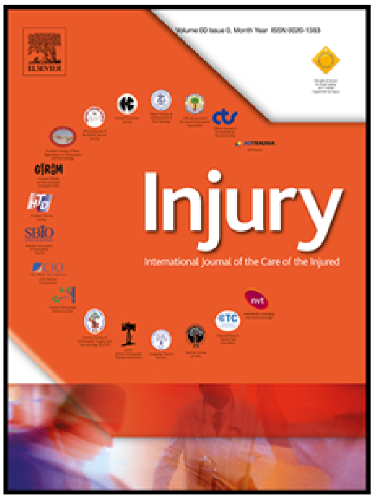

Evaluation of the computer-assisted virtual surgical technology in preoperative planning for distal femoral fracture

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PII: S0020-1383(19)30693-X
DOI: https://doi.org/10.1016/j.injury.2019.10.085
Reference: JINJ 8427

To appear in: *Injury*

Accepted date: 27 October 2019

HIGHLIGHTS

- The computer-assisted virtual surgical technology could aid clinicians rapidly achieve precise and reliable preoperative planning for distal femoral fractures.
- Compared with conventional method, the technique provided results of less operative time, lower blood loss, fewer fluoroscopic images and shorter hospital stays.
- Satisfying clinical and radiographic outcomes were obtained after treating distal femoral fractures aided by the technique.

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Abstract

Background: The application of computer-assisted virtual surgical technology in preoperative planning for distal femoral fractures has been rarely presented. This study aimed to evaluate the intra-operative realization of this technology and the clinical outcomes based on it for distal femoral fractures.

Methods: Between February 2014 and May 2017, 32 patients with distal femoral fractures treated by open reduction and internal fixation were included and divided into 2 groups on the basis of preoperative planning methods: conventional (n = 17) and virtual surgical (n = 15). The time required for virtual segmentation, reduction, and fixation of the fracture fragments in virtual surgical group were analyzed. Operation time, intra-operative blood loss, times of fluoroscopy during operation and days of hospital stay in two groups were compared. Postoperative functional outcomes were assessed using the Knee Society Score (KSS), Short Form-36 (SF-36) scoring systems, and visual analogue scale (VAS) for pain.

Results: Mean total planning time for 33-A, 33-B, and 33-C fractures in virtual surgical group were 43.0 ± 1.7, 23.0 ± 1.3, and 51.4 ± 3.7min, respectively. Compared with the conventional group, Patients in virtual surgical group had lower blood loss, fewer fluoroscopic images, less operative time, and shorter days of hospital stay (p<0.05). No significant difference could detected in the KSS, SF-36, or VAS scores between the two groups at the final follow-up (p>0.05).

Conclusions: Computer-assisted virtual surgical technology could rapidly complete

surgical treatment protocol, improve operative efficiency, and provide satisfying clinical and radiographic outcomes for distal femoral fractures.

Keywords distal femoral fractures; computer-assisted virtual surgical technology; preoperative planning; three-dimensional imaging

Introduction

Distal femoral fractures have recently been reported to account for nearly 1% of all fractures and about 3% to 6% of all femoral fractures. In the elderly population, most of these fractures are related to low-energy injuries. Moreover, the incidence likely will increase as the population ages [1, 2]. The major goal of operative treatment of distal femoral fractures is anatomic reduction and high primary stability of internal fixation, which is hard to achieve in unstable or displaced complex fractures, especially in osteopenic bone [3, 4]. What is more, the outcomes of surgical management sometimes are unsatisfactory [5-7]. These outcomes are associated with imprecise preoperative assessment of fracture characteristics, imperfect intraoperative fracture reduction, and improper implant choices [8-10]. Thus, effective preoperative planning is proposed, as it may reduce the risks associated with inadequate assessment and improve the results of surgical treatment [8, 10-12].

Over the years, classical tracing paper or simple measurements on an image viewer for X-ray or CT scans were generally used for the preoperative planning of fracture management. The benefits of the conventional method are simplicity, familiarity, low cost, and less exposure to radiation [13, 14]. However, for a complicated three-dimensional (3D) fracture structure, it is difficult to visualize which direction to reduce the fragments, and which screw size to choose prior to surgery, according to the information presented on the conventional two-dimensional (2D) images. Currently, as digital medicine and imaging modalities gather pace, 3D printing technology and computer-assisted virtual surgical technology based on computed tomography (CT) post-processing have become new and promising approaches for preoperative planning of orthopedic surgery. [10-13, 15]. A 3D printed bone model provides surgeons with a direct and interactive display of fracture characteristics. In addition, it can be used to rehearse the surgery procedures in vitro such as simulating fracture reduction and reasonable placement of internal fixation [9, 10, 12, 16]. However, the technology is difficult to be widely applied for the reason that procedures for printing, segmentation, and immobilization of the 3D model are high-cost, time-consuming, tedious, and complex [8]. The application of computer-assisted virtual surgery technology makes multi-level and multi-angle evaluation of the fracture plane come true. With the aid of it, surgeons can perform virtual surgery, including reducing fracture fragments and selecting appropriate internal fixation devices [11, 13]. In the past, the application of virtual surgery required clinicians to have basic knowledge of computer image processing and use related softwares proficiently. With the further development of computer technology, an effective computer-assisted virtual surgical system has been developed and proved to be more convenient and efficient in comparison with 3D printing technology in preoperative planning for displaced 3 and 4-part fractures of the proximal humerus [8, 11, 13]. The novel system also provided better clinical outcomes than conventional methods for treatment of humeral fractures [8, 11, 17].

To our best knowledge, the computer-assisted virtual surgical technology is rarely used in the management of distal femoral fractures. It is not clear what the technique would contribute to the treatment of such fractures. We hypothesized that this novel technology would be beneficial to make surgical treatment protocol, raise operative efficiency, and improve clinical outcome for distal femoral fractures. The purposes of this study were (1) to present the procedure of virtual surgical technology in preoperative planning for distal femoral fractures, (2) to compare the intra-operative realization of preoperative planning between the new method and the traditional one, and (3) to determine the difference of clinical outcome after treating these fractures based on two methods.

