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EVALUATION OF TREATMENT OUTCOMES FOR PROXIMAL HUMERUS FRACTURES USING LOCKING PLATES BASED ON PREOPERATIVE 3D RECONSTRUCTION AND 3D PRINTING

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ABSTRACT

Background: *Proximal humerus fractures are among the most common injuries, accounting for approximately 4-5% of all fractures, particularly prevalent in the elderly. Treating complex fractures, especially those with significant displacement, remains a challenge for orthopedic surgeons. The use of locking plates has been proven effective due to their ability to provide stable fixation and support anatomical recovery. However, accurate preoperative surgical planning plays a crucial role in ensuring optimal treatment outcomes. With advancements in 3D reconstruction and printing technology, personalized treatment planning has become more feasible than ever. This study aims to evaluate the treatment outcomes of proximal humerus fractures using locking plates based on preoperative 3D reconstruction and printing.* ***Objectives:*** *To comment on the characteristics of proximal humerus fractures on conventional X-ray and CT scan with 3D reconstruction and printing, evaluate the surgical outcomes of proximal humerus fractures treated with locking plate fixation.* ***Materials and method:*** *A cross-sectional descriptive study was conducted on 59 patients with proximal humerus fractures who underwent CT scan with 3D reconstruction and printing before surgery. The surgery was performed based on the evaluation of 3D-printed models. Postoperatively, patients were followed up for 6 months and assessed based on clinical outcomes, postoperative X-ray imaging, and shoulder joint functional recovery (according to the Constant-Murley score).* ***Results:*** *The average age was 56.3 ± 13.045 (23-83) years, and the age group of 40-60 years accounted for 44.1%. The majority of cases (76.3%) were classified as Neer III. Surgical time under 60 minutes accounted for 69.5% of the total cases. The majority of patients achieved excellent shoulder joint functional recovery, representing the highest proportion (78%).* ***Conclusion:*** *The study demonstrates that the use of 3D reconstruction and printing technology before surgery offers numerous benefits in the treatment of proximal humerus fractures using locking plates. This method improves surgical accuracy, reduces surgical time and complication rates, and enhances shoulder joint functional recovery.*

Keywords: *Proximal humerus fractures, 3D reconstruction, 3D printing, 3D-printed models, CT scan, Constant-Murley score.*

I. INTRODUCTION

Proximal humerus is one of the important anatomical landmarks of the upper limb bones, playing an important role in ensuring the range of motion of the shoulder joint (one of the joints with the largest range of motion in the body). The components of proximal humerus such as the humeral head, anatomical neck, greater tuberosity, lesser tuberosity, and surgical neck are the anchor points of many rotator cuff muscle blocks, contributing to stabilizing and increasing the range of motion of the joint, combined with broken bones contributing to fixing the rotator cuff tendon anchor points, ensuring maximum recovery of limb function. Their management complexity stems from the shoulder joint's intricate anatomy and the variability in bone quality, particularly in older patients [1], [2].

Proximal humeral fractures represent approximately 4-5% of all fractures and are most commonly seen in elderly populations. According to Neer, the majority of proximal humeral fractures with minimal or no displacement can be effectively managed through conservative treatment. However, more recent studies indicate that a significant proportion, up to 64%, of these fractures are displaced. Conservative management, while suitable for non-displaced fractures, is often associated with various complications, such as malunion, stiffness, and prolonged immobilization [3], [4], [5]. As a result, surgical intervention is increasingly recommended for displaced proximal humeral fractures. Surgical treatment aims to achieve anatomical reduction and provide stable fixation, which facilitates early postoperative mobilization and functional rehabilitation. This approach not only enhances fracture healing but also improves overall shoulder function and patient outcomes [6], [7].

Understanding the importance of the proximal humerus, anatomical restoration is essential, especially in cases of complex fractures. Currently, with the assistance of 3D rendering technology, a comprehensive and individualized assessment of fracture patterns can be achieved, leading to better treatment planning. For individual cases with significant variations in proximal humeral fractures, especially complex fractures, 3D printing offers unique applications that align with the need for personalized treatment. 3D printing technology enhances preoperative planning through the establishment of fracture models, guiding surgical treatment, reducing surgical time, and minimizing operative trauma [4].

II. MATERIALS AND METHODS

2.1. Materials

Inclusion criteria:

Patients ≥ 16 years old.

The patient was diagnosed with a closed proximal humerus fracture due to trauma, involving 2, 3, or 4 displaced fragments, classified as group III to V according to the Neer classification, and was indicated for treatment with locking plate fixation. Preoperative 3D modeling and printing were performed.

Exclusion criteria:

Pathological fractures.

Patients who do not provide consent.

Patients with systemic infections, infected (osteitis) bone.

2.2. Methods

Research design: Cross-sectional descriptive study.

Simple sign: n = 59 patients

Study objectives:

To characterize fracture patterns in patients including: Fracture severity using the Neer classification system (Fracture type based on conventional radiography and 3D-printed models).

