Treatment Outcomes of Applying External Fixator on Distal Radius Fractures: A Randomized Clinical Trial to Compare between Two Directions of Force Exertion in Parallel to Radius Shaft and Perpendicular to the Distal Radius Articular Surface

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Research Article

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Abstract

Background: External fixation has been one of the conventional managements of unstable distal radius fracture. The main aim of this paper is to compare two methods of applying distractive force along the radius shaft versus perpendicular to the distal radius articular surface.

Design: Sixty patients with unstable distal radius fracture were included in present clinical trial and randomized in two groups, using block randomization method. In group A (first arm), distraction force was exerted parallel to the radius shaft. In group B (second arm), the external fixator was adjusted based on radial and palmar tilt of the mean population healthy wrist so that distraction was exerted perpendicular to the wrist articular surface.

Methods: Radiological and clinical parameters were evaluated in both groups of patients pre-operatively, immediately after surgery, and 6 weeks post-operatively. We also followed up patients clinically at 12 weeks after surgery. PRWE, Mayo, and DASH questionnaires were used in order to assess patients' clinical and functional states.

Results: The method used in group B resulted in better improvement of palmar tilt both immediately ($P = 0.007$) and at 6 weeks follow up ($P = 0.013$) post-operatively in comparison with patients in group A. Radius height and radial inclination were also better restored when using the proposed modified method ($P = 0.001$ and <0.001, respectively). Clinical outcomes were not different between two groups.

Conclusion: Applying distractive force perpendicular to the distal radius articular surface seems to improve some radiological outcomes, probably due to better reduction maintenance, when compared with the technique of applying distraction force along distal radius shaft axis.

Level of Evidence: Level I (clinical trial study)

Introduction

Background Distal radius fractures are among the most common fracture types in emergency setting,[1, 2] and a traditional treatment is using bridging external fixators especially when the fracture is unstable.[3-5] However, this method, which is based on the ligamentotaxis theory, is criticized for loss of palmar tilt. Over-distraction is yet another problem that reduces the success rate of treatment because of joint stiffness.[6-8] To address the mentioned problems, combined techniques like Kirschner wire supplementation[9, 10] and bone graft[11, 12] were suggested.

Rationale Using the technique of applying distraction force perpendicular to the wrist joint is hypothesized to improve the taxis and, therefore, its related complications.[13] This theory argues that the mentioned modification in the direction of the distractive force when applying the bridging external fixation may prevent the shearing force created parallel to articular surface and consequently displacement of the radial side fragments and articular step **[Figure 1]**. Thus, having the wrist joint in flexion and ulnar deviation, during fixation, in accordance with palmar tilt and radial inclination prior to fracture may improve the treatment outcomes.[13] However, there is no controlled study to compare these two methods clinically and radiologically.

Questions/purposes This randomized clinical trial study therefore set out to compare 1) radiological and 2) clinical outcomes between two techniques of applying longitudinal distraction force along distal radius axis as well as perpendicular to the wrist articular surface.

Materials And Methods

Study Setting

This randomised clinical trial was conducted in two tertiary hospitals. A random sample of patients were recruited between 2020 and 2021. They were provided with and signed written informed consent forms before enrolment. Ethical approval for this study was obtained from the related Ethics Committee (approval number: IR.MUMS.REC.1397.697). This study is registered at Iranian Registry of Clinical Trials (IRCT) with approval code of IRCT20200313046759N1 at 25/10/2021. The conduction of this research accords with the Declaration of Helsinki and adheres to the CONSORT guidelines. Our unit's most common standard care for unstable distal radius fractures is percutaneous pinning (PCP) and external fixation. The other option is internal fixation using plates. In our consent form we described both methods and their advantages and disadvantages, so patients could choose between them. Patients who agreed with PCP and external fixation then enrolled in present study.

Patients

In this parallel-designed randomised clinical trial, patients who were attending the hospital emergency department with acute unilateral distal radius fractures were randomly recruited by our hand surgeon (A. M). A priori sample size compute was conducted using G*power 3.1.9.4, with the effect size of 0.84 based on similarly designed study's [14] results, alpha error of 0.05, power of 95%, and 1:1 ratio allocation; which resulted in 38 patients in each group. Thus, 77 patients with unstable fracture were considered based on having one or more of the following criteria: intra-articular radiocarpal fracture, over 20° of dorsal angulation, dorsal comminution, and more than 5 mm shortening.[15] In case they had the indication of treatment with external fixator, they were contacted and informed about the study. Of those, 68 patients agreed to participate, and were provided with written informed consent forms. The exclusion criteria were patients with prior history of wrist fracture, inflammatory diseases in affected wrist, open fracture, and concomitant carpal bones fracture. Accordingly, 8 patients were further excluded, leaving 60 patients as study sample for final evaluation.

