

# A comparison of bridging external fixation vs. combined external fixation for preventing radial height loss in older patients with distal radius fractures

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**Abstract.** Distal radius fractures are common injuries in older adult patients. The present prospective study aimed to compare the efficacies of bridging external fixation (BEF) and combined external fixation (CEF) in preventing radial height loss in older patients with distal radius fractures. Between January 2018 and December 2022, a total of 118 patients with distal radius fractures, aged 55-70 years, were randomly subjected to either BEF or CEF. Standard radiographs were used to measure radiological parameters, including radial height, palmar tilt, radial inclination, ulnar variance, articular step-off and Lidström classification. All patients were examined for active range of motion, grip strength, supination torque, level of pain during specified activities with a numeric rating scale, modified Mayo Wrist Score, Disabilities of the Arm Shoulder and Hand score, Patient-Rated Wrist Evaluation score and patient satisfaction. The patient characteristics showed significant differences in terms of operative time ( $t=12.52$ ;  $P<0.01$ ), successful closed reduction ( $\chi^2=32.74$ ;  $P<0.01$ ), change to open surgery ( $\chi^2=32.74$ ;  $P<0.01$ ) and cost ( $t=4,585.26$ ;  $P<0.01$ ). The

t-tests showed significant differences ( $P<0.01$ ) in the radiological parameters of intraoperative closed reduction between the two groups. By contrast, no significant differences ( $P>0.05$ ) were observed in the radiological parameters between bone healing and final follow-up within each group, and in the radiological parameters of bone healing and final follow-up between the two groups. Lidström classification showed significant differences between bone healing and final follow-up within the BEF group ( $\chi^2=5.96$ ;  $P<0.05$ ) and the CEF group ( $\chi^2=8.18$ ;  $P<0.01$ ), but no significant differences at the time of bone healing ( $\chi^2=3.57$ ;  $P=0.06$ ) and final follow-up ( $P=0.12$ ) between the two groups. Furthermore, the t-tests showed no significant differences ( $P>0.05$ ) in the functional and clinical outcomes between the two groups at the final follow-up. In conclusion, CEF may be as effective as BEF in preventing radial height loss in older patients with distal radius fractures. Percutaneous bony distraction may be more effective than conventional distraction manoeuvres in achieving anatomical reduction with minor morbidity. The two techniques demonstrate a similar ability for bone remodeling. Further studies on the therapeutic advantages of CEF over BEF are warranted, especially considering its lower cost compared with BEF.

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## Introduction

Distal radius fractures (DRFs) are one of the most common fractures, accounting for ~18% of fractures in older adult patients (1). Surgical treatments for DRFs often achieve good reduction, but the incidence of reduction loss due to osteoporosis and comminution is as high as 30%, especially for radial height loss (RHL) (2). Currently, there is no consensus regarding the prevention of RHL.

Previous studies have confirmed that the normal distal radius of the wrist can withstand an axial load of up to 80% (3). RHL often occurs due to insufficient radial support against the axial load, especially in non-surgical treatments. RHL may also be observed in patients undergoing open reduction and internal fixation with a volar locking plate for intra- and extra-articular DRF. Figl *et al* (4) found the incidence of

RHL was 25% with a mean radial shortening of 1.8 mm (range, 1-3 mm) 1 year after surgery. As a result, the mean extension-flexion movement and grip strength were reduced by 21 and 35%, respectively. As for risk factors for RHL, LaMartina *et al* (5) suggested that these include advanced age, poor bone quality, short distance between fracture site and articular surface, and postoperative ulnar-positive deformity. An external fixator combined with open reduction and volar plating can effectively prevent the RHL in older patients with comminuted DRF compared with volar plating alone, as reported by Han *et al* (6). Furthermore, Ruch *et al* (7) reported effective maintenance of RHL using a cross-wrist supporting plate; however, the disadvantages include creating a dorsal incision and breaking the blood supply to the fractured end. Therefore, this technique is used less than the conventional external fixation (8). As an alternative method to treat RHL, Kulshrestha *et al* (9) suggested the bridging external fixation (BEF) for 6 to 8 weeks; this technique uses a bridging external fixator that spans the wrist. However, this technique is insufficient in older patients with comminuted DRF. Non-BEFs often yield instability as only one or two screws capture the fragments. To reinforce the stability of distal fragments, combined external fixation (CEF), combining both BEF and non-BEF, was used in the present study (Fig. 1).

The present prospective study aimed to compare the efficacies of BEF and CEF in preventing RHL in older patients with DRF.

## Patients and methods

**Patient selection.** The research protocol was approved by the Investigational Review Board of Jingxing County Hospital (Shijiazhuang, China; approval no. 2017005), and written informed consent was obtained from all participants prior to the study. The patients involved in this study consented to the publication of their images.

Between January 2018 and December 2022, 147 consecutive older patients ( $\geq 55$  years) (10) with DRF were prospectively enrolled in the present study. Preoperatively, standard posteroanterior and lateral wrist radiographs were obtained from all patients. Computed tomography (CT) scans and three-dimensional reconstructions were performed, as required (Fig. 2). Magnetic resonance imaging was performed when a ligament tear was suspected. Fracture diagnoses and types were determined by three senior orthopaedic surgeons who were not involved in the treatments.