To evaluate: Discrepancies between 3D model predictions and actual intraoperative findings.

Surgical duration.

Accuracy of plate-and-screw fixation when guided by 3D models.

Functional recovery outcomes using standardized assessment scales.

Implementation process:

- CT Scanning

+ Purpose: To collect detailed 3D imaging data of the fracture site for 3D modeling and surgical planning.

+ Procedure: Patients undergo high-resolution CT scans of the shoulder area. Imaging data is stored in DICOM (Digital Imaging and Communications in Medicine) format.

- **3D Modeling**

+ Purpose: To create an accurate 3D model of the humerus and fracture site to assist in surgical planning.

+ Software used: Radiant or Inobitec (specialized software for processing CT scan data and creating 3D models); 3D Slicer (open-source software for medical image analysis and processing).

+ Procedure: Import DICOM data into the software. Perform segmentation to separate bone and soft tissue structures. Generate a 3D model of the humerus and fracture site. Simulate fracture reduction and plate/screw placement on the 3D model [8], [9].

- **3D Printing**

+ Purpose: To create a 1:1 scale physical model to assist in surgical planning and preoperative practice.

+ 3D printing equipment: Use FDM (Fused Deposition Modeling) or SLA (Stereolithography) 3D printers.

+ Printing material: PLA plastic or resin, ensuring high durability and accuracy.
Procedure: Export the 3D model file in STL format. Set printing parameters (resolution, scale, support structures). Print the bone model and verify its accuracy [3], [4], [5].

- Surgery

+ Purpose: To perform locking plate fixation surgery based on the preoperative 3D model plan.

+ Procedure: Use the 3D model to determine the precise placement of the plate and screws. Perform open surgery. Verify plate and screw placement using a C-arm during surgery.

- Postoperative Follow-Up

Clinical Evaluation

Evaluation time points: Immediately after surgery, 1 month, 3 months, and 6 months.

Evaluation criteria:

Shoulder joint function: Assessed using the Constant-Murley

Imaging Evaluation

Method: Shoulder joint X-ray.

Evaluation criteria: Bone union: Assessed based on X-ray images; Plate and screw placement: Check accuracy and stability.

Research ethics: I hereby confirm that this research is reliable and accurate. The study has been approved by the Institutional Review Board (IRB) for Biomedical Research, with approval number: 23.128.HV/PCT-IRB, and the approval date: March 20, 2023.

Data analysis: The results are presented in mean±SD and percentages. Data were evaluated based on the descriptive statistics. Data were then put to statistical analysis using SPSS 22.0.

III. RESULTS

3.1. Characteristics of fracture

Table 1. Neer C.S. Classification on X-ray

Neer C.S.	Number of part to X-ray			Total	%
	2-part	3-part	4-part		
III	35	7	0	42	71.2
IV	11	3	0	14	23.7
V	3	0	0	3	5.1
Total	51	8	0	59	
%	83.1	16.9	0		100

The majority of cases (71.2%) fell under the Neer III classification, with the majority being 2-part (35 cases). The Neer IV classification accounted for 23.7% of the total cases, primarily 2-part (11 cases). The Neer V classification was very rare, with only 3 cases (5.1%). There were no cases classified as 4-part.

Table 2. Neer C.S. Classification on 3D-printed model

Neer C.S.	Number of part to 3D-printed model			Total	%
	2-part	3-part	4-part		
III	1	41	0	42	71.2
IV	0	11	3	14	23.7
V	0	3	0	3	5.1
Total	1	55	3	59	
%	1.7	93.2	5.1		100

The majority of cases (71.2%) fell under the Neer III classification, with nearly equal numbers of 3-part (41 cases) and 2-part (1 cases). The Neer IV classification accounted for 23.7% of the total cases, primarily 3-part (11 cases) with 3 cases being 4-part. The Neer V classification was very rare, with only 3 cases (5.1%), all were 3-part. The number of 4-part cases was very limited, with only 2 cases (3.4%).

On 3D printed model, the rate of 3-part cases was 93.2% of the total cases, while on X-rays, this rate was only 16.9%. This indicated that 3D printed model had a significantly better ability to detect 3-part cases compared to X-rays. 3D printed model were superior in detecting 3-part cases, which could aid in selecting the appropriate diagnostic method and thereby guide better treatment planning for patients.

Table 3. Assess the degree of displacement caused by the intervention on the calcar

Calcar		Displacement			Total
		No	Minimal	Significant	
No	Medial instability	5	3	0	8
	No medial instability	1	5	1	7
Vis calcar	Medial instability	23	3	0	26
	No medial instability	13	1	1	15
Plate	Medial instability	3	0	0	3
	No medial instability	0	0	0	0

Calcar		Displacement			Total
		No	Minimal	Significant	
Total	Medial instability	28	6	0	59
	No medial instability	17	6	2	

Analysis of the data from Table 3 revealed the relationship between the type of intervention, medial instability status, and the degree of calcar displacement. Among the 59 recorded cases, the majority (76.3%) showed no displacement, particularly in the "vis calcar" intervention group (23/26 cases). While the "vis calcar" intervention demonstrated clear effectiveness in reducing displacement, the "plate" group had insufficient data to draw definitive conclusions. These results suggested that the internal column may play a protective role against significant displacement, while also highlighting the efficacy of the "vis calcar" method in structural stabilization. However, further research with a larger sample size, particularly for the "Plate" group, is needed to confirm these findings.

