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Application and Efficacy Evaluation of 3D Printed Splint in Manual Reduction and External Fixation of Distal Radius Fractures

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Abstract

Objective: To evaluate the clinical efficacy and safety of personalized three-dimensional (3D) printed splints for external fixation after manual reduction of distal radius fractures. **Methods:** Clinical data of 108 patients with closed distal radius fractures treated at Yulin Orthopedic Hospital of Integrated Traditional Chinese and Western Medicine from January 2023 to January 2025 were retrospectively analyzed. All patients underwent manual reduction and external fixation and were assigned to a control group (traditional bamboo splints, n = 56) or an observation group (3D printed splints, n = 52) according to fixation method. Baseline characteristics, Patient-Rated Wrist Evaluation (PRWE) scores, Visual Analogue Scale (VAS) scores, wrist range of motion and grip strength (expressed as percentages of the contralateral side), radiographic parameters (radial styloid height, ulnar inclination, volar tilt, and articular step-off), fracture healing time, and complications were compared. **Results:** All patients completed 6 months of follow-up. At 1 week, 3 months, and 6 months after reduction, VAS and PRWE scores were lower in the observation group than in the control group (all $P < 0.001$). At 6 months, wrist range-of-motion and grip-strength percentages were higher in the observation group (all $P < 0.001$). At final follow-up, radial styloid height, ulnar inclination, and volar tilt were greater, whereas articular step-off was smaller, in the observation group than in the control group (all $P < 0.001$). Fracture healing time did not differ significantly between the groups ($P = 0.15$). One patient in the control group had fixation failure and underwent surgery, whereas no fixation failure or pressure ulcer occurred in the observation group; the difference in complication rate was not statistically significant (Fisher's exact test, P =

1.000). **Conclusion:** Compared with traditional bamboo splints, personalized 3D printed splints can better maintain radiographic reduction after manual reduction of distal radius fractures and may help reduce pain and promote wrist functional recovery. Their safety appears acceptable, but differences in complications require confirmation in larger studies.

Keywords

3D Printed Splint, Distal Radius Fracture, Manual Reduction, External Fixation

1. Introduction

Distal radius fracture refers to a fracture occurring in the region adjacent to the distal articular surface of the radius, typically involving the radial styloid process, the articular surface, and the bone near the distal metaphysis [1]. In young adults, it is often caused by high-energy trauma (e.g., traffic accidents, falls from height) and frequently presents with displacement and multiple injuries. In the elderly, particularly perimenopausal and postmenopausal women, osteoporosis makes them prone to low-energy falls, leading to a significantly higher incidence [2]. Although surgical treatment provides good reduction and fixation outcomes, manual reduction and external fixation remain the primary treatment for most patients with closed distal radius fractures at their first visit. Traditional splints and casts are widely used in clinical practice, but they have limitations in terms of conformity, breathability, and comfort, which to some extent compromise the effectiveness of conservative treatment and may lead to re-displacement or complications [3]. In recent years, the application of three-dimensional (3D) printing technology in the medical field has developed rapidly, with preliminary applications and reports in assisting internal and external fixation for wrist/radius, ankle, tibia, and complex trauma [4]-[6]. However, systematic clinical evidence regarding its use for external fixation after manual reduction of distal radius fractures remains relatively limited. This study aims to evaluate the clinical efficacy and safety of 3D-printed splints for external fixation following manual reduction of distal radius fractures, comparing them with traditional bamboo small splints to provide a reference for clinical practice. The report is as follows.

2. Materials and Methods

2.1. Clinical Data

A retrospective analysis was conducted on 108 patients with closed distal radius fractures who were treated at the outpatient clinic of Yulin Integrative Medicine Orthopedic Hospital from January 2023 to January 2025. All patients underwent manual reduction and external fixation. They were divided into a control group (traditional bamboo small splint, n = 56) and an observation group (3D-printed

splint, n = 52) based on the actual fixation method. Before reduction, all patients underwent DR (Digital Radiography) or CT (Computed Tomography) examination, with MRI (Magnetic Resonance Imaging) performed when necessary, to determine the fracture type, degree of displacement, and rule out pathological fractures. Reductions were performed by the same group of senior orthopedic surgeons. This study was approved by the Ethics Committee of our hospital (approval number: 202401101). Anonymized clinical data were used, and informed consent related to the study was implemented in accordance with the ethics approval. The two groups were comparable in terms of general data including sex, age, disease duration, affected side, injury mechanism, fracture classification, and pre-reduction VAS and PRWE scores, with no statistically significant differences ($P > 0.05$) (Table 1).