Methods

Study population

We retrospectively reviewed the clinical and imaging data of patients with distal femoral fractures who were treated with locking plates and open reduction and internal fixation. We searched medical records and a medical imaging database and identified 35 consecutive patients with such fractures who were treated from February 2014 to May 2017. According to inclusion and exclusion criteria (Table 1), 2 patients with ipsilateral tibial and fibular fractures and 1 patient with inadequate follow-up were excluded (Figure 1). Finally, 32 patients with distal femoral fractures (13 men and 19 women) and a mean age of 55.7 years (range, 18 to 87 years) constituted the study population. The left side was involved in 14 cases and the right side in 18 cases. All fractures were classified according to the AO/OTA system [18], and the classifications were confirmed intraoperatively. Eleven patients had 33-A, 10 patients had 33-B, and 11 patients had 33-C fracture. The institutional review board approved this study, and written informed consent was obtained.

All patients had radiographs of the injured limb made preoperatively and at each follow-up visit. Follow-up was conducted at 3, 6, and 12 months postoperatively and yearly thereafter. CT scans were performed preoperatively and at 12 months postoperatively. All CT images were obtained using a 16-detector spiral CT scanner (GE Light Speed CT) and saved in Digital Imaging and Communication in Medicine (DICOM 3.0) format (.dcm).

Preoperative Evaluation and Planning

All the patients were divided into 2 groups: the conventional group and the virtual surgical group. The preoperative planning for conventional group was performed in the clinical setting from February 2014 to January 2016, and computer-assisted virtual surgical technology was added to the preoperative planning between February 2016 and May 2017. All preoperative plans were conducted by the senior surgeon (Y.C.).

In the conventional group, preoperative planning was based on radiography and CT images in combination with the surgeon's experience, which was the regular method for most orthopaedic surgeons.

In the virtual surgical group, Thin-slice CT axial images of all subjects were input into the computer-assisted virtual surgical system (Super Image Orthopedics Edition 1.0; Cybermed Ltd, Shanghai, China) [19]. The software was developed using Java language on NetBeans (Sun Microsystems, Inc., Santa Clara, CA) and OpenInventor (Mercury Computer Systems/TGS Unit, San Diego, CA) platforms. Two- and three-dimensional images of the fracture zone of the distal femur were reconstructed by multiple planar reconstruction (MPR) and volume rendering technology (VRT), respectively. For analyzing injury details, the operative planning steps were as follows (Figure 2).

Fracture fragments segmentation

Three-dimensional images of the distal femoral fractures were reconstructed by a surface shaded display (SSD) algorithm with a reconstruction interval of 0.625 mm. The density threshold was 150 H, and the automatic removal of the image size was <500 mm^3. The 3D interactive and automatic segmentation technology, a technique which introduced intelligent human computer interaction and combined methods of 3D topological narrow segmentation technique, was applied to distinguish all fracture fragments in the 3D SSD image. Then different colors could be assigned to the different fracture fragments (Figure 3).

Simulated reduction

Simulated reduction was obtained using a semi-automatic fragment reconstruction approach in the 3D SSD image. Fracture fragments were reduced automatically by manually selecting three characteristic points on each fragment. When the corresponding characteristic points were selected, the fragments were dragged and rotated into correct anatomical positions automatically. Occasionally, the users had to do some additional fine adjustment for the positions (Figure 4).

Internal fixation device selection and simulated implantation

The appropriate plates were chosen from the internal fixation devices database of the system with the advanced AO principles and guidelines for clinical application of the locking plate [20]. Implantation was simulated using a semiautomatic approach in the 3D SSD image. The screws to be used were inserted into the plate. The accurate length of the screws used was recorded (Figure 5).

Operative technique

According to fracture types, reasonable body positions and surgical approaches were selected. The approach was lateral, medial or sequential combined. When the joint was involved, an anterolateral parapatellar arthrotomy was chosen to reduce and fix joint fragments first. After intraspinal or general anesthesia, the skin and subcutaneous tissues were opened layer by layer until the fracture fragments was exposed clearly. Then, the fracture was reduced manually and temporarily fixed with Kirschner wires. The reduction was confirmed by the C-arm machine. For 33-B fractures, the screw directions were perpendicular to the major fracture line and along the longest axis of the femoral condyle. For 33-A and 33-C fractures, the plate was inserted along the femoral shaft from distally to proximally and temporarily secured with Kirschner wires. Then, screws were applied to the condyle and finally to the shaft. After fixation, the accuracy of reduction and implant placement was evaluated by direct visualization and fluoroscopically. In the virtual surgical group, appropriate internal fixation devices based on pre-measured data were chosen to fix fractures. However, in the conventional group, the length of screws and plates had to be measure during the operation. All surgical procedures were performed by the senior surgeon (Y.C.), who had 19 years of clinical experience in treating fractures of distal femur.

After the surgery, the limb was raised on pillows for the purpose of subsiding soft tissue swelling around the wound. Continuous passive motion (CPM) and physiotherapy with passive motion were also encouraged soon after surgery. At 10 days postoperatively, patients were recommend to do knee-joint flexion and extension exercises. Partial weight bearing was allowed at 8 weeks postoperatively, and full weight bearing was allowed until the confirmation of radiographic union.

Outcome evaluation

The operative time, intraoperative blood loss and fluoroscopy times were recorded for both groups. The functional outcomes were evaluated at the time of the 18-month follow-up with the Knee Society Score (KSS), a visual analogue scale (VAS) for pain, and Short Form-36 (SF-36) physical component summary (PCS) scoring systems and range of motion (knee-joint flexion). VAS was scored by the patient from 0 to 10, where 0 is defined as no pain, and 10 as the worst pain possible. The SF-36 PCS outcome was normalized to a 100-point scale ([score – 10] × 100/20). Postoperative complications were also recorded.

Statistical analysis

Patient and fracture characteristics were compared between two groups using the following statistical tests: the Mann–Whitney's U test for age, BMI, injury-surgery interval days, Fisher's exact test to compare gender, diabetes, smoking, side involved, Pearson Chi-square for education, surgical approach and AO/OTA classification. Clinical outcomes in two groups were tested by the Mann–Whitney's U method or the Kruskal–Wallis method except complication rates, which was tested by the Fisher's exact method. The time needed of the computer-assisted virtual surgical technology in preoperative planning for three types of fracture was also done using the Kruskal–Wallis test. Significance was defined as $p < 0.05$. Statistical analysis was performed with SPSS software (version 19.0; IBM).

