Computerized Virtual Surgery Planning for ORIF of Proximal Humeral Fractures

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The authors evaluated the effectiveness of computerized virtual planning for open reduction and internal fixation (ORIF) of proximal humeral fractures. Between June 2011 and July 2013, a total of 46 patients with proximal humeral fractures were included in the current study. Preoperatively, fracture data were obtained via computed tomography (CT) reconstruction. Based on the dataset obtained from CT scanning, the 3-dimensional model of fractures was constructed and virtual segmentation, restoration, and internal fixation were performed. All eligible cases were treated by ORIF with locking plates. Intraoperatively, operative time, blood loss, and fluoroscope frequency were recorded. Postoperatively, the curative effect was evaluated by quality of fracture restoration reconstruction and plate position. In addition, fracture healing time and complications were recorded in the follow-up period. Average operative time was 85.6 minutes, and intraoperative blood loss ranged from 60 to 150 mL. Postoperatively, 1 patient experienced avascular necrosis, and no cases of screw penetration or screw loosening were observed. The coincidence rate of plate position was 91.3% according to height and 95.7% based on the position of the intertubercular sulcus and greater tuberosity. At the end of the follow-up period, mean shoulder function score was 83.9 (range, 58-96). Eighty-seven percent of patients had an excellent or good outcome. Computerized virtual planning facilitated ORIF and showed good results for patients with complex proximal humeral fractures. It may be a favorable option for treating fractures of the proximal humerus.

Proximal humeral fractures at the upper end of the humerus are common fractures in people of all ages. In younger individuals, they often result from high-energy trauma and a fall from a height. However, in older people with osteoporosis, a simple fall can result in a fracture of this region. It is reported that proximal humeral fractures account for approximately 5% of all fractures and 45% of all humeral fractures, and their incidence is increasing.

Great advances have been made in the treatment of proximal humeral fractures; however, the treatment of complex fractures remains controversial. Recently, there is a trend toward treating complex fractures with stable systems, including plates and intramedullary nails, especially in older individuals. Open reduction and internal fixation (ORIF) with a locking plate has been widely used in the treatment of proximal humeral fractures and is associated with a loss of reduction, screw loosening, and osteonecrosis. Three-dimensional (3-D) technology has been developed to provide a virtual locking system for improved outcomes of ORIF.

The authors of the current study prospectively analyzed the use of 3-D reconstruction technology to treat patients with proximal humeral fractures. A total of 46 patients with proximal humeral fractures underwent ORIF between June 2011 and July 2013. Preoperatively, a 3-D model of each fracture was obtained using Superimage version 1.0 software (Cybermed, Shanghai, China). The goal of this study was to evaluate the effect of computerized virtual surgery planning on ORIF for proximal humeral fractures.

Materials and Methods

Patients

Patients diagnosed with proximal humeral fractures and treated with ORIF between June 2011 and July 2013 at the authors’ institution were included in this study. Fractures were confirmed to be traumatic multipart fractures according to the Neer classification system. Patients with pathologic and old fractures and those presenting with sequelae of cerebral infarction and paraplegia were excluded from the study. All patients provided informed consent, and approval was obtained from the Medical Research Ethics Committee.

A total of 46 patients (20 males and 26 females) were included in the study. Mean patient age was 61 years (range, 31-77 years). All patients were diagnosed with unilateral fractures, 22 of which were in the right humerus and 24 of which were in the left humerus. Mechanism of injury was a stumble in 31 patients, a traffic accident in 9, and a fall in 6. According to the Neer classification, 24 fractures were 2-part fractures, 17 were 3-part fractures, and 5 were 4-part fractures.

Preoperatively, basic fracture data were obtained via computed tomography (CT) reconstruction. All patients were treated with ORIF within 6 to 120 hours of injury.

Three-dimensional Model Reconstruction

Digital Imaging and Communications in Medicine (DICOM) datasets obtained via CT scanning were imported into Superimage software, and 3-D models of the proximal humeral fractures were created using the quick surface reconstruction function of Superimage software (Figures 1A-B).

Virtual Segmentation and Restoration of Fractures

Using the intelligent segmentation function of Superimage software, the 3-D model of each proximal humeral fracture was automatically segmented according to the main fracture fragments (Figures 1C-D). Strong adhesion present at fracture-block interfaces may lead to the failure of automatic partitioning that can be prevented by the manual etching of the fracture aperture. After virtual formation of independent fracture-block units, restoration of the fracture blocks was performed by removing the fracture fragments. Then the corrected anatomical morphology of the proximal humerus was obtained (Figures 1E-F).

Virtual Internal Fixation With Locking Plate

With the application of instrumental implantation function of Superimage software, a virtual model was created for implant evaluation. From the instrument library, the anatomical locking plate for each proximal humerus was selected for virtual surgery. The plate was placed on the surface of the proximal humerus in the 3-D model with a focus on height, position, and joint degree between bone surface and locking plate. Then appropriate-length screws were implanted into the humeral head and shaft with the perspective and length measurement function of Superimage software (Figures 1G-H).