This was a retrospective, non-randomized study. The allocation of patients to either fixation method was based on shared decision-making between the attending physician and the patient, taking into account: (1) financial considerations (the 3D-printed splint is more costly); (2) fracture severity (patients with comminuted intra-articular or potentially unstable fractures were more likely to be recommended the 3D-printed splint); (3) patient preferences regarding comfort and breathability; and (4) equipment availability (the 3D-printing process was not fully available before the second half of 2023). All patients made an informed voluntary choice, and no randomization was performed.

Table 1. Comparison of baseline data between the two groups [n (%)].

Item	Control group (n = 56)	Observation group (n = 52)	t/χ^2	P value
Gender [n (%)]			$\chi^2 = 0.00$	0.96
Male	17 (30.4%)	16 (30.8%)		
Female	39 (69.6%)	36 (69.2%)		
Age (years)	69.5 ± 11.8	68.2 ± 12.4	0.56	0.58
Duration of disease (h)	6.9 ± 4.1	6.5 ± 3.9	t = −0.52	0.61
Affected side [n (%)]			$\chi^2 = 0.00$	0.97
Left	31 (55.4%)	29 (55.8%)		
Right	25 (44.6%)	23 (44.2%)		
Traditional classification [n (%)]			Fisher	1.00
Colles' fracture	45 (80.4%)	42 (80.8%)		
Smith's fracture	9 (16.1%)	8 (15.4%)		
Barton fracture	2 (3.5%)	2 (3.8%)		
Pre-reduction VAS score (points)	6.5 ± 1.3	6.4 ± 1.2	t = −0.41	0.68
Pre-reduction PRWE score (points)	63.0 ± 9.9	62.1 ± 9.5	t = −0.48	0.63

2.2. Inclusion and Exclusion Criteria

Inclusion criteria: 1) Diagnosed with closed distal radius fracture by clinical and radiological examination; 2) First visit after injury and received manual reduction and external fixation; 3) Complete medical records and 6-month follow-up data; 4) No history of trauma or surgery affecting functional evaluation of the affected wrist.

Exclusion criteria: 1) Open fracture; 2) Old fracture, nonunion, or malunion; 3) Combined with other fractures of the ipsilateral upper limb, or combined with nerve, blood vessel, or tendon injury; 4) Local skin damage, infection, or intolerance to external fixation; 5) Pathological fracture or definite metabolic bone disease other than osteoporosis; 6) Unable to cooperate with follow-up or missing primary outcome data.

2.3. Treatment Methods

2.3.1. Control Group

The patient was seated with the affected limb abducted. Local infiltration anesthesia was administered at the distal radius fracture site using 5 mL of 1% lidocaine plus 10 mL of 0.9% sodium chloride injection. After anesthesia took effect, an assistant held the upper segment of the patient's affected forearm (10 - 15 cm from the fracture site) with both hands, while the surgeon held the patient's palm and fingers (thumb on the palmar side, the other four fingers on the dorsal side). Slow continuous traction was applied along the longitudinal axis of the forearm for 3 - 5 minutes to relieve impaction and restore length. Then reduction was performed according to the direction of fracture displacement: for distal fragments displaced dorsally, the distal fragment was pushed palmarly during continuous traction with slight wrist flexion; for distal fragments displaced palmarly, the distal fragment was pushed dorsally with slight wrist extension; for those with abnormal ulnar deviation angle, the ulnar deviation angle was appropriately adjusted after correcting anteroposterior displacement. After reduction, the contour of the distal radius was palpated to confirm disappearance of crepitus and abnormal mobility, and the appearance of the wrist was basically restored. When reduction was satisfactory, the assistant maintained the wrist in functional or neutral position (determined by fracture type), and the surgeon applied fixation using a homemade bamboo small splint from our hospital. The tightness was adjusted to allow one or two fingers to be inserted between the splint and the skin. The fixation period was 6 - 8 weeks.