The eligibility criteria for the study were as follows: i) Patients aged between 55 and 70 years; ii) closed distal radius fractures; iii) acute fractures within 14 days of injury; iv) confirmed diagnoses of A2, A3, B1, B3, C1, C2 and C3 fractures based on the AO Foundation and Orthopaedic Trauma Association (AO/OTA) Classification (11); and v) a normal opposite upper limb for comparison. Patients meeting any of the following conditions were excluded: i) Patients aged  $< 55$  years, as osteoporosis rarely occurs (n=9); ii) patients aged  $> 70$  years, as malunion is often tolerable (n=6); iii) open fractures (n=7); iv) type A1 fractures, as these do not involve the radius; v) type B2 fractures, as fixation with pins is difficult; vi) combined ligament injuries (n=2); vii) fractures  $> 14$  days old, as percutaneous reduction becomes difficult (n=3);

viii) patients who refused to undergo external fixation (n=1); and ix) patients who declined to participate in the study (n=1) (Fig. 3).

Patients were randomly and blindly allocated to the BEF (n=61) and CEF (n=57) groups using a computational pseudo-random number generator. Patients in the BEF group underwent BEF, whereas those in the CEF group were subjected to CEF. All operations were performed by the same senior surgeon.

**Conventional distraction and BEF.** Conventional distraction and BEF surgery were performed under brachial plexus anesthesia without tourniquet control. Fracture reduction was achieved using a distraction manoeuvre, as described by Capo *et al* (12). Insertion of two 3.5-mm Schanz pins (Hengshui Zengli Medical Instrument Co., Ltd.), into the second metacarpal and proximal radius was performed, and a bridging external fixator (Hengshui Zhengli Medical Instrument Company Ltd.) was installed to maintain reduction. Several 2.5-mm Steinmann pins (Hengshui Zengli Medical Instrument Co., Ltd.), were inserted to secure small fragments, as needed. The reduction quality was assessed using intraoperative X-rays.

**Bony distraction and CEF.** Bony distraction and CEF surgery were also performed under brachial plexus anesthesia without tourniquet control. The surgery involved the insertion of two to three 2.5-mm transverse Steinmann pins into the second metacarpal and two to three pins into the proximal radius, respectively (Fig. 4A). A 2.5-mm Steinmann pin was manually placed across the fracture line from the anterior to the posterior wrist. The insertion point was located 0.5 cm distal to the fracture line that was identified on X-rays and 0.5 cm medial to the radial artery that could be palpated easily. The attending surgeon pulled both ends of the reduction pin distally to reduce the fracture (Fig. 4B). The normal volar tilt of the radius was restored by pulling the dorsal pin end more distally and the volar pin end more proximally. The reduction was maintained using several oblique pins inserted from the radial styloid and proximal radius. Satisfactory reduction was confirmed by fluoroscopy (Fig. 4C). All K-wires were bent toward the fracture site,  $\sim 2$  cm away from the skin. The monomers (liquid) and polymers (powder) of the bone cement (Palacos Bone Cements; Heraeus Medical GmbH) were mixed, which changed the bone cement viscosity from a runny liquid to a dough-like state. Subsequently, the mixture was applied to all bent pin ends to allow it to harden into a solid material (Fig. 4D and E). Satisfactory reduction was confirmed using intraoperative radiography (Fig. 5A and B).

**Converting to open surgery.** The patients with failed reduction (radial inclination  $< 15^\circ$ , radial shortening  $< 5$  mm, dorsal tilt  $> 15^\circ$  and articular step-off  $> 2$  mm), irrespective of group, were converted to open volar plating as described by Alter *et al* (13).

**Postoperative management.** The injured wrist was protected using a dorsal splint, which allowed for a range of motion (ROM) of the fingers and thumb. The splint was removed after 4 weeks. Radiographs were taken every 2 weeks until bone healing had occurred, and the external fixators were removed (Fig. 5C and D). ROM exercises of the wrist were performed thereafter.

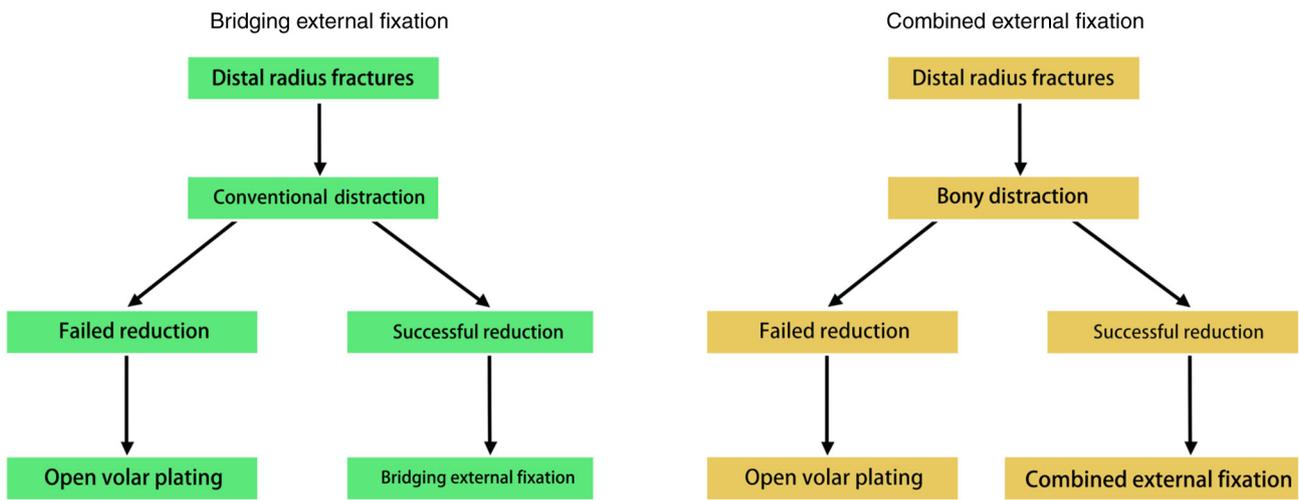


Figure 1. Flow diagram showing bridging external fixation and combined external fixation for distal radius fractures.