Surgery

After general anesthesia or brachial plexus anesthesia was administered, each patient was placed in a beach-chair position. An incision was made by a deltopectoral approach, avoiding injury to the cephalic vein. The tendon of the long head of the biceps, greater and lesser tuberosity, and intertubercular sulcus of the humerus were identified, and the soft tissue and periosteum around the fracture were protected to avoid injury.

According to the computerized virtual surgical plan, rebuilding the integrity of the proximal humerus was performed through traction, rotation, stretching the shaft, and prying the humeral head. The reconstructed proximal humerus was temporarily fixed with Kirschner needles (Figures 2A-B). After correct restoration was confirmed under C-arm fluoroscopy,
the appropriate locking plate corresponding with the computerized virtual plan was used to fix the head and tuberosity fragments to the shaft (Figures 2C-F). The plate was placed at 2 to 4 mm behind the intertubercular sulcus and 5 to 8 mm from the greater tuberosity. Then, at least 5 screws were inserted into the humeral head at a distance of 5 mm from the articular surface. The humeral shaft was fixed with at least 2 locking screws. The greater tuberosity and lesser tuberosity were sutured through the holes of the locking plate.

**Postoperative Care**

Postoperatively, all patients were treated with standardized rehabilitation. A sling was used to maintain fixation for the first 2 weeks postoperatively, and antibiotics were administrated to prevent infection for 1 to 2 days. Passive-motion exercises, pendulum exercises, and range of motion were initiated on postoperative day 1. Anteflexion and external rotation exercises were allowed on postoperative day 3. After 6 weeks, active shoulder exercises were encouraged. After 12 weeks, gradual weight training was allowed for the fractured limb.

**Curative Effect Evaluation**

Operative time, blood loss, and fluoroscopy frequency were recorded intraoperatively. Radiographs were obtained immediately postoperatively. The quality of fracture restoration (collodiaphyseal angle), reconstruction, and plate position were evaluated by Image-Pro Plus version 5.0 software (Media Cybernetics, Rockville, Maryland). A collodiaphyseal angle of 125° to 140°, a plate 2 to 4 mm behind the intertubercular sulcus and 5 to 8 mm below the greater tuberosity, and a plate orientation corresponding to the proximal humeral axis (<5°) were considered to agree with the computerized virtual planning (Figure 3).

In the follow-up period, fracture healing time was evaluated on radiographs.
and complications were recorded, including infection, screw penetration, bone nonunion, subacromial impingement syndrome, humeral head necrosis, and fixation failure. Shoulder function was evaluated by a scoring system described by Constant and Murley. Four parameters were assessed: pain (15 points), activities of daily living (20 points), range of motion (40 points), and deltoid power (25 points), for a total possible score of 100 points. Subjective assessments of pain and activities of daily living were based on patient feedback. Objective assessments of range of motion and shoulder power were made by physicians. Shoulder function was evaluated based on final scores as follows: >86=good; 71 to 85=mild; 56 to 70=moderate; <55=poor.

RESULTS

Average operative time was 85.6 minutes (range, 72-115 minutes). Average fluoroscopy frequency was 7.3 times per patient (range, 4-11 times). Mean blood loss was 98.3 mL (range, 60-150 mL). Radiographs showed that 43 patients had a collodiaphyseal angle of 125° to 140°, 2 patients had a collodiaphyseal angle greater than 140°, and 1 patient had a collodiaphyseal angle less than 125°. The coincidence rate of plate position was 91.3% according to height and 95.7% based on the position of the intertubercular sulcus and greater tuberosity. The coincidence rate of the proximal humeral axis was 93.5%, and 3 patients had an angle error ranging from 5° to 10°.

All patients were followed for a minimum of 6 months (mean, 13 months [range, 6-24 months]). Mean fracture union time was 12.3 weeks (range, 10-16 weeks). Postoperatively, one patient experienced avascular necrosis of the humeral head. There were no cases of infection, screw penetration, fixation failure, or other complications. At the end of the follow-up period, mean Constant-Murley shoulder function score was 83.9 points (range, 58-96 points). The number of patients with good, mild, and moderate shoulder function was 28, 12, and 6, respectively. Eighty-seven percent of patients had an excellent or good outcome.

Figure 2: Obverse (A) and side (B) views of the reconstructed proximal humerus temporarily fixed with Kirschner needles. Obverse (C) and side (D) views of the locking plate fixation intraoperatively. Obverse (E) and thorax (F) views of the left shoulder joint postoperatively.
Proximal humeral fractures are common injuries with significant morbidity among older people. Palvanen et al\textsuperscript{11} reported that among people aged 60 years or older, the age-specific incidence of fracture increased 13.7\% with a 1-year age increase. It was speculated that the number of fractures in elderly people would triple in 2030.\textsuperscript{11} Operative treatment for displaced and complex fractures of the proximal humerus is one of the most difficult problems in orthopedic shoulder surgery.\textsuperscript{12} The development of locking plate technology has expanded the clinical application of ORIF. However, reports suggest that the complication rate resulting from ORIF ranges from 9.7\% to 39\% and includes screw penetration, fixation failure, implant fracture, and deep infection.\textsuperscript{13,14} Except for complex proximal humeral fractures, accurate preoperative assessment of fragment displacement and internal fixation quality play key roles in successful joint restoration.\textsuperscript{15}