Results

Computer-assisted preoperative planning

In the virtual surgical group, 3D reconstruction, segmentation, and simulated reduction and fixation were achieved in all cases. The time needed for each stage (including segmentation, simulated reduction and fixation of fractures), and total spent time, are shown in Figure 6. In 33-A group and 33-C group, reducing the fracture fragments took the most time. While for 33-B group, fixing the fracture fragments was the most time-consuming step. Differences at all stages were significant ($P<0.01$). The mean total time required for planning in 33-A, 33-B, and 33-C groups were 43.0 ± 1.7 minutes (range, 40.9 to 45.6 minutes), 23.7 ± 1.3 minutes (range, 21.6 to 27.10 minutes), and 51.4 ± 3.7minutes (range, 46.8 to 56.4 minutes), respectively. When compared 33-A group with 33-B group, the difference of total time between groups was significant ($P<0.05$). When compared 33-C group with 33-B group, the difference between groups was also significant ($P<0.01$). Whereas if compared 33-A group with 33-C group, there was no significant between groups ($P = 0.251$). These results revealed that the more complex the fracture was, the more time was required for preoperative planning.

Besides, the planned size of the plate and the length of the screws were used in all the actual operations. The high consistency between the surgical procedure and the computer-assisted preoperative planning was showed on postoperative radiographs (Figure 5).

Clinical Data

Of 32 patients, 17 (53.1%) were in the conventional group and 15 (46.9%) in the virtual surgical group. The demographic and baseline characteristics are shown in Table 2. The mean follow-up period was 24.2 months (range, 18 to 33 months) in the conventional group, and 24.7 months (range, 18 to 33 months) in the virtual surgical group (p = 0.374). The mean time from injury to surgery was 2.9 ± 1.2 days (range, 0 to 7 days) in the conventional group, and 2.7 ± 1.0 days (range, 0 to 7 days) in the virtual surgical group (p = 0.794).

Functional and Radiographic Outcomes

Less operative time, lower blood loss, fewer fluoroscopic images and shorter hospital stays were seen in the virtual surgical group than in the conventional group ($p < 0.05$ for all) (Table 3). Especially for 33-A and 33-C fractures, the operative time, blood loss and fluoroscopic images in the virtual surgical group are over to the conventional group (Figure 7). As for the length of stay, the virtual surgical group is better than the conventional group in patients with 33-A fractures (Figure 7). However, in the evaluation of postoperative functional recovery, no significant difference were observed for the KSS, VAS, SF-36 PCS score, and range of motion of the injured limb in two groups though higher scores obtained in virtual surgical group (Table 3).

Complications

One patient in the conventional group, an 81-year-old woman with a type of 33-C fracture, had implant failure, and she underwent a second operation (Table 3). There was no significant difference between the two groups with regard to postoperative complication rate (Table 3).

Discussion

It has long been recognized that preoperative planning is valuable in orthopedic surgery. Nowadays, with the increase of technical complexity of procedures and equipment, its significance has become more obvious. Accordingly, the methods of preoperative planning for orthopedic surgery emerge in endlessly. Among them, 3D printing technology and computer-assisted virtual surgical technology are the two main advanced ways [8, 10-13, 15]. Either of these two methods has been reported to offer advantages in shorting operative time, diminishing intraoperative bleeding, reducing intraoperative fluoroscopy images and obtaining better functional outcomes for the management of complex acetabular and humeral fractures [8, 10, 11, 21]. However, the process for surgical planning based on 3D printing technology is time-consuming and high-cost [8, 9]. Yiting Lou et al [9] reported that a few days were required for planning in the treatment of tibial plateau fractures assisted by 3D printing technology. Yanxi Chen et al [8] reported a similar experience that approximately 30 hours were took for proximal humeral fractures. Regarding the time cost in preoperative planning, virtual surgery technology seems to have an advantage over 3D printing technology. By using a virtual 3D software, Suero et al [22] achieved preoperative planning of tibial plateau fractures in an average of 3 hours. As to extremely complex acetabular fractures, Fornaro et al [23] completed the segmentation only in an average of two hours. In our study, the average total time required for planning of 33-A, 33-B, and 33-C fractures were only 43.0 ± 1.7, 23.0 ± 1.3, and 51.4 ± 3.7min, respectively. The total planning time is related to the complexity of the fracture. More severe fractures required a longer planning time. As to the three simulation stages of segmentation, reduction and fixation of complex fractures, such as types of 33-A and 33-C, the step took most time is reduction rather than segmentation. But for 33-B fractures, the process of segmentation still occupies more time than reduction, which may be due to the fact that these fractures are relatively simple and easily reductive. Compared with virtual 3D softwares mentioned above, the system used in our study further shortened the time required for preoperative planning of complex fractures, especially for the part of simulated segmentation (up to almost 15.4 min in the AO C3.3 fracture case). Some softwares only based on edge or region segmentation method [22-24], which need manually extract the regions of interest from two-dimensional images slice by slice. The processes are time-consuming and frequently not applicable in clinical routine. The 3D interactive and automatic segmentation technique used in this study enables clinicians who do not have professional experience in image processing to perform fragment segmentation in a short time. Moreover, interaction process could be completed with simple and effective control (e.g., mouse click mode) on a personal computer. Based on above advantages, the segmentation of each fracture fragment could be accelerated under the service of the technique.