Study design

Before operation, imaging study was performed for measuring the radiological parameters of joint displacement (palmar tilt, radial high, radial inclination, articular step and wrist alignment). These measurements were conducted before allocation of patients to either group in order to ensure blindness of data. The letters A and B were used for conventional treatment; the letters C and D were used considered for our proposed method of treatment, before randomization to conceal the group assignment Patients were then randomly allocated (1:1 ratio) to one of the two groups using block randomization method (block size: 4, block number: 15, permutation number: 24) by a biostatistician, and one group was set to undergo external fixation operation applying fixator parallel to radius shaft (group A = 30) and the other group with external fixator perpendicular to the distal radius articular surface (group B = 30).

Operation

All patients were hospitalized and were initially managed by long forearm splint. The operation procedure was performed with the patient in the supine position following induction of general anaesthesia. Then, the arm was prepped and draped. Using the appropriate manoeuvre of traction, flexion, and ulnar deviation, closed reduction was performed. Before fixation, re-imaging was done to ensure appropriate reduction by fluoroscopy. Then, with one radial side and one ulnar side pins, closed fixation was performed. Closed reduction and correct fixation (placement of the pins) were again verified with fluoroscopy and proximal schanz pins were inserted in radius shaft. First, we determined the entrance points for pins in lateral side, and then through a 5-mm skin incision and soft tissue dissection to the bone (using 11 bistoury). Two separated 2.5 mm schanz pins were placed perpendicular to the radius shaft and proximal to the fracture line. Via a limited incision on second metacarpal bone base, a 2.5 mm schanz pin was placed in metaphysis-diaphysis junction and extended through third metacarpal lateral cortex. Another 2.5 mm schanz pin was placed in second metacarpal shaft. For fixation and distraction, we used a pre-fabricated external fixator with two adjustable joints for palmar tilt and radial deviation respectively. External fixator was mounted to the schanz pin using the two techniques below:

1. All external fixator indices were set on zero and, longitudinal distraction force was applied parallel to distal radius axis (group A) **[Figure 2-A]**.
2. The external fixator indices were set in accordance with mean population wrist radial inclination (24 degrees) and palmar tilt (10 degrees). Then, distraction force was applied perpendicular to the wrist joint (group B) **[Figure 2-B]**. In order to make sure the distraction force is exerted perpendicular to the articular surface, we estimated the direction of force based on Mashhad population normal distal radius indices previously determined in Vaezi et al.[16] Accordingly, normal radial inclination and palmar tilt were considered 24 and 10 degrees, respectively.

After external fixator insertion, over distraction under guide of fluoroscopy was performed in a controlled way until 2 mm distraction occurred in radio-lunate joint.[17] We then gradually decreased the distraction to 1 mm. The day after operation and after performing true PA and lateral distal radius radiographs, we recorded the radial inclination and palmar tilt as well as joint displacement (radial height, radial inclination, articular step, and wrist alignment) using IC Measure software (version 2.0.0.286, the imaging source, Bremen, Germany) to compare the radiological outcome between two groups.

Post-operation management

To gather data, we further recorded radiological data parameters at 6 weeks follow up. The fixator was also removed at 6 weeks, after we clinically ensured that the union achieved. Patients' clinical data using grip strength dynamometry and wrist range of motion as well as VAS, Quick DASH, Mayo wrist score and PRWE questionnaires were gathered at 6 and 12 weeks post-operatively. Follow-up data was gathered by a medical intern who is trained in orthopaedic research fields (KE). To ensure blindness, we asked her to fill measurement tools after extraction of external fixators.

Tools (Data Sources)

We used the biplanar adjustable joint bridging external fixator (Avisa Co., Mashhad, Iran). It includes a radius fixing plate with two clamps, a metacarpus fixing plate with two clamps, and a coupling treaded bar. The radius plate includes two joints. The proximal joint has one degree of freedom along coronal plan (for radial deviation adjustment) and the distal joint on coronal plan (for palmar tilt adjustment). A single nut between two plates distracts the clamps **[Figure 3]**.