Figure 2. Imaging results of a 62-year-old female patient who suffered a type C3 distal radius fracture in the left wrist. (A) Posteroanterior X-ray showing comminuted fracture with compression of the distal radius. (B) Lateral X-ray demonstrating an intra-articular fracture and anterior displacement. (C) Coronal CT plane showing an intra-articular fracture. (D) Sagittal CT plane image. CT, computed tomography.

**Outcome evaluation.** Radial height, palmar tilt, radial inclination, ulnar variance and articular step-off were measured using standard radiography. Fracture consolidation and Lidström

classification (14) was determined using radiography. The wrist ROM was measured using a goniometer (Fig. 6). Grip strength was measured with a hand dynamometer (Jamar<sup>®</sup>; J.A. Preston Corporation). Pronation torque of the wrist was assessed using the McConkey method (15) at five rotation positions (90° supination, 45° supination, neutral, 45° pronation and 80° pronation). All measurements were compared with those on the opposite side. To eliminate the discrepancy between dominant and non-dominant hand strength, the scores for analysis were based on the premise that grip strength was 15% higher on the dominant side than that on the non-dominant side, and no correction was required for left-handed individuals, according to a previous study (16). At the final follow-up, the patients were asked to complete the following questionnaires: The level of pain during specified activities based on a numeric rating scale (NRS), a modified Mayo Wrist Score, a Disabilities of the Arm Shoulder and Hand score, a Patient-Rated Wrist Evaluation score and a patient satisfaction score questionnaire (17-21). To evaluate efficiency of the two external fixation techniques, those patients undergoing open surgery were excluded.

**Statistical analysis.** All statistical analyses were performed using SPSS version 21.0 (IBM Corp.). Continuous variables are expressed as the mean ± SD. Pearson's  $\chi^2$  test and Fisher's exact test were used for qualitative data. An unpaired t-test was used for the between-group analyses, while a paired t-test was used for the within-group analyses. Pearson's  $\chi^2$  test and Fisher's exact test were used to compare the Lidström classification. An unpaired t-test was used to compare the radiological parameters and clinical outcomes between the BEF group and the CEF group.  $P < 0.05$  was considered to indicate a statistically significant difference.

**Results**

In the present study, 147 patients were reviewed, with 118 patients (49 men and 69 women) eligible for the final analysis (Table I). The BEF group comprised 61 patients, with a mean age of  $61.97 \pm 3.61$  years (range, 56-68 years). According

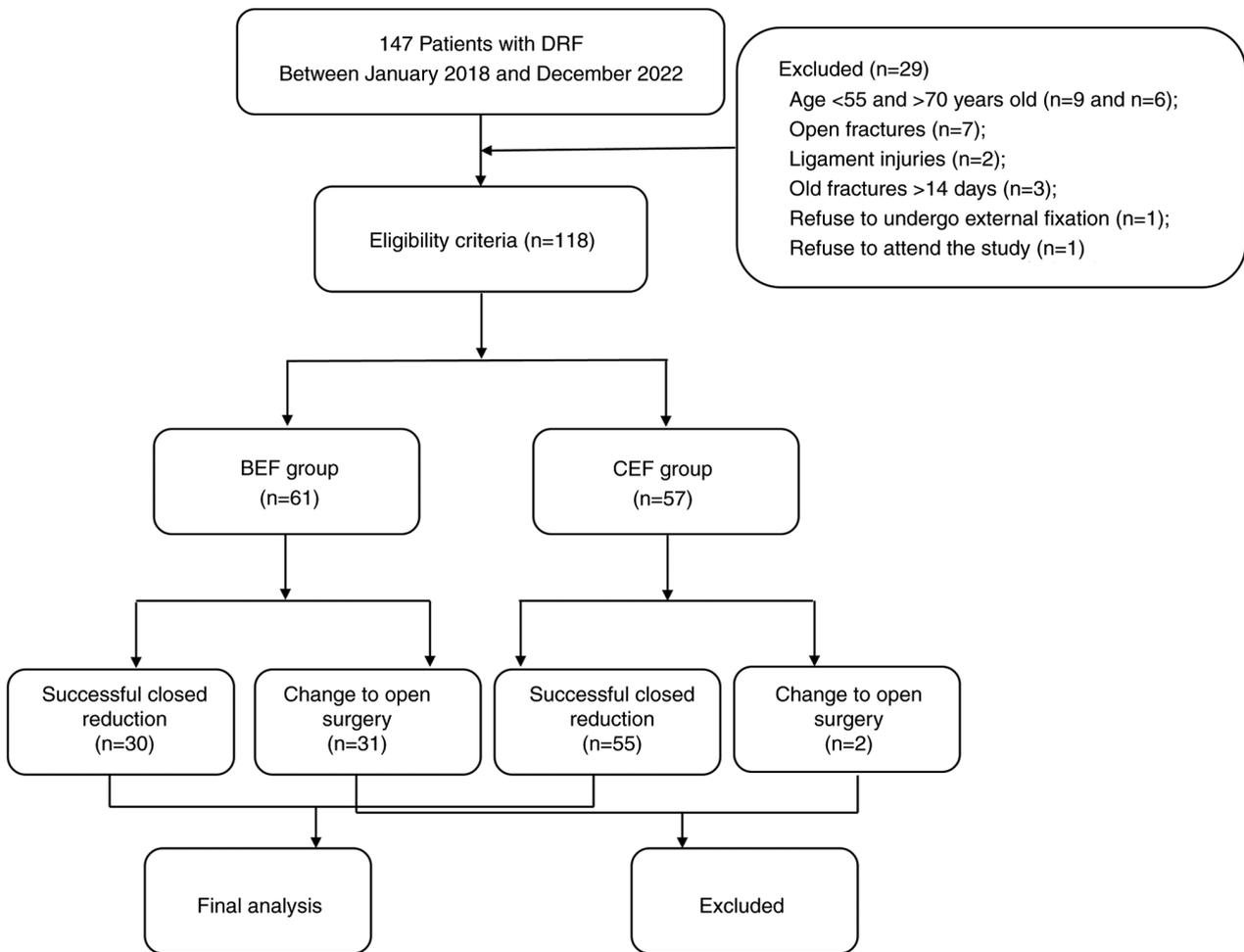


Figure 3. Consolidated Standards of Reporting Trials flow diagram of 147 patients (147 distal radius fractures).