In this study, differences between the traditional surgery and the surgery assisted by virtual surgical technology in the treatment of distal femoral fractures were determined as well. Patients with 33-A and 33-C fractures in the virtual group had a shorter operative time, lower blood loss, and fewer fluoroscopic images than those in the conventional group. These advantages may be explained by the fact that the reconstruction process provides surgeons with more detailed observation and intuitive understanding of fracture characteristics, which allows surgeons to confirm the details of the fracture, determine the morphology of the fracture line and the number and location of fragments, examine the collapse and comminution of the articular surface, verify the potential existence of bone defects, and determine whether bone grafting is required. Moreover, suitable internal implants were obtained on the basis of simulated surgery. These methods are helpful to accurately restore the fragments and select the appropriate internal implants during the operation. Besides, in the virtual surgical group， patients with 33-A fractures were observed to have less hospitalization days. The superiority may have resulted from the fact that reasonable surgical approaches have been chosen after detailed observation of fracture features, which reduced unnecessary stripping of soft tissue during operation, minimized occurrence of postoperative wound complications, and accelerated the healing of wound. Finally, the length of stay in the hospital was shortened. For the patients with type 33-C fractures in two groups, because of the injury of knee joint, the implementation of postoperative rehabilitation training was affected, and the postoperative recovery was relatively slow in a short period of time, which may lead to no significant difference in hospitalization time between both groups. As regard to the patients with type 33-B fractures in these groups, there were no significant difference in many aspects, which indicated that the amount of new information gained in simple fractures may not merit the time invested in preoperative planning. In terms of functional outcomes, an unexpected result was that no significant difference could be detected between the two groups. It is possible that all surgical procedures were completed by the surgeon with rich clinical experience and most of the fractures in both groups had satisfactory reduction and stable fixation, which ensured good clinical outcomes and generated only a little difference in the scores of functional evaluation. In our future work, we will replicate the present study to test this conjecture with more surgeons with different skill levels.

In addition, there are several other advantages for using the technique in the management of distal femoral fractures. On the one hand, surgeons can make a more detailed informative preoperative discussion with patients about the treatment and expected results of the surgery, so as to reduce patients' misunderstandings and create a harmonious doctor-patient relationship. On the other hand, it saved money for some patients because of shortening hospitalization time. What’s more, no extra treatment costs were incurred for the patients, since preoperative planning in the virtual surgical group was performed using a computer-aided orthopaedic clinical research platform developed by our research team.

Some limitations in this study should be noted. First, CT scans are necessary for such kind of planning, which adds additional radiation exposure, although it was minimized by the current technology [25-27]. Second, some differences were found between preoperative planning and intraoperative implementation. The surgical simulation was performed in a situation without soft tissues so that plates and screws could be placed in any direction. Actually, predetermined position of implants may be affected by certain factors such as intraoperative exposure difficulties, unclear operation field, neurovascular variations, occult fracture lines, and so on. Therefore, elements like these should be considered before performing a surgical procedure. Third, the software used in this study was in Chinese, thus limiting the reproducibility of this technique. Similarly, availability and access to virtual planning software are also restricted. Additional weaknesses of this study were its retrospective and nonrandomized nature and the relatively small sample size. There was potential for chronological bias as both groups were done in different time frame. Further research must be done in a larger randomized prospective study. Finally, the duration of stay in our hospital system may not be relevant to other treatment environments around the world.

Conclusion

The results of this study confirmed that the computer-assisted virtual surgical technology was able to aid clinicians rapidly achieve precise and reliable preoperative planning for distal femoral fractures. Compared with conventional method, it is more efficient to use this novel technique, providing shorter operative time, lower blood loss, and fewer fluoroscopic images. More than that, the technology showed satisfying clinical and radiographic outcomes in treating distal femoral fractures. Our study suggest a reference for clinicians to select a rational preoperative plan for distal femoral fractures.

References

1. Court-Brown, C.M. and B. Caesar, Epidemiology of adult fractures: A review. Injury, 2006. **37**(8): p. 691-7.
2. Martinet, O., et al., The epidemiology of fractures of the distal femur. Injury, 2000. **31 Suppl 3**: p. C62-3.
3. Landis, J.R. and G.G. Koch, The measurement of observer agreement for categorical data. Biometrics, 1977. **33**(1): p. 159-74.
4. Sanders, R., et al., Double-plating of comminuted, unstable fractures of the distal part of the femur. J Bone Joint Surg Am, 1991. **73**(3): p. 341-6.
5. Henderson, C.E., et al., 2010 mid-America Orthopaedic Association Physician in Training Award: healing complications are common after locked plating for distal femur fractures. Clin Orthop Relat Res, 2011. **469**(6): p. 1757-65.
6. Hoffmann, M.F., et al., Clinical outcomes of locked plating of distal femoral fractures in a retrospective cohort. J Orthop Surg Res, 2013. **8**: p. 43.
7. Zlowodzki, M., et al., Operative treatment of acute distal femur fractures: systematic review of 2 comparative studies and 45 case series (1989 to 2005). J Orthop Trauma, 2006. **20**(5): p. 366-71.
8. Chen, Y., et al., Computer-Assisted Virtual Surgical Technology Versus Three-Dimensional Printing Technology in Preoperative Planning for