Below are tools for measuring clinical variables. These data were recorded at 6 and then 12 weeks post-operatively:

- Goniometry: Wrist range of motion in six positions of flexion, extension, pronation, supination, radial deviation and ulnar deviation were measured three times, the mean of which was recorded.
- Grip strength: With the patients in sitting position, elbow in 90 degrees flexion and neutral forearm and wrist position, grip strength was measured three times with Jamar grip dynamometer (J. A. Preston Corporation, Clifton, NJ), the mean of which was recorded.
- Patient-Rated Wrist Evaluation (PRWE) questionnaire: This questionnaire evaluates three factors of wrist pain, disability in activities of daily living and disability with doing specific activities. It consists of 15 items and each item has ten scores; based on item scores, scale scores are calculated ranging from 0 (no pain or disability) to 100 (most severe pain and disability).[18] We used the translated and validated version of the questionnaire in Persian.[19]
- Quick Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire: The Quick DASH questionnaire includes 11 items from the original 30-item DASH evaluating upper limb symptoms and disabilities. Questions are about the patient's ability to perform different activities, sleep quality, social and regular daily activities, pain severity, and tingling. Each item has five response options; based on item scores, scale scores are calculated ranging from 0 (no disability) to 100 (most severe disability).[20] We used the translated and validated version of the questionnaire for Persian speakers.[21]
- Mayo wrist score questionnaire: It assesses four domains of pain, satisfaction, wrist range of motion and grip strength. Each domain is scored from 0 to 25 points to produce a total score out of 100 points. Higher scores mean better function: Scores of 90-100 are interpreted as "excellent" function,

80-89 as “good”, 65-79 as “intermediate” and a score of less than 65 is considered “poor”.[22] The physician completes this questionnaire for patient, and thus the translated version is not required.

- Pain Visual Analogue Score (VAS): In order to quantify the severity of pain, we used the VAS scale, scaled continuously from 0 (no pain) to 10 (worst pain) on a 10 centimetre scale.[11] [23] We then measured the distance from 0 to the point where patients marked their pain level in cm.
- Radiography: Radiological parameters were measured three times by taking PA and lateral distal radius radiographs once before surgery and then immediately and 6 weeks post-operatively. Radiographs were performed under supervision of one of our researchers (KM) to reassure the radiology beam is perpendicular to sagittal plane of radius shaft. Radiological parameters were measured by a radiologist’s technician, who was blind to group allocation of patients. The measured parameters are:

A. Radius palmar tilt: Taking lateral view, this parameter is the angle made by the line vertical to radius shaft and the line tangent to the volar to dorsal aspect of the distal radius **[Figure 4-A]**.

B. Wrist malalignment: The angle between the lines drawn along the long axes of Capitate and radius from a lateral view **[Figure 4-B]**.

C. Radial inclination: The angle between the line vertical to the radius shaft axis and the line that connects the distal radio-ulnar joint (the midpoint of volar and dorsal lips) with styloid process in PA view **[Figure 4-C]**.

D. Radius height: Taking PA view, this parameter is the distance in millimeter between two parallel lines which are vertical to radius shaft. One line is drawn from level of the ulnar aspect of the articular surface (the midpoint of volar and dorsal lips) and the other from apex of radius styloid **[Figure 4-D].**

E. Articular step: Measurement of depression or protuberance in joint surface using AP view. In fractures with multiple articular steps, we calculated this value by considering the most depressed and bulged steps among them.

Statistical analysis

Data were analysed using SPSS (version 22). Quantitative data are reported as the mean ± SD, and qualitative data as number in percentage. After determination of variable data distribution with Kolmogrov-Smirnov test, comparison between two groups were performed using independent T-test when the data were normally distributed; otherwise, we used Mann Whitney test. In order to compare the data before and after surgery within each group, paired T-test was performed for variables which had normal distribution and Wilcoxon test for variables with non-normal distribution. P values less than 0.05 were considered statistically significant. Finally, power analysis was conducted using G*power (version 3.1.9.4) for each comparison between two groups. For normally distributed variables initially analyzed by independent T-test, we used difference between two independent means (t-test) Post hoc, considering alpha error = 0.05. For variables with non-normal distribution initially analyzed by Mann Whitney test, we used two independent groups’ (non-parametric) test Post hoc, considering parent distribution as Laplace and alpha error=0.05.

Results

Descriptive data

Finally, 60 patients were analysed (30 patients in each group) by original assigned groups. Demographic data including age, gender, and basic clinical data such as the involved side and fracture type based on Fernandez classification [24] were gathered. The most frequent types were type 1 (32 patients) and type 3 (22 patients). Demographic data did not differ between two groups of patients **[Table 1]**.