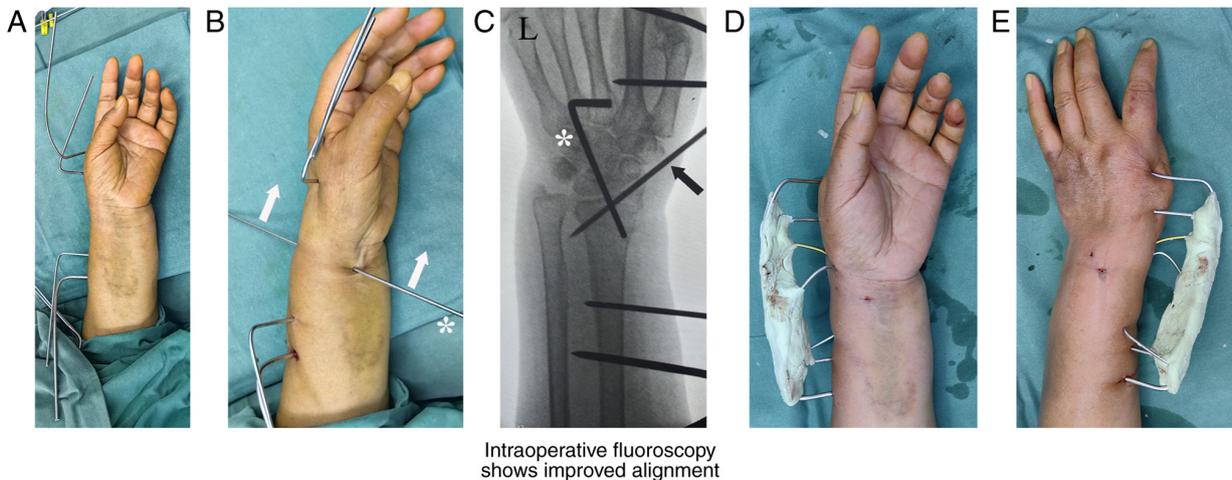


Figure 4. Intraoperative images of the same patient as in Fig. 2. (A) Two 2.5-mm Steinmann pins were placed into the second metacarpal and the proximal fragment of the radius, respectively. (B) A reduction pin (indicated by the asterisk) was placed across the fracture site and bony destruction power (arrow) was applied to the pin. (C) An oblique pin (arrow) was inserted from the radial styloid across the fracture line, with intraoperative fluoroscopy showing improved alignment. However, continuous distraction was maintained until the bone cement solidified. (D) A volar view showing that combined fixation (BEF and non-BEF) was complete. (E) Dorsal view. BEF, bridging external fixation.

to the AO/OTA classification, the fracture types in the BEF group were as follows: 3 cases of A2, 8 of A3, 7 of B1, 12 of B3, 17 of C1, 11 of C2 and 3 of C3. The mean follow-up period

was  $29.70 \pm 3.47$  months (range 24-36 months). The CEF group included 57 patients, with a mean age of  $61.51 \pm 4.00$  years (range, 55-70 years). According to the AO/OTA classification,

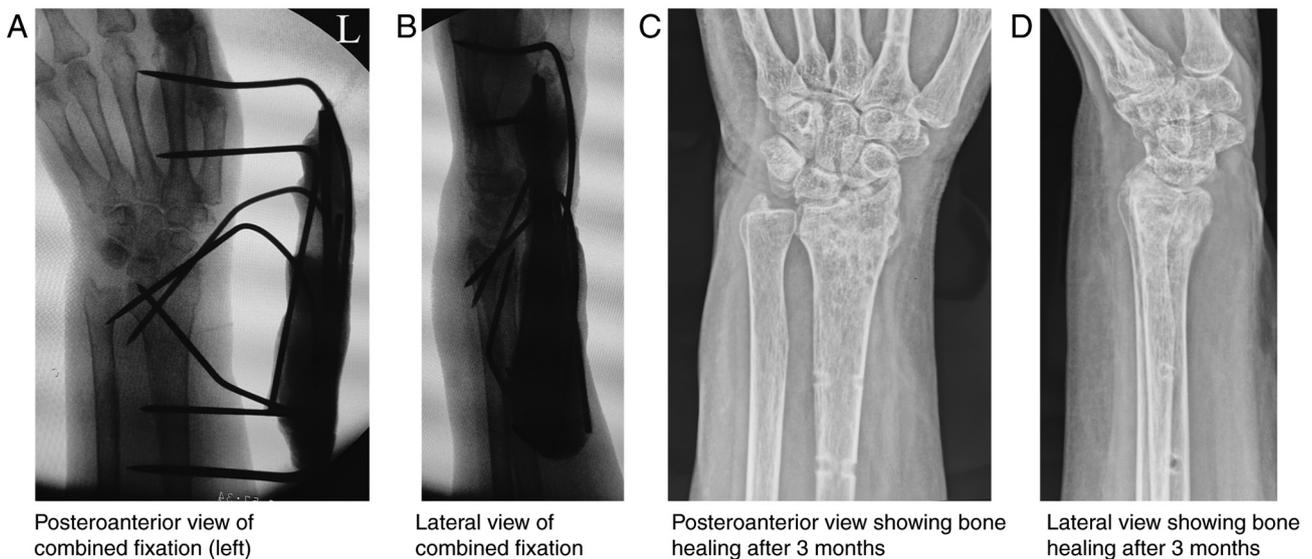


Figure 5. Intraoperative imaging of the same patient as in Fig. 2. (A) Posteroanterior X-ray showing reduction and combined external fixation. (B) Lateral view. (C) Bone healing after 3 months. (D) Lateral view.