2.3.2. Observation Group

The manufacturing process of the 3D-printed splint was as follows: (1) Data acquisition and 3D model reconstruction: CT scanning of the patient's affected limb was performed with a slice thickness of <1 mm to obtain complete CT data of the affected limb. The data were imported into medical modeling software Mimics Medical 21.0. Through threshold segmentation, the bone and forearm skin contour of the affected side were extracted and three-dimensionally reconstructed. (2) 3D data processing and simulated reduction: The skin contour model of the affected limb was set to transparent in Mimics Medical 21.0. The fracture fragments were

simulated to be reduced using commands such as rotation and translation to generate a digital reduction prescription, which assisted clinical manual reduction. After completing the simulated reduction, the reduced skin contour models were merged into a whole using Boolean operations and saved in STL (STereoLithography) format. (3) Splint design and 3D printing: The reduced skin contour model was imported into Rhino 8 software. Four personalized splints were designed according to the fixation principles of traditional small splints, with a splint thickness of 3 mm. The radial and dorsal sides extended 2 cm beyond the wrist joint to limit dorsiflexion and radial deviation. Holes were added to improve breathability. Finally, medical-grade polylactic acid (PLA) material was used to prepare the splints via a fused deposition modeling (FDM) 3D printer. After reduction, the splints were fixed on the patient's affected limb. The specific steps are shown in Figure 1.

Figure 1. Fracture simulation reduction and 3D-printed small splint fixation (1A: Acquisition of CT data of the affected limb before reduction; 1B, 1C: Establishment of the 3D model of the affected bone and the skin contour image of the forearm; 1D, 1E: Simulated reduction; 1F: Splint design, simulation, and 3D printing; 1G: Finished splint; 1H: Post-fixation X-ray after application of the 3D-printed splint, showing satisfactory reduction and fixation; 1I, 1J: External appearance of the splint after manual reduction).

2.3.3. Post-Reduction Management

Inform the patient and their family to keep the fixation area clean and dry, avoid contact with water, pressure, or impact, and not to adjust the fixation device on their own. Instruct the patient to perform active finger flexion and extension exercises to promote blood circulation, prevent swelling, and avoid joint stiffness. Advise the patient to return to the hospital for follow-up after 1 week to assess fracture healing and the tightness of the fixation. If symptoms such as finger numbness, pallor, cyanosis, severe pain, or loosening/breakage of the fixation device occur, seek immediate medical attention. The above-mentioned rehabilitation guidance, follow-up schedule, and criteria for splint adjustment/removal were identical between the control group and the observation group; both groups followed the same unified postoperative management protocol. Neither group received additional physical therapy or other rehabilitation interventions during the immobilization period. The criteria for splint removal were also the same for both groups: satisfactory fracture healing (confirmed by X-ray showing continuous callus bridging across the fracture site), absence of local tenderness and longitudinal percussion tenderness, no abnormal mobility of the affected limb, and completion of the 6 to 8 week immobilization period before gradual removal.

2.4. Efficacy Evaluation Indicators

Clinical efficacy indicators: Assess VAS and PRWE scores before reduction and at 1 week, 3 months, and 6 months after reduction, with the 6-month PRWE score as the primary functional outcome. Fracture healing time, wrist range of motion (pronation/supination, flexion/extension, radial/ulnar deviation, all expressed as the percentage of the affected side relative to the healthy side), grip strength (expressed as the percentage of the affected side relative to the healthy side), and complications are also recorded. Complications include fixation failure, fracture redisplacement, skin pressure ulcers, neurovascular compression, and conversion to surgery due to failure of conservative treatment. Radiological indicators: All patients undergo anteroposterior and lateral wrist X-ray examinations before reduction, after reduction, and during follow-up. Radial styloid height, radial ulnar deviation angle, radial palmar tilt, and articular step-off are measured. This article focuses on reporting the radiological outcomes at the last follow-up.

2.5. Statistical Methods

Statistical analyses were performed using SPSS 26.0 software. Measurement data are expressed as mean ± standard deviation ($\overline{x} \pm s$). Normality was tested using the Shapiro-Wilk test, and homogeneity of variances was tested using Levene's test. For data that were normally distributed with equal variances, the independent-samples t-test was used; for data with unequal variances, Welch's t-test was used; for non-normally distributed data, the Mann-Whitney U test was used. For repeated measures at multiple time points, repeated-measures ANOVA was used to examine the main effects of group, time, and the group × time interaction. When the sphericity assumption was violated, the Greenhouse-Geisser correction

was applied, and Bonferroni correction was used for post-hoc pairwise comparisons. Count data are expressed as number (percentage) [n (%)], and comparisons between groups were performed using the chi-square test; Fisher's exact test was used when any expected frequency was <5. All tests were two-tailed, and a P value < 0.05 was considered statistically significant. Exact P values were reported whenever possible, except for P < 0.001.