The current authors used a computer-assisted approach to virtually plan ORIF surgery in 46 patients with complex proximal humeral fractures. Other than one case of avascular necrosis, there were no complications of infection, screw penetration, or fixation failure. At final follow-up, mean Constant-Murley shoulder function score was 83.9 points (range, 58–96 points), and the rate of excellent and good outcomes was 87\%. A recent study of 82 patients with 3- or 4-part proximal humeral fractures indicated that the average duration of general ORIF surgery was 98 minutes and the average blood loss was 200 mL, which shows that computerized virtual planning may have an advantage in reducing operative time and blood loss.\textsuperscript{16} Regarding shoulder function assessment, average Constant-Murley score was 72.6±13.2 points according to Sun et al\textsuperscript{16} and 72 points according to Brunner et al,\textsuperscript{17} both of which are lower than the average score of 83.9 points seen in the current study.

Complications are common in patients treated with ORIF. As outlined in a previous study, 52 (34\%) of 155 patients encountered complications during 1-year follow-up.\textsuperscript{18} Another study reported that the complication rate in patients undergoing ORIF was 11.8\% (8 cases in 68 patients).\textsuperscript{16} The complications were mainly associated with incorrect surgical technique, screw penetration, screw loosening, soft tissue infections, and avascular necrosis.\textsuperscript{16} Recent evidence shows that 29\% of patients underwent reoperation attributed to numerous complications.\textsuperscript{19} It has been reported that screw penetration is one of the most common complications, occurring in 17\% of humeral fractures treated with ORIF. A previous study showed that 42\% of complications in patients with humeral fractures resulted from screw penetration of the humeral head.\textsuperscript{20}

In the current study, 1 (2.2\%) patient of 46 experienced avascular necrosis, but no screw-related complications occurred. In the process of virtual internal fixation, the position and length of the screw were evaluated, which reduced the rate of screw penetration and screw loosening.

As outlined in previous studies, accurate preoperative analysis of the fracture pattern, implants, and internal fixation method is critical to the outcome of complex fractures treatment.\textsuperscript{21,22} Anatomical restoration plays a key role in offering excellent outcomes for patients with proximal humeral fractures.\textsuperscript{22} The current study showed good outcomes of ORIF with the application of computerized virtual planning. The size and shape of the fracture fragment, the orientation of the fracture line, and the degree of fracture displacement were clearly determined on the 3-D reconstruction and virtual segmentation. Postoperative radiographs showed that the fracture restoration rate was 93.5\% according to the collodiaphyseal angle. Although the collodiaphyseal angle in 3 patients was beyond the range of 125° to 140°, there was no varus or valgus displacement of the humeral head.

The locking plates used in this study have the advantages of an anatomic design, the presence of suture holes, and high torsional stability. Proper plate position ensures the accurate location and trajectory for screws and plays a key role in the fixation and stability of the structure. This study’s results showed that the coincidence rate of plate position was 91.3\% according to height and 95.7\% based on the position of the intertubercular sulcus and greater tuberosity. The coincidence

\textbf{DISCUSSION}

Figure 3: Postoperative computed tomography scan showing the position of the locking screws (A). Image showing how restoration corresponded with virtual planning (B).
rate of the proximal humeral axis was 93.5% with errors less than 10°. Accurate placement of the locking plate can facilitate fracture healing in a better anatomical position, which contributes to the recovery of shoulder function. The computerized preoperative planning facilitated the difficult tasks of locking plate fixation and fracture restoration and resulted in good outcomes for patients with proximal humeral fractures.

Computerized virtual surgery planning has been increasingly applied in various orthopedic areas and has significantly improved the accuracy and integrity of orthopedic surgery. The 3-D visualization improved the recognition of fracture complexity in each patient, which contributed to reductions in operative time, blood loss, intraoperative injuries, and postoperative complications. The good postoperative results of patients with complex proximal humeral fractures in the current study may be attributed to the computerized preoperative surgery planning.

This study has some limitations. First, the sample size was relatively small. Second, the computerized virtual surgery planning mainly focused on the fractures and ignored the tissues around the fractures, which increased the difficulty of the surgery. Finally, there was no control group in the study. In the future, efforts should be made to investigate how to choose a specific implant for each patient based on his or her individual anatomy using 3-D modeling.

**CONCLUSION**

Patients with proximal humeral fractures treated with ORIF showed good outcomes. An accurate preoperative assessment of fracture fragments is crucial for successful restoration. The computerized virtual surgery planning for proximal humeral fractures showed advantages in improving the surgery’s safety and integrity and reducing operative time and complications. Although improvements have been made in surgical outcomes after computerized virtual surgery planning, its wide application for complex fractures should be investigated in the future.

**REFERENCES**