the CEF group included 4 A2, 6 A3, 10 B1, 8 B3, 12 C1, 13 C2, and 4 C3 fractures. The mean follow-up period was  $28.53 \pm 2.76$  months (range, 24-33 months). A successful closed reduction was achieved in 30 patients (49.2%) in the BEF group and 55 patients (96.5%) in the CEF group. Pin-site infection occurred in 1 patient (3.3%) in the BEF group and 1 patient (1.8%) in the CEF group. Statistically significant differences were observed in operative time ( $t=12.52$ ;  $P<0.01$ ), successful closed reduction ( $\chi^2=32.74$ ;  $P<0.01$ ), change to open surgery ( $\chi^2=32.74$ ;  $P<0.01$ ) and treatment cost ( $t=4585.26$ ;  $P<0.01$ ). However, no statistically significant differences were found in AO/OTA classification ( $\chi^2=2.81$ ;  $P=0.83$ ), time between injury and operation ( $t=1.17$ ;  $P=0.25$ ), infection ( $\chi^2=0.19$ ;  $P=0.67$ ), bone healing time ( $t=0.69$ ;  $P=0.49$ ) and follow-up duration ( $t=1.17$ ;  $P=0.09$ ).

The radiological parameters of intraoperative closed reduction, bone healing and final follow-up were compared between the BEF group and the CEF group (Table II). The BEF group showed no significant differences regarding radial height ( $t=0.16$ ;  $P=0.88$ ), palmar tilt ( $t=0.40$ ;  $P=0.69$ ), radial inclination ( $t=0.46$ ;  $P=0.65$ ), ulnar variance ( $t=0.02$ ;  $P=0.98$ ) and articular step-off ( $t=0.93$ ;  $P=0.36$ ) between bone healing and the final follow-up. Similarly, the CEF group also showed no significant differences in radial height ( $t=0.69$ ;  $P=0.49$ ), palmar tilt ( $t=0.06$ ;  $P=0.95$ ), radial inclination ( $t=0.14$ ;  $P=0.89$ ), ulnar variance ( $t=0.39$ ;  $P=0.70$ ) and articular step-off ( $t=0.86$ ;  $P=0.39$ ) between bone healing and the final follow-up. Bone healing showed no significant differences in radial height ( $t=1.19$ ;  $P=0.24$ ), palmar tilt ( $t=0.41$ ,  $P=0.69$ ), radial inclination ( $t=0.37$ ;  $P=0.71$ ), ulnar variance ( $t=0.30$ ;  $P=0.77$ ) and articular step-off ( $t=0.92$ ;  $P=0.36$ ) between the BEF group and CEF groups. Similarly, the final follow-up also showed no significant differences in radial height ( $t=0.78$ ;  $P=0.44$ ), palmar tilt ( $t=0.76$ ;  $P=0.45$ ), radial inclination ( $t=0.84$ ;  $P=0.40$ ), ulnar variance ( $t=0.60$ ;  $P=0.55$ ) and articular step-off ( $t=0.60$ ;  $P=0.55$ ) between the two groups. However, there were significant differences in

radial height ( $t=10.06$ ;  $P<0.01$ ), palmar tilt ( $t=8.77$ ;  $P<0.01$ ), radial inclination ( $t=9.05$ ;  $P<0.01$ ), ulnar variance ( $t=4.19$ ;  $P<0.01$ ), articular step-off ( $t=5.05$ ;  $P<0.01$ ) and articular step-off  $\geq 2$  mm ( $t=23.45$ ;  $P<0.01$ ) during intraoperative closed reduction between the two groups (Table II).

Based on the Lidström classification, the BEF group included 19 excellent and 11 good results at the time of bone healing, and 27 excellent and 3 good results at the final follow-up; the CEF group included 45 excellent and 10 good results at the time of bone healing, and 54 excellent and 1 good result at the final follow-up. Significant differences were observed between bone healing and the final follow-up in the BEF group ( $\chi^2=5.96$ ;  $P<0.05$ ) and in the CEF group ( $\chi^2=8.18$ ;  $P<0.01$ ). However, there were no significant differences between the BEF and CEF groups regarding bone healing ( $\chi^2=3.57$ ,  $P=0.06$ ) or the final follow-up ( $P=0.12$ ) (Table III). The mean cost of CEF was Renminbi (RMB)  $563.73 \pm 7.91$  (7 to 12 pins, each costing RMB 5.04; bone cement, RMB 517), while the mean cost of BEF was RMB  $8,023.35 \pm 5.53$  (3 to 6 pins, each costing RMB 5.04; external fixator, RMB 8000) ( $t=4,585.26$ ;  $P<0.01$ ). The cost of CEF was  $\sim 7\%$  of that of BEF (Table I).