3. Results

3.1. Clinical Efficacy Indicators

Table 2 shows that there were no statistically significant differences in VAS scores or PRWE scores between the two groups before reduction (all P > 0.05). At 1 week, 3 months, and 6 months after reduction, the VAS scores and PRWE scores in the observation group were lower than those in the control group (all P < 0.001). At 6 months after reduction, the percentages of wrist range of motion (pronation/supination, flexion/extension, radial/ulnar deviation) and grip strength on the affected side relative to the healthy side in the observation group were 89.5 ± 8.2%, 92.3 ± 9.1%, 85.2 ± 7.8%, and 88.5 ± 8.5%, respectively, which were significantly higher than those in the control group (78.3 ± 7.5%, 82.5 ± 8.3%, 75.3 ± 7.1%, and 78.3 ± 7.8%, respectively), and the differences were statistically significant (all P < 0.001, Table 3).

Table 2. Comparison of VAS scores and PRWE scores between the two groups at different time points ($\overline{x} \pm s$, points).

Indicator	Indicator Group	Before reduction	1 week after reduction	3 months after reduction	6 months after reduction
VAS score	Control group	6.5 ± 1.3	4.1 ± 1.0	2.3 ± 0.7	1.3 ± 0.4
	Observation group	6.4 ± 1.2	3.2 ± 0.8	1.5 ± 0.5	0.8 ± 0.3
	t-value	−0.41	−5.14	−6.79	−7.30
	P-value	0.68	<0.001	<0.001	<0.001
PRWE score	Control group	63.0 ± 9.9	45.2 ± 9.1	28.5 ± 7.2	18.3 ± 5.1
	Observation group	62.1 ± 9.5	38.5 ± 8.2	21.3 ± 6.1	12.5 ± 4.3
	t-value	−0.48	−4.01	−5.59	−6.36
	P-value	0.63	<0.001	<0.001	<0.001

Table 3. Comparison of wrist function between the two groups at 6 months after reduction ($\overline{x} \pm s$, %).

Indicator	Control group (n = 56)	Observation group (n = 52)	t-value	P-value
Pronation/Supination range of motion	78.3 ± 7.5	89.5 ± 8.2	7.41	<0.001
Flexion/Extension range of motion	82.5 ± 8.3	92.3 ± 9.1	5.85	<0.001
Radial/Ulnar deviation range of motion	75.3 ± 7.1	85.2 ± 7.8	6.90	<0.001
Grip strength	78.3 ± 7.8	88.5 ± 8.5	6.50	<0.001

3.2. Radiological Indicators

At the last follow-up, the radial styloid height, radial ulnar deviation angle, and radial palmar tilt in the observation group were greater than those in the control group, while the articular step-off was smaller than that in the control group, with all differences being statistically significant (all P < 0.001), as shown in Table 4.

Table 4. Comparison of radiological indicators at the last follow-up between the two groups ($\overline{x} \pm s$).

Indicator	Control group	Observation group	t value	P value
Radial styloid height (mm)	10.2 ± 1.5	11.5 ± 1.2	4.95	<0.001
Radial ulnar deviation angle (˚)	20.3 ± 1.8	22.5 ± 1.5	6.87	<0.001
Radial palmar tilt (˚)	11.5 ± 1.3	13.2 ± 1.2	7.05	<0.001
Articular step-off (mm)	1.2 ± 0.3	0.5 ± 0.2	−14.15	<0.001

Note: t values are calculated as observation group minus control group; P < 0.001 indicates a statistically significant difference.

3.3. Fracture Healing Time and Complications

The fracture healing time was (84.5 ± 10.2) days in the observation group and (87.3 ± 9.8) days in the control group, with no statistically significant difference between the two groups (t = −1.45, P = 0.15). One case of fixation failure requiring conversion to surgery occurred in the control group, resulting in a complication rate of 1.79%; no complications such as fixation failure or skin pressure ulcers were observed in the observation group, with a complication rate of 0.00%. Fisher's exact test showed no statistically significant difference in complication rates between the two groups (P = 1.000).