Table 1. Demographic and pre-operation radiological parameters data (N=60)

Variable	Group A (N=30) Mean (SD)	Group B (N=30) Mean (SD)	P value
Age (Year) [a]	44.93 (SD 14.49)	43.90 (SD 11.07)	0.757
Sex % (Male) [b]	53.30%	56.70%	1.000
Involved side % (Right) [b]	56.70%	53.30%	1.000
Fracture type (%) [c]			
Type 1	23.30%	30.00%	0.154
Type 2	5.00%	0.00%	
Type 3	16.70%	20.00%	
Type 4	3.30%	0.00%	
Type 5	1.70%	0.00%	
VAS pain score [d]	6.20 (SD 2.31)	6.37 (SD 1.73)	0.676
Radius height [d]	2.60 (SD 1.81)	3.47 (SD 2.43)	0.113
Palmar tilt [d]	18.23 (SD 8.05)	17.10 (SD 11.81)	0.237
Radial inclination [a]	16.57 (SD 8.34)	16.30 (SD 5.15)	0.882
Wrist alignment [a]	17.50 (SD 7.81)	16.80 (SD 7.04)	0.717
Articular step [d]	0.43 (SD 0.73)	0.40 (SD 0.67)	0.934

a: Independent T test, b: Fischer's exact test, c: Chi square test, d: Mann Whitney test

Pre-operation

There was no difference in pain VAS score and radiological parameters between two study groups before surgery **[Table 1]**.

Post-operation

Palmar tilt was significantly different between two groups immediately after surgery. No other radiological parameters were notably different **[Table 2]**.

Table 2. Comparison of radiological parameters between two methods immediately after surgery

Variable	Two groups (Mean (SD))		P value
	Group A	Group B	
Radius height [a]	9.03 (SD 2.17)	9.40 (SD 2.18)	0.309
Palmar tilt [a]	6.60 (SD 3.92)	8.93 (SD 4.27)	**0.007**
Radial inclination [b]	23.33 (SD 4.10)	24.20 (SD 3.22)	0.366
Wrist alignment [a]	11.57 (SD 3.91)	13.13 (SD 4.97)	0.327

a: Mann Whitney test, b: Independent T test

6 weeks post-operatively

There was a significant difference in palmar tilt (P = 0.013), radius height (P = 0.001) and radial inclination (P < 0.001) between group A and group B 6 weeks after surgery. Other radiological and clinical (range of motion, grip strength and clinical questionnaire scores) parameters were not different **[Table 3]**. Most patients were classified as poor (38 patients) and intermediate (14 patients) according to Mayo wrist score, and there was also no difference in this score between two groups. Power analysis showed power of 91, 64 and 99 percent for radius height, palmar tilt and radial inclination, respectively.

Table 3. Comparison of radiological and clinical parameters between two methods 6 weeks after surgery

Parameters	Variable	Two groups (Mean (SD))		P value
		Group A	Group B	
Radiological parameters	Radius height [b]	8.23 (SD 2.46)	10.47 (SD 2.62)	**0.001**
	Palmar tilt [a]	7.03 (SD 3.57)	8.80 (SD 3.56)	**0.013**
	Radial inclination [a]	20.10 (SD 3.29)	23.30 (SD 2.87)	**< 0.001**
	wrist alignment [a]	12.00 (SD 3.97)	13.27 (SD 4.70)	0.311
	Articular step [a]	0.10 (SD 0.31)	0.10 (SD 0.31)	1.000
Wrist range of motion	Flexion [b]	48.17 (SD 16.32)	50.50 (SD 14.58)	0.562
	Extension [b]	41.33 (SD 16.08)	39.33 (SD 15.85)	0.629
	Radial deviation [a]	21.33 (SD 6.94)	21.83 (SD 6.63)	0.745
	Ulnar deviation [a]	38.17 (SD 12.70)	39.50 (SD 11.92)	0.616
	Pronation [a]	62.00 (SD 12.77)	61.50 (SD 15.15)	0.726
	Supination [a]	66.50 (SD 14.63)	62.30 (SD 14.90)	0.239
Clinical scores	Grip strength [b]	24.97 (SD 12.66)	25.73 (SD 12.37)	0.813
	DASH [a]	31.18 (SD 21.60)	27.28 (SD 15.69)	0.711
	PRWE [b]	38.93 (SD 18.29)	36.43 (SD 15.69)	0.572
	Mayo [b]	56.67 (SD 20.36)	58.17 (SD 16.63)	0.756
	VAS [a]	3.70 (SD 2.53)	3.40 (SD 1.17)	0.725