At the final follow-up, there were no significant differences between the two groups in terms of active ROM (flexion:  $t=0.80$ ,  $P=0.43$ ; extension:  $t=1.48$ ,  $P=0.14$ ; radial deviation:  $t=0.96$ ,  $P=0.34$ ; ulnar deviation:  $t=1.07$ ,  $P=0.29$ ; pronation:  $t=1.17$ ,  $P=0.25$ ; and supination:  $t=0.82$ ,  $P=0.41$ ), grip strength ( $t=0.98$ ,  $P=0.33$ ), supination torque ( $90^\circ$  of supination:  $t=1.48$ ,  $P=0.14$ ;  $45^\circ$  of supination:  $t=1.55$ ,  $P=0.13$ ; neutral:  $t=0.62$ ,  $P=0.54$ ;  $45^\circ$  of pronation:  $t=0.94$ ,  $P=0.35$ ; and  $80^\circ$  of pronation:  $t=0.80$ ,  $P=0.43$ ), wrist pain (activities of daily living:  $t=1.33$ ,  $P=0.19$ ; and hard work:  $t=1.75$ ,  $P=0.09$ ), modified Mayo Wrist score ( $t=0.86$ ,  $P=0.39$ ), Disabilities of the Arm Shoulder and Hand score ( $t=0.78$ ,  $P=0.44$ ), Patient-Rated Wrist Evaluation score ( $t=0.93$ ,  $P=0.36$ ), and patient satisfaction ( $t=1.74$ ,  $P=0.09$ ) (Table IV). Figs. 7, 8 and 9 show another representative case.



Figure 6. Follow-up of the patient from Fig. 2 after 2 years. (A) Ulnar deviation. (B) Radial deviation. (C) Extension. (D) Flexion. (E) Pronation. (F) Supination.

## Discussion

The present study found that CEF may be as effective as BEF in preventing RHL in older patients with DRF. Percutaneous bony distraction may be more effective than conventional distraction manoeuvres for achieving anatomical reduction with minor morbidity. Both conventional and bony distraction manoeuvres can produce similar functional outcomes and patient satisfaction only if a good reduction has been achieved. The outcomes show that there are no complications due to the

percutaneous bony distraction. The two techniques demonstrate a similar ability for bone remodeling. Moreover, CEF is less expensive than BEF.

RHL is commonly observed in older patients due to the axial load on the wrist (22). RHL produces abnormal volar tilt, radial inclination and ulnar variance (23). The abnormalities further contribute to the development of ulnar impaction syndrome, triangular fibrocartilage complex tears, distal radioulnar joint instability, ulnar carpal arthritis, and rupture of the extensor tendons of the little and ring fingers (24).

Table I. Patient characteristics of the two groups.

Characteristics	BEF group (n=61)	CEF group (n=57)	Statistical value	P-value
Mean age ± SD (range), years <sup>a</sup>	61.97±3.61 (56-68)	61.51±4.00 (55-70)	0.66	0.51
Sex (m:f), n <sup>b</sup>	26:35	23:34	0.06	0.80
Injured side (l:r), n <sup>b</sup>	22:39	19:38	0.10	0.76
Dominance, n <sup>b</sup>	34	31	0.02	0.88
Cause, n <sup>c</sup>			0.33	0.98
Fall	27	25		
Road traffic accident	19	17		
Sports	12	11		
Others	3	4		
AO/OTA, n <sup>c</sup>			2.92	0.84
A2	3	4		
A3	8	6		
B1	7	10		
B3	12	8		
C1	17	12		
C2	11	13		
C3	3	4		
Ulnar styloid fracture, n <sup>b</sup>	24	21	0.08	0.78
Mean hospital stay ± SD (range), days <sup>a</sup>	6.69±1.78 (4-10)	6.44±1.54 (3-9)	0.82	0.42
TBIO (range), days <sup>a</sup>	4.75±1.29 (3-7)	4.51±0.97 (3-6)	1.17	0.25
Mean operative time ± SD, min <sup>a</sup>	52.61±7.03 (42-65)	38.54±4.91 (30-47)	12.52	<0.01
Successful closed reduction, n (%) <sup>b</sup>	30 (49.2)	55 (96.5)	32.74	<0.01
Change to open surgery, n (%) <sup>b</sup>	31 (50.8)	2 (3.5)	32.74	<0.01
Infection, n (n/total n, %) <sup>c</sup>	1 (3.3) <sup>d</sup>	1 (1.8) <sup>e</sup>	-	1.00
Mean cost ± SD (RMB) <sup>a</sup>	8,023.35±5.53	563.73±7.91	4,585.26	<0.01
Mean bone healing time ± SD (range), weeks <sup>a</sup>	7.20±1.13 (6-9)	7.05±0.80 (6-8)	0.69	0.49
Mean follow-up time ± SD (range), months <sup>a</sup>	29.70±3.47 (24-36)	28.53±2.76 (24-33)	1.71	0.09

<sup>a</sup>Unpaired t-test; <sup>b</sup>Pearson's  $\chi^2$  test; <sup>c</sup>Fisher's exact test; <sup>d</sup>total patients, n=30 and <sup>e</sup>total patients, n=55, due to exclusion of patients who underwent open surgery. TBIO, time between injury and operation; AO/OTA, AO Foundation and Orthopaedic Trauma Association; m, male; f, female; l, left; r, right; RMB, Renminbi; BEF, bridging external fixation; CEF, combined external fixation.

Various surgical techniques can be employed for distal radius fractures in older patients. Non-surgical treatments using a splint or cast are commonly used in minimally displaced or reducible fractures, but RHL often occurs after 3 weeks due to osteoporosis, comminution and absorbable collapse at the fracture site (25,26). Open reduction and plating are straightforward techniques that provide radial support; however, an axial load can still be applied to the distal radius. RHL may also occur postoperatively in patients with osteoporosis, comminution or insufficient consideration. The use of a bridging external fixator can effectively avoid axial load on the distal radius and wire migration (27), but small fragments of the distal radius cannot be maintained, even when several spines are used. To reinforce fixation, CEF combining both BEF and non-BEF has been developed.