Displaced Three and Four-Part Fractures of the Proximal End of the Humerus. J Bone Joint Surg Am, 2018. **100**(22): p. 1960-1968.
9. Lou, Y., et al., Comparison of traditional surgery and surgery assisted by three dimensional printing technology in the treatment of tibial plateau fractures. Int Orthop, 2017. **41**(9): p. 1875-1880.
10. Zeng, C., et al., A combination of three-dimensional printing and computer-assisted virtual surgical procedure for preoperative planning of acetabular fracture reduction. Injury, 2016. **47**(10): p. 2223-2227.
11. Chen, Y., et al., Novel computer-assisted preoperative planning system for humeral shaft fractures: report of 43 cases. Int J Med Robot, 2015. **11**(2): p. 109-19.
12. Victor, J. and A. Premanathan, Virtual 3D planning and patient specific surgical guides for osteotomies around the knee: a feasibility and proof-of-concept study. Bone Joint J, 2013. **95-B**(11 Suppl A): p. 153-8.
13. Yoshii, Y., et al., Reproducibility of three dimensional digital preoperative planning for the osteosynthesis of distal radius fractures. J Orthop Res, 2017. **35**(12): p. 2646-2651.
14. Choplin, R.H., J.M. Boehme, 2nd, and C.D. Maynard, Picture archiving and communication systems: an overview. Radiographics, 1992. **12**(1): p. 127-9.
15. Brown, G.A., et al., Rapid prototyping: the future of trauma surgery? J Bone Joint Surg Am, 2003. **85-A Suppl 4**: p. 49-55.
16. Mitsouras, D., et al., Medical 3D Printing for the Radiologist. Radiographics, 2015. **35**(7): p. 1965-88.
17. Chen, Y., et al., Computer-assisted preoperative planning for proximal humeral fractures by minimally invasive plate osteosynthesis. Chin Med J (Engl), 2014. **127**(18): p. 3278-85.
18. Müller, M.E., The comprehensive classification of fractures of long bones. 1990, Berlin ; New York: Springer-Verlag. xiii, 201 p.
19. Jia, X.Y., et al., Postoperative Evaluation of Reduction Loss in Proximal Humeral Fractures: A Comparison of Plain Radiographs and Computed Tomography. Orthop Surg, 2017. **9**(2): p. 167-173.
20. Gautier, E. and C. Sommer, Guidelines for the clinical application of the LCP. Injury, 2003. **34 Suppl 2**: p. B63-76.
21. You, W., et al., Application of 3D printing technology on the treatment of complex proximal humeral fractures (Neer3-part and 4-part) in old people. Orthop Traumatol Surg Res, 2016. **102**(7): p. 897-903.
22. Suero, E.M., et al., Use of a virtual 3D software for planning of tibial plateau fracture reconstruction. Injury, 2010. **41**(6): p. 589-91.
23. Fornaro, J., et al., An interactive surgical planning tool for acetabular fractures: initial results. J Orthop Surg Res, 2010. **5**: p. 50.
24. Kim, S., et al., Automatic segmentation of supraspinatus from MRI by internal shape fitting and autocorrection. Comput Methods Programs Biomed, 2017. **140**: p. 165-174.
25. Boone, J.M., et al., Radiation exposure from CT scans: how to close our

knowledge gaps, monitor and safeguard exposure--proceedings and recommendations of the Radiation Dose Summit, sponsored by NIBIB, February 24-25, 2011. Radiology, 2012. **265**(2): p. 544-54.
26. Goodman, D.M., Initiatives focus on limiting radiation exposure to patients during CT scans. JAMA, 2013. **309**(7): p. 647-8.
27. Huda, W., A radiation exposure index for CT. Radiat Prot Dosimetry, 2013. **157**(2): p. 172-80.

Figure Legends

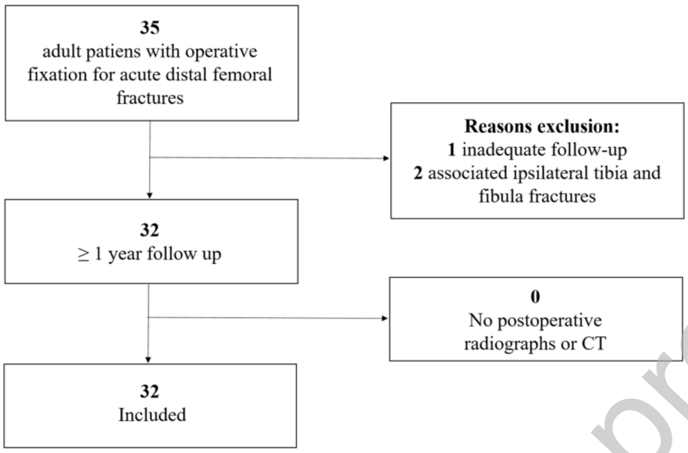

Figure. 1 Flow diagram of included and excluded patients.