a: Mann Whitney test, b: Independent T test

12 weeks post-operatively

There was no difference in any of clinical parameters (range of motion, grip strength and clinical questionnaire scores) between two groups of study 12 weeks after surgery **[Table 4]**. At week 12, according to Mayo classification scores, patients with “good” function increased to 10 patients and with “excellent” function increased to 8 patients, but there was still no notable difference in this score between two groups. Power analysis showed power of 16, 14 and 6 percent for DASH, PRWE and Mayo scores, respectively. In terms of complications assessed at 12 weeks post-operatively, there were no notable difference between frequencies of any early complications **[Table 5]**. Pin track infection was the most frequent complication (5 and 4 patients in group A and B, respectively). Two patients in group A and one patient in group B had simultaneous complications of pin track infection and pin loosening. Reflex sympathetic dystrophy and median neuropathy also co-existed in one patient in each group.

Table 4. Comparison of clinical parameters between two methods 12 weeks after surgery

Parameters	Variable	Two groups (Mean (SD))		P value
		Group A	Group B	
Wrist range of motion	Flexion [b]	51.17 (SD 14.00)	54.33 (SD 11.87)	0.349
	Extension [b]	45.83 (SD 13.07)	44.50 (SD 14.70)	0.712
	Radial deviation [a]	22.83 (SD 6.25)	23.83 (SD 5.83)	0.594
	Ulnar deviation [a]	38.30 (SD 13.48)	40.50 (SD 11.62)	0.425
	Pronation [b]	64.33 (SD 10.96)	64.00 (SD 13.03)	0.915
	Supination [a]	67.67 (SD 13.82)	65.83 (SD 12.87)	0.545
Clinical scores	Grip strength [b]	27.70 (SD 12.40)	29.93 (SD 12.72)	0.494
	DASH [a]	13.42 (SD 11.33)	11.28 (SD 8.79)	0.629
	PRWE [a]	16.90 (SD 13.65)	14.58 (SD 11.31)	0.528
	Mayo [a]	73.50 (SD 15.66)	72.50 (SD 12.23)	0.976
	VAS [a]	1.13 (SD 1.43)	0.90 (SD 1.18)	0.625

a: Mann Whitney test, b: Independent T test

Table 5. Comparison of complications at 12 weeks post-operatively

Complication	Group A (N=30)	Group B (N=30)	P value
Pin track infection	5	4	0.718
Pin loosening	1	2	0.554
Transient median neuropathy	2	1	0.554
Radial neuropathy	1	0	0.313
Reflex sympathetic dystrophy	1	1	1.000

All analyses were performed using Chi square test.

Discussion

Background: The criticisms of external fixation in distal radius fractures include wrist and finger stiffness and reflex sympathetic dystrophy as the results of over distraction, malunion, acute carpal tunnel syndrome (CTS) and radius shortening.[7, 8, 25, 26] Research on the subject has been mostly restricted to limited comparisons of bridging with non-bridging fixators[26] or external versus internal fixation.[5] However, research has not dealt with comparing treatment outcomes between two methods of external fixation: direction of distraction force in parallel to the radius shaft and perpendicular to distal radius articular surface. The results of present study indicated that palmar tilt, radial height and radial inclination were better reestablished when distraction is applied perpendicular to the joint surface. However, we could not find any difference in terms of clinical outcomes.

Limitation: The study is limited by a relatively short follow up time. One probable weakness in the study methodology was the lack of uninjured hand radiographies to enable us to exert the distraction force exactly perpendicular to the injured hand articular surface based on each patient's normal articular indices. This issue could not be addressed because of the ethical limitation in terms of radiation dose. Thus, we considered the previously studied mean indices of the city population studied in Vaezi et al.[16] to estimate the articular angles, and therefore apply the distraction force approximately perpendicular to the joint surface . Thirdly, the study did not evaluate the distraction force range when applying two methods. As described in methodology, we performed percutaneous pinning (PCP) prior to external fixation as the standard procedure for all patients. This may have obscured the radiological difference in articular space fragments between two groups to some extent. However, we hypothesize that if ethical principles would allow us to perform PCP after external fixation, we could note the difference in articular anatomy more precisely. Low power of analysis in clinical outcomes comparison was another source of weakness in this study.