3.2. Surgical time

Table 4. Surgical time data table

Surgical time	Patients	Percent
<60	41	69.5
60-90	17	28.8
>90	1	1.7
Total	59	100

The majority of patients (69.5%) had a short surgical time of less than 60 minutes. Only one patient (1.7%) had a prolonged surgical time exceeding 90 minutes. The data indicates that most surgeries were performed relatively quickly.

3.3. Functional Outcome

Table 5. Shoulder joint functional recovery according to the Constant-Murley score

Result	Patients	Percent
90-100 points: Excellent	46	78
80-89 points: Good	9	15.3
70-79 points: Moderate	2	3.4
60-69 points: Poor	1	1.7
Below 60 points: Very poor	2	1.7

The majority of patients achieved excellent shoulder joint functional recovery, representing the highest proportion (78%). Cases with poor and very poor results accounted for a very low percentage (1.7% each), indicating that the current treatment method is highly effective.

IV. DISCUSSION

Historically, open reduction and internal fixation (ORIF) has been the preferred treatment for young patients with 3- and 4-part proximal humerus fractures to preserve bone stock and ensure anatomic healing. Neer originally recommended conservative management for most proximal humeral fractures that are minimally displaced or non-displaced. However, recent studies indicate that up to 64% of these fractures are actually displaced. While non-operative treatment remains appropriate for non-displaced fractures, it is often associated with complications such as malunion, joint stiffness, and prolonged immobilization. As a result, surgical intervention is increasingly advocated for displaced proximal humeral fractures to improve outcomes [6], [7].

Advantages of 3D Printing Technology

It provided a comprehensive and accurate view of fracture patterns: 3D printing technology allows for the creation of detailed 3D models from CT-scan data, enabling doctors to observe and analyze the structure of fractured bones in a visual and precise manner. On CT scans, the rate of 3-part fractures is 93.2% of the total cases, while on X-rays, this rate is only 16.9%. This indicates that CT scans have a significantly better ability to detect 3-part fractures compared to X-rays. The 3D model demonstrates superior capability in detecting medial column instability. The application of calcar screw fixation or augmented plates significantly enhances structural integrity and bone stability, which directly impacts limb functionality. Which can aid in selecting the appropriate diagnostic method and thereby guide better treatment planning for patients. This is particularly useful in complex fracture cases, where a thorough understanding of the anatomical structure is crucial for surgical planning [8], [9].

Additionally, it contributes to shorter surgical procedures and more accurate locking plate positioning: With the support of 3D reconstruction technology from software and 3D printing of models for evaluation, the results have significantly reduced surgical time compared to other studies mentioned above. Surgical time under 60 minutes accounted for 69.5% of the total cases. With 3D models, surgeons can plan the surgery in detail before proceeding, which helps minimize surgical time and increases the accuracy of locking plate placement [8], [9]. This not only saves time but also reduces risks during the surgical procedure.

Simultaneously, it aids in enhancing both anatomical and functional recovery of the shoulder joint: 3D printing technology helps create customized models for each patient, supporting optimal anatomical and functional recovery of the shoulder joint. This is particularly important in ensuring that the shoulder joint can function normally after surgery. In the study, the majority of patients achieved excellent shoulder joint functional recovery, representing the highest proportion (78%).

Besides the benefits that 3D printing technology offers, there are also the following disadvantages

It has high costs and requires advanced technological equipment: 3D printing technology requires significant investment in equipment and software, which can increase treatment costs. Additionally, the use of this technology demands specialized training for medical staff to operate and utilize it effectively.

There is a need for long-term studies to assess long-term efficacy: While 3D printing has demonstrated significant promise in aiding surgical procedures and functional recovery, comprehensive long-term studies remain essential to evaluate its sustained effectiveness. Such research will be crucial in confirming whether 3D printing technology provides enduring benefits for patients [8], [9], [10].

V. CONCLUSION

3D printing technology has opened remarkable advances in supporting surgery and functional recovery of the shoulder joint, especially in complex fracture cases. Thanks to its ability to create precise and personalized anatomical models, this technology assists surgeons in detailed surgical planning, simulating reduction steps, selecting surgical approaches, and designing patient-specific plates and screws. This not only enhances surgical accuracy but also significantly reduces operative time, blood loss, and the number of X-ray exposures, while improving communication between surgeons and patients. However, the adoption of 3D printing still faces certain challenges, notably high investment costs and the need for advanced technological equipment and specialized operational skills. Moreover, although short-term outcomes are promising, long-term studies are still required to comprehensively evaluate the sustained effectiveness and cost-effectiveness of this technology in clinical practice.

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