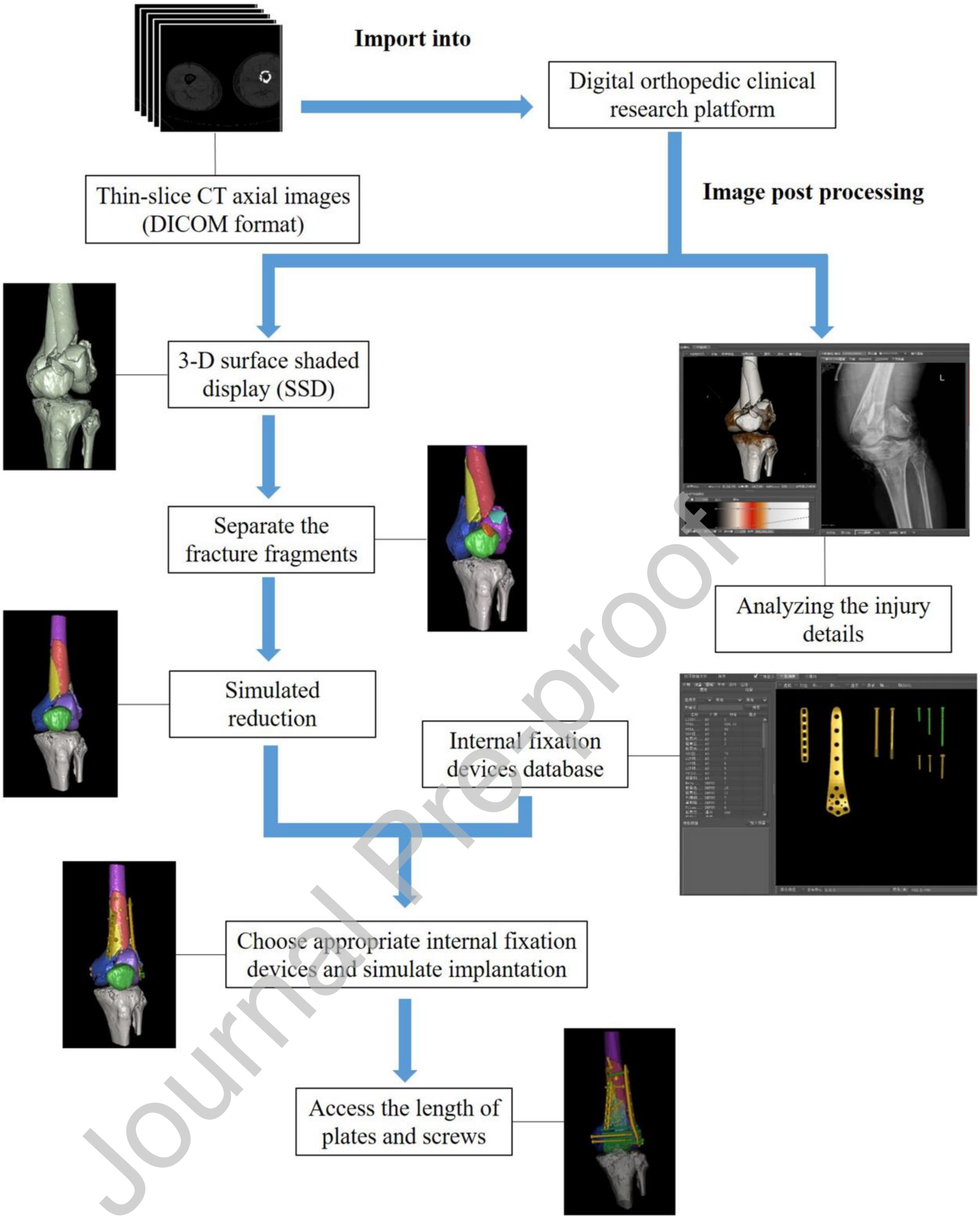

Figure. 2 Study flow diagram of computer-assisted virtual surgical technology in preoperative planning for distal femoral fractures.

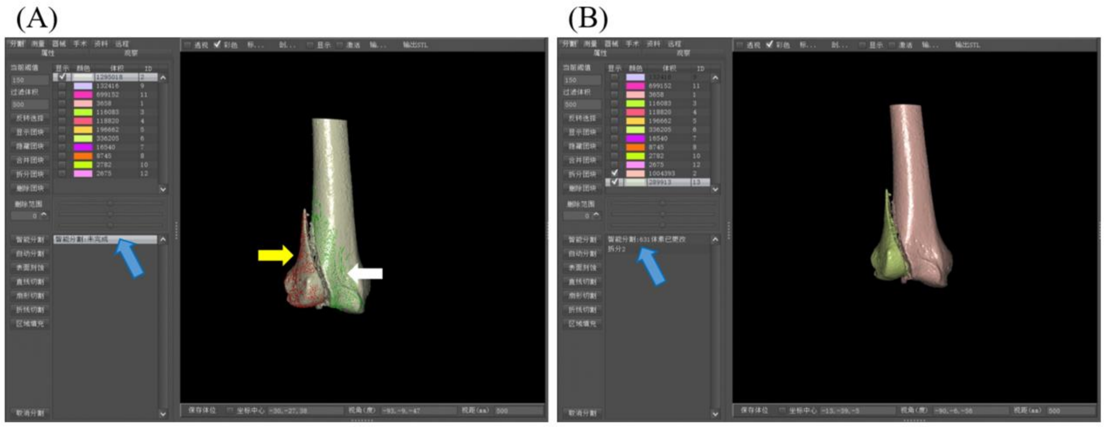

Figure. 3 Three-dimensional segmentation for the 3D SSD image of the distal femoral fractures. (A) The distal femoral fractures first appear as a whole and the same color identification. Then, the two separated fracture fragments were labeled green (white arrow) and red (yellow arrow) respectively by the 3-D interactive and automatic segmentation technology (blue arrow) in a user manual operation. (B) After the 'Enter key' was clicked, the software segmentation processing was started. The segmentation of fracture fragments was finished, and the 631 voxels were removed (blue arrow).

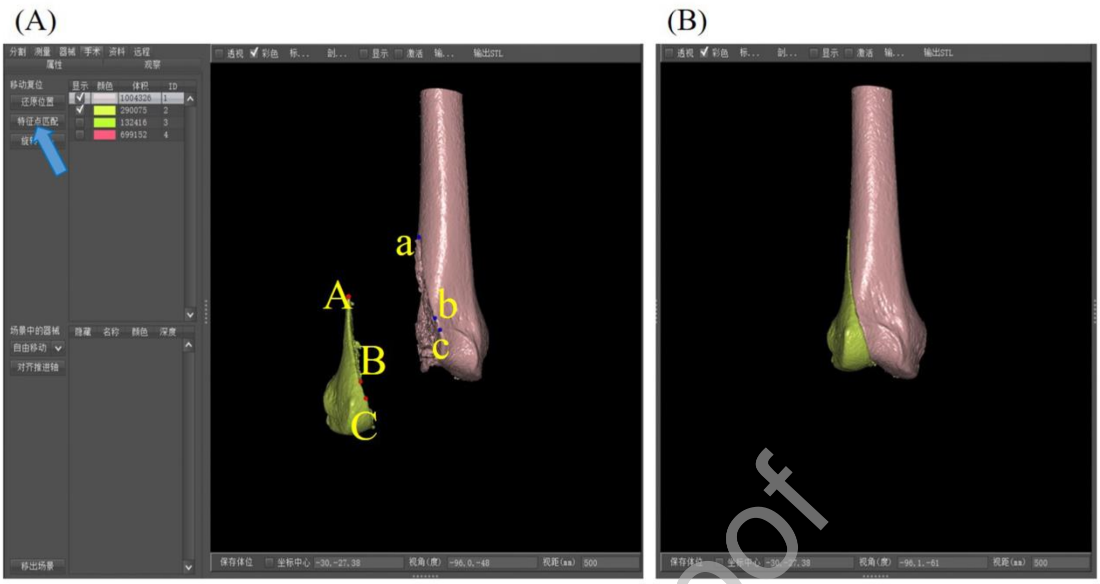

Figure. 4 (A, B) The virtual reduction was simulated by clicking 'the key of sign three characteristic points match (blue arrow)' through the manual operation according to the one to one anatomy relationship between the medial femoral condyle (point A, B and C) and the distal femoral shaft (point a, b and c). And bones were matched into correct anatomical positions automatically.