Discussion: There is evidence in support of using external fixators that are adjustable in multiple planes for reestablishing the anatomic alignment and, therefore, maintenance of fracture reduction during healing.[27-29] Volar translational maneuver during application of longitudinal traction is said to help restoring baseline palmar tilt, and consequently avoiding finger stiffness and carpal tunnel syndrome.[28, 29] In a recent study, external fixation results were moderate in 28 percent and poor in 9 percent of the patients evaluated by Modified of Gartland and Werley Demerit point system.[30] In a case series study in 2014, distraction force was applied perpendicular to the distal radius articular surface using bridging external fixator (having injured joint in palmar tilt and radial inclination, equal to the uninjured side, during fixation). They stated that results of this method were comparable to studies of non-bridging external fixation or other combined methods in terms of clinical and functional parameters. They finally hypothesized that perhaps less needed traction to maintain the reduction and direction of the distraction force perpendicular to the articular surface led to restoration of articular compatibility.[13] One limitation of this study was lack of a cohort group treated with conventional method of external fixation to compare outcomes, and this made us curious to conduct the present study. As the difference in radiological outcomes were more significant at 6 weeks follow up in our study, we can say that the proposed method was more successful in reduction collapse prevention, rather than in reduction creation at first place.

To sum up, our proposed method could restore palmar tilt, radial inclination and radius height more properly when compared with the prior external fixation technique. Since radiological difference in radius height and radial inclination was observed at 6 weeks follow up and not immediately post-operation, group B method was more successful in prevention of reduction collapse. It is necessary to mention that although the radiological parameters were statistically significant, but we are in doubt whether these amounts are also clinically significant. Maybe with longer follow ups, it will become evident that some delayed complications like late arthrosis, which causes pain and decreased range of motion, also subside.

Conclusion

The results of this clinical experiment show that applying distraction force perpendicular to the distal radius articular surface during fixation of distal radius fracture makes an improvement in terms of radiological outcomes post-operatively, compared with conventional technique. This is the first report of comparing two directions of distractive force in a cohort of patients, and suggests further investigation on this external fixation technique with longer patient follow ups to examine whether clinical parameters also improve or not.

Declarations

Consent for publication: Not applicable

Competing interests: The external fixator used in this study is made in Avisa Co., Mashhad, Iran, and Dr. Ali Moradi is a shareholder in the company.

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Ethics approval and consent to participate: This study was approved by the Research Ethics Committee of Mashhad University of Medical Sciences, Mashhad, Iran (approval number: IR.MUMS.REC.1397.697). This research was conducted in full compliance with the codes of ethical conduct from the 1964 Declaration of Helsinki. This clinical trial adheres to the CONSORT guidelines. Patients were provided with written informed consent forms before they were enrolled.

Statement of the location: Present study was performed in Imam Reza hospital, Mashhad University of Medical Sciences (MUMS).

Data availability: Correspondence and requests for materials should be addressed to Moradial@mums.ac.ir.

Keywords: Distal radius fracture; external fixator; distraction force; perpendicular; clinical outcome; radiological outcome

Informed consent declaration: Patients were provided with written informed consent forms before they were enrolled.

Clinical trial registration: This study is registered at Iranian Registry of Clinical Trials (IRCT) with approval code of IRCT20200313046759N1.

Authors' contributions:

Conceptualization: AM

Methodology: AM, AB, DJ

Software: DJ

Validation: DJ

Formal analysis: MDBO

Investigation: DJ, KE

Resources: AM, AB

Data Curation: MDBO, DJ

Writing - Original Draft: MDBO, AM

Writing - Review & Editing: MDBO, AM

Visualization: Not Applicable

Supervision: AM, AB

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Funding acquisition: AM

All authors read and approved the final manuscript.