Meng *et al* (28) reported a study in which 78 types of A2, A3 and B1 distal radius fractures were treated using percutaneous fixation using a cemented K-wire CEF. It was suggested that this minimally invasive technique effectively prevented

redisplacement and wire migration, as the cement frame secured all the pins together. Moreover, percutaneous bony distraction is also more powerful and effective than conventional distraction in restoring the radial height, resulting in a high-quality reduction. This simplifies the preoperative plan, as all distal fragments can be automatically reduced under powerful bony distraction. The rationale is that the ligaments and tendons surrounding the wrist (such as the rotator cuff of the shoulder) are tension-like splints, pushing the fragments to be reduced. The present study showed that BEF and CEF achieved similar radiological parameters and functional outcomes. However, CEF had more advantages than BEF in achieving a higher rate of successful closed reduction, shorter operative time and lower treatment cost. The Lidström classification categorises DRFs based on the fracture line, direction of displacement, degree of displacement, articular involvement and distal radioulnar joint involvement. The similar changes observed between the time of bone healing and the final follow-up in both techniques suggest a comparable ability for bone remodeling.

Table II. Radiological parameters measured at the time of intraoperative closed reduction, bone healing and final follow-up.

Parameter	BEF group (n=61 <sup>a</sup> ; n=30 <sup>b</sup> )	CEF group (n=57 <sup>a</sup> ; n=55 <sup>b</sup> )	t value	P-value
<b>Radial height, mm</b>				
Intraoperative closed reduction	10.06±1.07	12.13±1.16	10.06	<0.01
Bone healing	11.78±1.15	12.09±1.15	1.19	0.24
Final follow-up	11.73±1.14	11.94±1.18	0.78	0.44
t value <sup>c</sup>	0.16	0.69		
P-value <sup>c</sup>	0.88	0.49		
<b>Palmar tilt, °</b>				
Intraoperative closed reduction	10.08±1.26	12.09±1.22	8.77	<0.01
Bone healing	11.94±1.10	12.04±1.17	0.41	0.69
Final follow-up	11.82±1.09	12.03±1.24	0.76	0.45
t value <sup>c</sup>	0.40	0.06		
P-value <sup>c</sup>	0.69	0.95		
<b>Radial inclination, °</b>				
Intraoperative closed reduction	20.14±1.65	22.84±1.59	9.05	<0.01
Bone healing	22.69±1.89	22.84±1.58	0.37	0.71
Final follow-up	22.49±1.51	22.79±1.63	0.84	0.40
t value <sup>c</sup>	0.46	0.14		
P-value <sup>c</sup>	0.65	0.89		
<b>Ulnar variance, mm</b>				
Intraoperative closed reduction	1.78±1.10	1.08±0.61	4.19	<0.01
Bone healing	1.05±0.58	1.01±0.59	0.30	0.77
Final follow-up	1.04±0.56	0.96±0.60	0.60	0.55
t value <sup>c</sup>	0.02	0.39		
P-value <sup>c</sup>	0.98	0.70		
<b>Articular stepoff, mm</b>				
Intraoperative closed reduction	1.58±0.91	0.87±0.57	5.05	<0.01
Bone healing	0.85±0.39	0.76±0.46	0.92	0.36
Final follow-up	0.74±0.47	0.68±0.45	0.60	0.55
t value <sup>c</sup>	0.93	0.86		
P-value <sup>c</sup>	0.36	0.39		
<b>Articular stepoff ≥2 mm, n</b>				
Intraoperative closed reduction	25	2	23.45	<0.01
Bone healing	0	0		
Final follow-up	0	0		

<sup>a</sup>Intraoperative closed reduction; <sup>b</sup>bone healing and final follow-up; <sup>c</sup>paired t-test between bone healing and final follow-up regarding the radiological parameters. Data are presented as mean ± SD for unpaired t-test and paired t-test. BEF, bridging external fixation; CEF, combined external fixation.

The indication for CEF is AO/OTA classification type A2, A3, B1, B3, C1, C2 and C3 distal radius fractures, especially in older adult patients (≥55 years) with poor bone quality and comminuted fractures, either open or closed fractures, and either extra- or intraarticular fractures. Contraindications include minor displacement, old fractures, infection status and health issues. The advantages of CEF are that it is easy to perform and has a high success rate, especially if surgeons are familiar with the volar wrist anatomy; inexperienced surgeons can identify structures using ultrasonography or place the reduction pin via blunt dissection through a small

incision. Pin migration into the radiocarpal joint due to articular fragmentation is rare; however, pin reduction may also be achieved in this setting. Alternatively, adjustment of the pin direction is preferred. Anatomical reduction with intact soft tissues surrounding the wrist may lead to superior wrist function. No complications due to over-distraction to the ligaments are observed. However, the shortcomings of CEF include the risk of iatrogenic injuries to the tendons, median nerve, superficial branch of the radial nerve and radial artery (29). The present study confirmed that minimally invasive CEF can achieve satisfactory fracture reduction and

Table III. Lidström classification at the time of bone healing and the final follow-up.