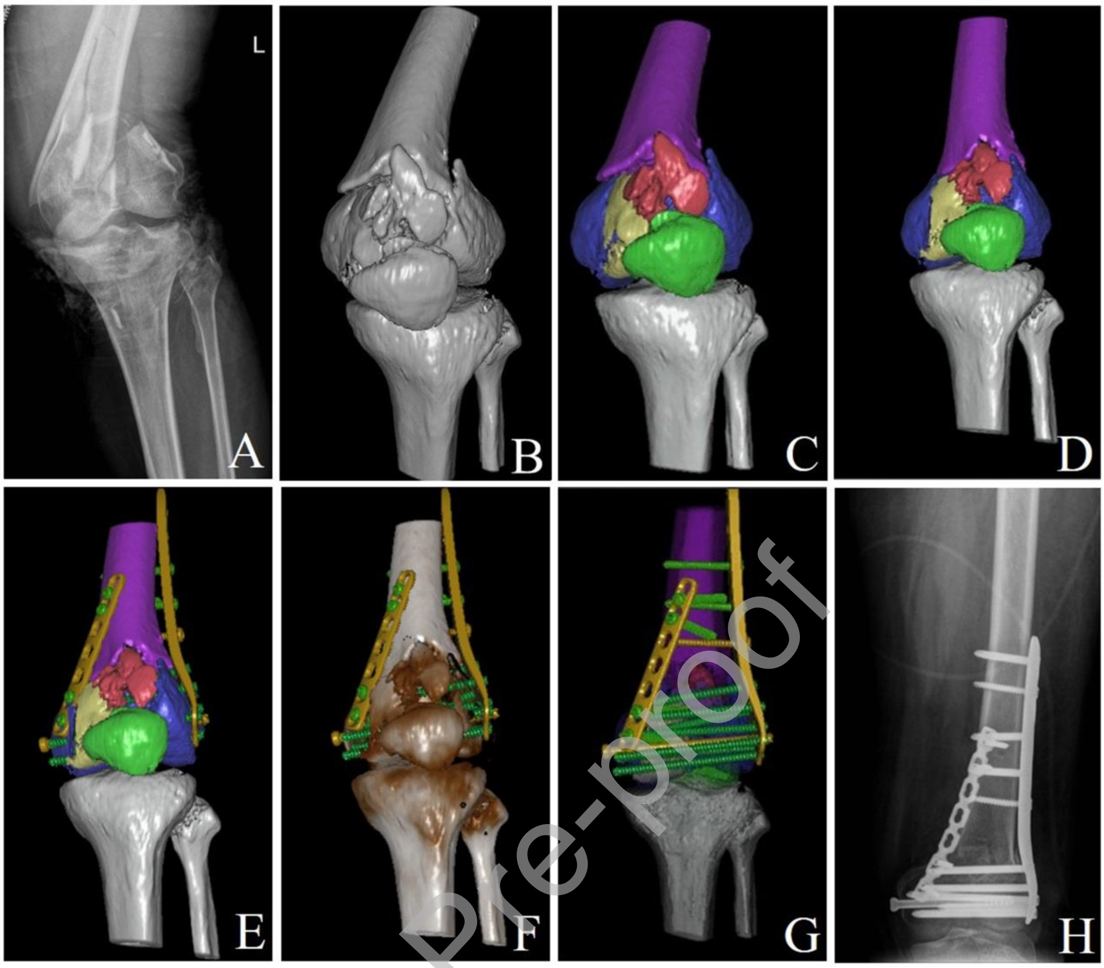

Figure. 5 Application of computer-assisted virtual surgical technology in preoperative planning for distal femoral fractures. (A, B) Lateral radiograph and 3D image of a 41-year-old man who was injured in a car accident with a left-sided multiplanar comminuted C3-type fracture. (C) The distal femur marked with different colors after segmentation of the fracture fragments. (D, E, and F) Proper internal fixation devices were placed (E) after simulation of the fracture reduction (D) and presented by 3D VR image (F). (G) The size of the plate and the length of the screws were assessed in the perspective mode. (H) Postoperative radiograph showing the high consistency between the surgical procedure and the preoperative planning.

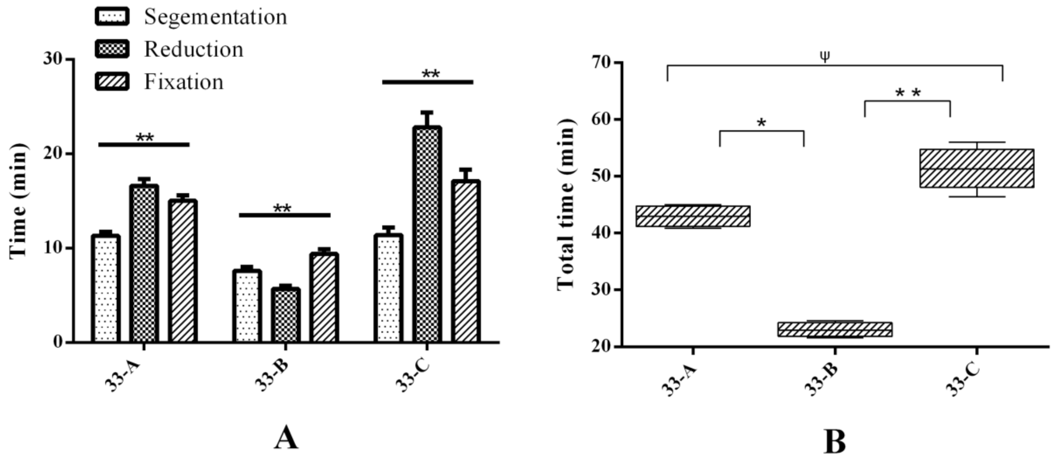

Figure. 6 The chart demonstrates the time needed for preoperative planning for three types of fractures in different stages. (A) Values are expressed as mean (bars) and SD (error bars). (B) The box shows the upper, lower quartile, and the median, the whiskers show the upper and lower limits. $^{*}P$ < 0 .05, $^{**}P$ < 0 .01, $^{\psi}P$ > 0.05.