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Figures

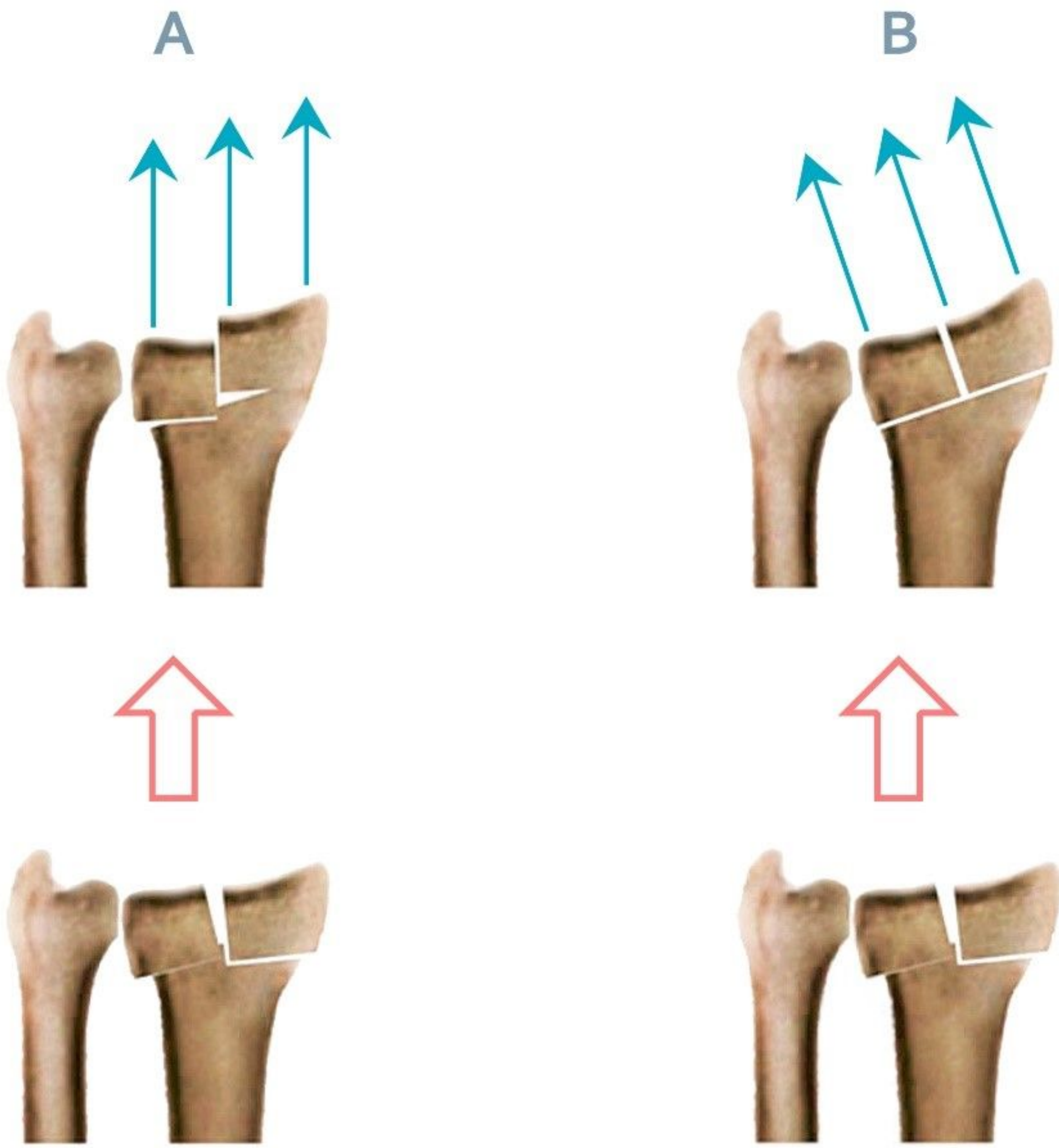

Figure 1

A-B. Illustration of the theoretical modification in external fixation directed force: force in parallel to radius shaft, which causes shear stress, and therefore articular step (A); force perpendicular to the distal radius joint surface, which shows more proper reduction (B).