4. Discussion

Distal radius fractures account for approximately one-sixth of all body fractures and are among the most common fracture types in clinical practice. Most patients are treated conservatively. In conservative treatment, the quality of reduction directly determines the outcome, and maintaining fracture alignment after reduction is the core of successful external fixation [7]. Compared with traditional splints, personalized 3D-printed splints can be customized according to the patient's body surface contour and fracture fragment morphology, achieving precise fitting and uniform load distribution. Moreover, the flexible material and structural design can balance breathability, stiffness, and elasticity, improving patient comfort [8].

The radiological results of this study showed that at the last follow-up, the observation group had better radial styloid height, ulnar deviation angle, and palmar tilt, as well as smaller articular step-off, indicating that 3D-printed splints have good stability in maintaining key anatomical parameters of the distal radius. This is consistent with the findings of Jia *et al.* [9]. It should be noted that the traditional Colles/Smith/Barton classification used in this study is primarily based on the direction of fracture displacement and does not fully reflect the degree of intra-ar-

ticular involvement or fracture instability, which may compromise the accurate assessment of fracture severity. However, the distribution of this classification did not differ significantly between the two groups, suggesting that the composition of fracture types was comparable between groups and thus limiting the potential confounding effect on our main conclusions. Traditional splints rely on the physician's experience for manual shaping and often fail to fully conform to the complex curved surfaces of the patient's forearm and wrist, which can lead to local stress concentration or ineffective fixation, resulting in progressive loss of reduction [7]. In contrast, 3D-printed splints, through three-dimensional reconstruction and individualized design, better match the patient's anatomy, distribute stress more evenly over the fixation area, reduce micromotion at the fracture site, and provide a stable mechanical environment for fracture healing [10]. In this study, one case of fixation failure requiring conversion to surgery occurred in the control group, while no such case was observed in the observation group. However, due to the small number of events, the difference in complication rates between the two groups did not reach statistical significance, and further validation with larger sample sizes is needed.

Furthermore, this study found that the observation group had lower PRWE and VAS scores than the control group at 1 week, 3 months, and 6 months after reduction, and also showed better recovery of wrist range of motion and grip strength at 6 months after reduction, suggesting that 3D-printed splints may be more beneficial for wrist functional recovery and pain management. The reasons mainly include: more stable fixation provides a prerequisite for early functional exercise, allowing patients to start active exercises earlier and prevent complications such as joint stiffness and muscle atrophy [9]; the 3D-printed splint is made of lightweight polymer material, and the hollow design improves breathability, reduces skin-related discomfort, enhances patient compliance, and decreases pain perception [4]; the precise fitting design eliminates the need for excessive wrapping, reduces excessive pressure on soft tissues, leaves room for functional exercise, and is more conducive to blood circulation and swelling resolution [11] [12].

Regarding safety, no complications such as fixation failure or skin pressure ulcers occurred in the observation group, indicating that 3D-printed splints have good clinical safety. However, it must be emphasized that only one complication occurred in the control group, and Fisher's exact test did not show a statistically significant difference in complication rates between the two groups. Therefore, this study cannot yet conclude that 3D-printed splints have a significantly lower complication rate. The literature indicates that complications associated with traditional splint fixation mainly include pressure ulcers and fracture redisplacement [7]; theoretically, 3D-printed splints may reduce the risk of pressure injuries through uniform stress distribution and improved breathability, but this still requires verification with larger sample sizes and longer follow-up. In addition, the precise fixation concept of 3D printing technology is highly consistent with the core philosophy of traditional Chinese bone setting—"dynamic and static balance, equal emphasis

on bone and soft tissue"—representing an extension and development of traditional bone setting concepts in the context of modern technology [13]. In this study, PLA was used as the printing material, and its mechanical properties and biocompatibility met the requirements for external fixation. Although the material and modeling costs are higher than those of traditional bamboo splints, the overall cost is manageable. With the large-scale application of 3D printing technology in the future, its cost-effectiveness is expected to further improve.

5. Conclusion

In summary, compared with traditional bamboo small splints, 3D-printed splints demonstrate certain advantages in maintaining reduction of distal radius fractures, promoting wrist functional recovery, and alleviating pain, with good safety and clinical application value. This study is a single-center retrospective study with limited sample size and follow-up duration. The choice of fixation method may be influenced by patient economic factors, physician experience, and fracture complexity, introducing potential selection bias. The number of complications was small, resulting in insufficient statistical power for safety comparisons. Future studies with larger sample sizes, longer follow-up periods, and multicenter prospective randomized controlled trials or propensity score-matching studies are needed to further validate the conclusions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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