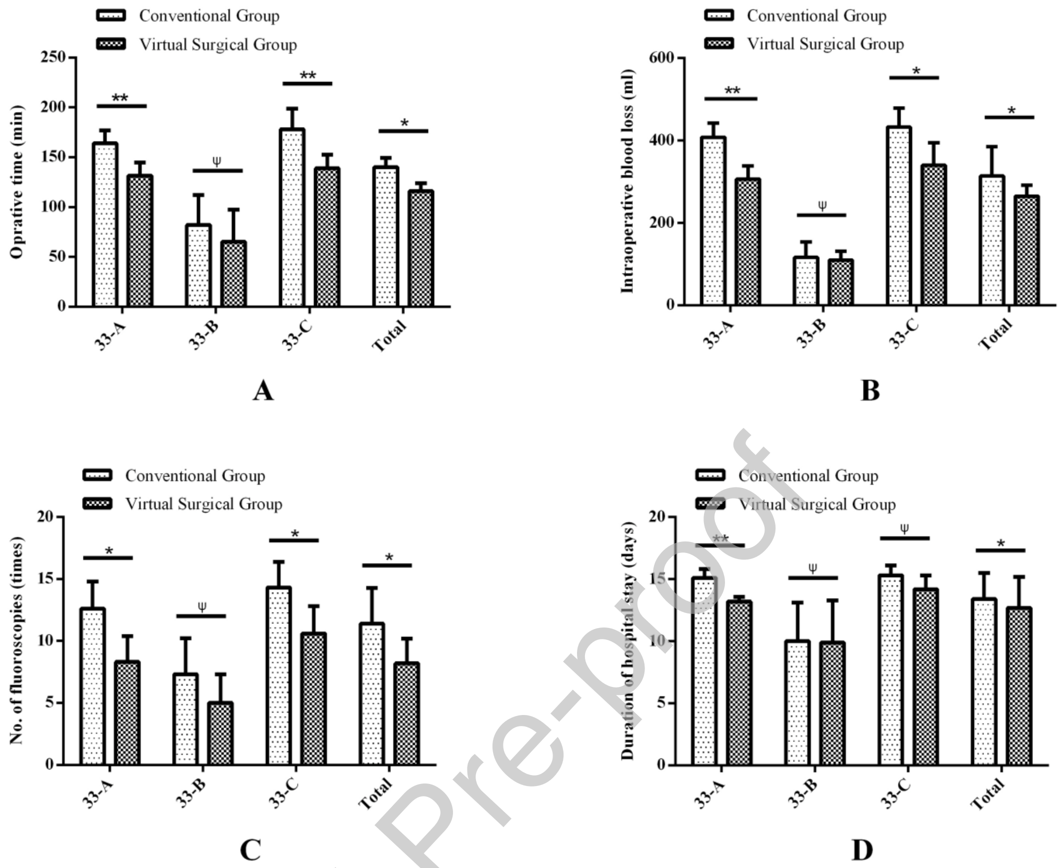

Figure. 7 Histograms of different metrics for three types of fractures in the two study groups. Values are expressed as mean (bars) and SD (error bars). $^{*}P$ < 0 .05, $^{**}P$ < 0 .01, $^{\psi}P$ > 0.05.

Table 1. Study criteria

Item	Description
Inclusion criteria	1. Closed distal femoral fractures that were displaced 33-A, 33-B, or 33-C according to the AO/OTA classification systems
	2. Fracture less than 3 weeks old
	3. Without neurologic injuries
	4. Single side injured
	5. Informed consent before preoperative planning
Exclusion criteria	1. Undisplaced fractures
	2. Multiple trauma
	3. Severe dementia (unable to follow postoperative recommendations)
	4. Pathological fractures
	5. Open fractures
	6. Ipsilateral fractures of the tibia and fibula

Table 2. Patient demographics and fracture characteristics.

Variables	Conventional Group (N = 17)	Virtual Surgical Group (N = 15)	P Value
Gender†			0.833
Male	7 (41.2)	6 (40.0)	
Female	10 (58.8)	9 (60.0)	
Age* *(yr)*	55.0 (18-87)	56.4 (20-86)	0.710
BMI§*(kg/m ^{2})*	24.8 ± 1.2	24.9 ± 0.9	0.786
Education†			0.978
Primary school	9 (52.9)	8 (53.3)	
Junior high school	5 (29.4)	4 (26.7)	
Senior high school or above	3 (17.7)	3 (20.0)	
Diabetes†	2 (11.8)	2 (13.3)	0.849
Smoking status†	4 (23.5)	3 (20.0)	0.576
Mechanism of injury†			0.922
Traffic accident	12 (70.6)	11 (73.4)	
Fall from height	4 (23.5)	2 (13.3)	
Other	1 (5.9)	2 (13.3)	
AO/OTA classification†			0.459
33-A	5 (29.4)	6 (40.0)	
33-B	6 (35.3)	4 (26.7)	
33-C	6 (35.3)	5 (33.3)	
Side involved†			0.517
Left	7 (41.2)	7 (46.7)	
Right	10 (58.8)	8 (53.3)	
Injury-surgery interval§ *(days)*	2.9 ± 1.2	2.7 ± 1.0	0.794
Surgical approach†			0.276
Lateral	9 (53.0)	9 (60.1)	
Medial	3 (17.6)	2 (13.3)	
Combined lateral and medial	3 (17.6)	2 (13.3)	
Anterolateral	2 (11.8)	2 (13.3)	

†The values are given as the number, with the percentage in parentheses. *The values are given as the mean, with the range in parentheses. §The values are given as the mean and the standard deviation. BMI = body mass index.

Table 3. Clinical outcomes in different groups.

Variables	Conventional Group (N = 17)	Virtual Surgical Group (N = 15)	P Value
Operative time† *(min)*	140 ± 9.3	116 ± 8.1	<0.05
Intraop. blood loss† *(mL)*	314 ± 71.7	265.3 ± 26.3	<0.05
No. of fluoroscopies†	11.4 ± 2.9	8.2 ± 2.0	<0.05
Duration of hospital stay† *(days)*	13.4 ± 2.1	12.7 ± 2.5	<0.05
Complication rate *(no. [%])*	1 (5.9)	0 (0.0)	0.794
VAS for pain† *(points)*	1.9 ± 0.3	1.6 ± 0.7	0.261
Knee society score† *(points)*	164.1 ± 3.42	167.3 ± 2.65	0.076
Range of motion† *(deg)*	119.8 ± 14.5	124.2 ± 8.1	0.655
SF-36 PCS† *(points)*	81± 13.3	88.0 ± 10.1	0.766

†The values are given as the mean and the standard deviation. VAS = visual analogue scale. SF-36 PCS = physical component summary score.

Conflict of Interest Statement

The authors declare that they have no conflict of interest in this study.