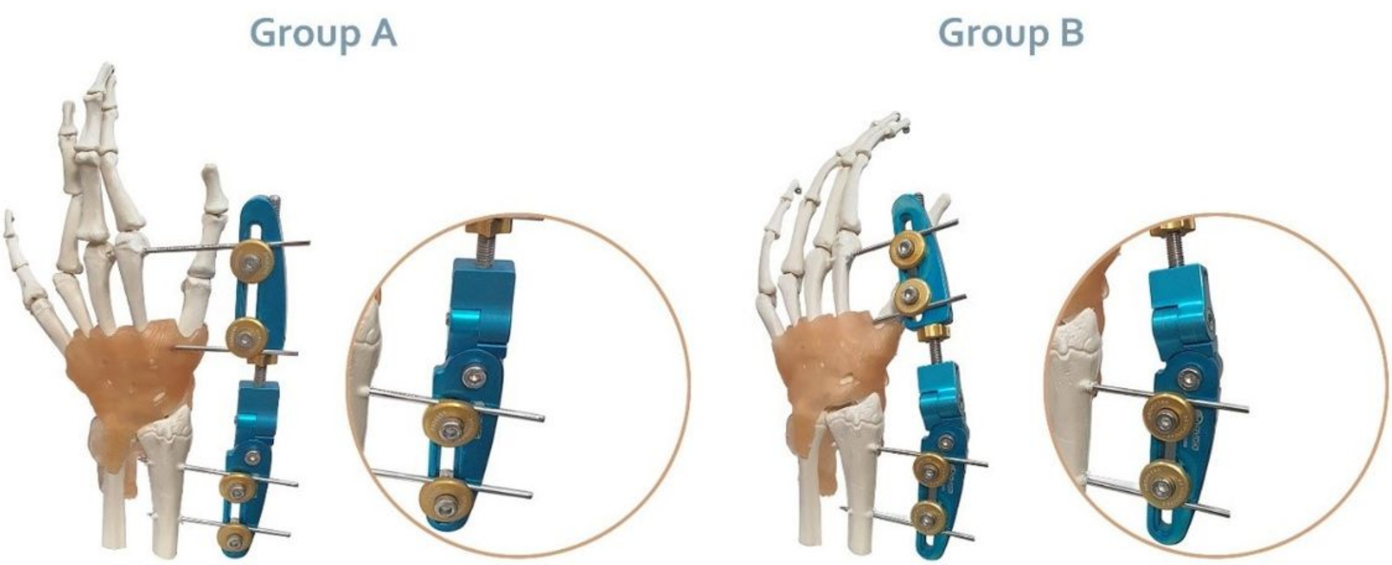

Figure 2

A-B. The external fixator setting: for patients in group A on whom distraction force was applied parallel to radius shaft (A), for patients in group B on whom distraction force was applied perpendicular to the wrist joint (B)

Figure 3

The biplanar adjustable joint bridging external fixator (Avisa Co., Mashhad, Iran) which consists of: 1- Metacarpal plate, 2- Radius plate, 3- Clamp, 4-Distal joint (for palmar tilt), 5- Proximal joint (for radial inclination), 6- Distraction nut.

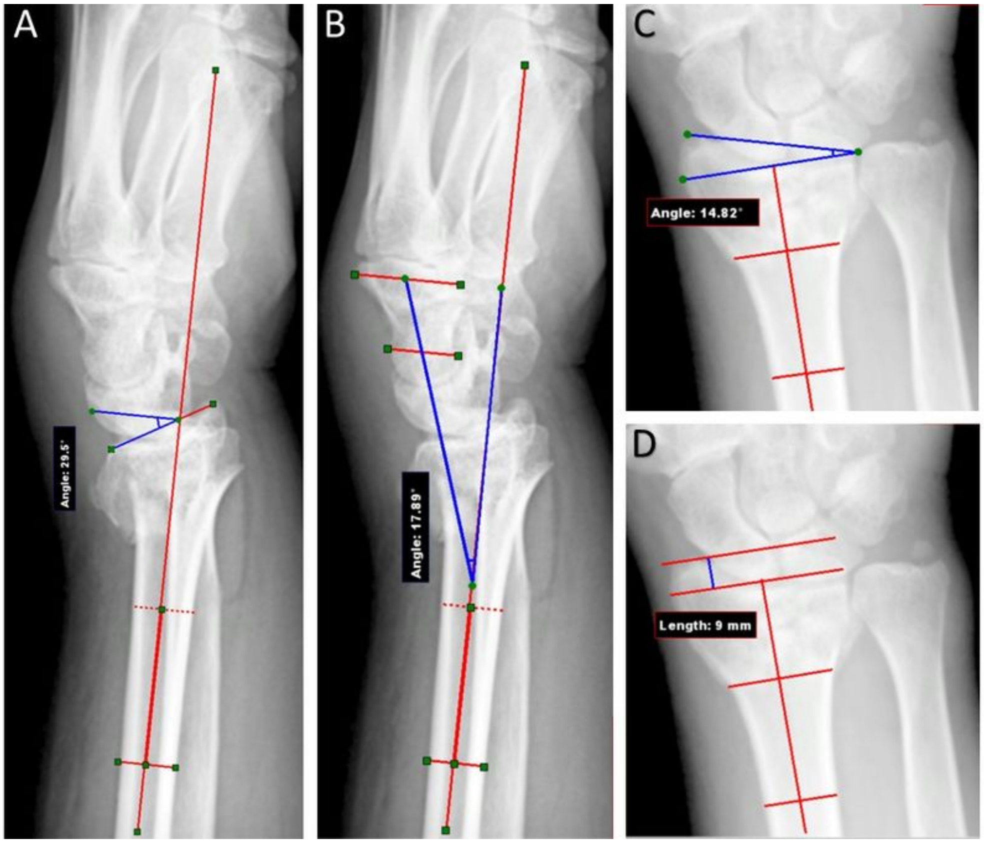

Figure 4

A-C. Measurement of radiological parameters before the operation: palmar tilt (A), wrist alignment (B), radial inclination (C) and radius height (D).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- RawDataExcel.xlsx