Classification (score)	BEF group (n=30)		CEF group (n=55)		BEF vs. CEF for bone healing <sup>a</sup>		BEF vs. CEF for final follow-up <sup>b</sup>	
	Bone healing	Final follow-up	Bone healing	Final follow-up	Statistical value	P-value	Statistical value	P-value
Excellent (90-100)	19	27	45	54	3.57	0.06	-	0.12
Good (80-90)	11	3	10	1				
Fair (60-80)	0	0	0	0				
Poor (<60)	0	0	0	0				
Statistical value <sup>a</sup>	5.96		8.18					
P-value	0.015		0.004					

<sup>a</sup>Pearson's  $\chi^2$  test; <sup>b</sup>Fisher's exact test. BEF, bridging external fixation; CEF, combined external fixation.

Table IV. Functional and clinical outcomes at the final follow-up.

Outcome	BEF group (n=30)	CEF group (n=55)	Statistical value <sup>a</sup>	P-value
Active ROM, °				
Flexion	68.13±6.14	69.02±4.09	0.80	0.43
Extension	52.43±3.39	53.36±2.37	1.48	0.14
Radial deviation	25.57±2.61	26.05±2.02	0.96	0.34
Ulnar deviation	29.60±3.20	30.40±3.33	1.07	0.29
Pronation	83.30±5.86	84.75±5.19	1.17	0.25
Supination	83.93±7.26	85.16±6.18	0.82	0.41
Grip strength, %	98.30±4.97	99.33±4.44	0.98	0.33
Supination torque, %				
90° of supination	80.93±4.17	91.18±3.47	1.48	0.14
45° of supination	94.53±1.81	95.02±1.08	1.55	0.13
Neutral	89.23±5.65	88.42±5.92	0.62	0.54
45° of pronation	89.70±4.04	90.47±3.40	0.94	0.35
80° of pronation	95.50±4.28	96.13±2.93	0.80	0.43
Wrist pain score (NRS)				
Rest	0	0	-	-
Activities of daily living	1.30±0.92	1.05±0.76	1.33	0.19
Hard work	1.83±1.29	1.40±0.97	1.75	0.09
Modified Mayo Wrist score	92.23±4.22	93.13±4.75	0.86	0.39
DASH score	8.00±5.10	8.85±4.66	0.78	0.44
PRWE score	9.80±4.90	8.69±5.46	0.93	0.36
Patient satisfaction	9.20±0.66	9.45±0.63	1.74	0.09

<sup>a</sup>Unpaired t-test. ROM, range of motion; NRS, numeric rating scale; DASH, Disabilities of the Arm, Shoulder and Hand; PRWE, Patient-Rated Wrist Evaluation; BEF, bridging external fixation; CEF, combined external fixation.

strong external fixation with a short operative time and low treatment cost.

Infection is a rare complication of minimally invasive surgery following distal radius fracture. Pin-site infection occurred in 1 patient (1/30, 3.3%) in the BEF group and in 1 patient (1/55, 1.8%) in the CEF group, and both are lower than the rate of pin-site infection (10.3%) reported in the

literature (30). Most pin-site infections are relatively minor and resolve with disinfectant care, oral antibiotic therapy and/or removal of the external fixator. Pin loosening is associated with a high risk of pin-site infection, which can be reduced by securing all the wire ends to a cemented CEF (28). The surgeons should not only pay attention to intraoperative sterilization but also to the treatment of related underlying

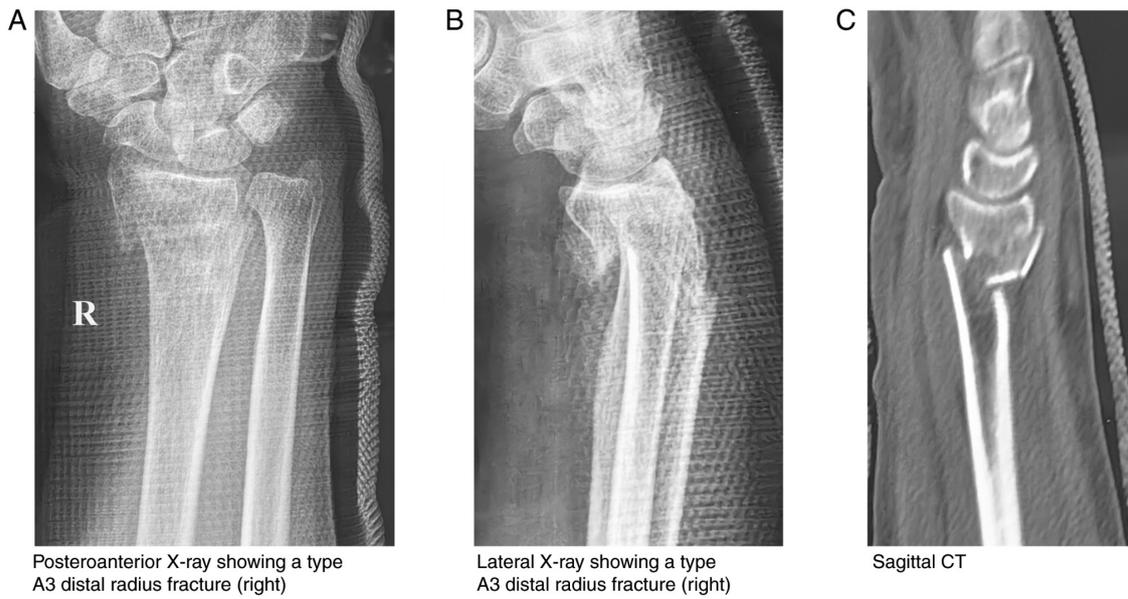


Figure 7. Imaging results of a 64-year-old female patient who suffered a type A3 distal radius fracture in the right wrist. (A) Posteroanterior X-ray showing an extra-articular fracture with lateral displacement. (B) Lateral X-ray showing anterior displacement. (C) Sagittal CT plane image. CT, computed tomography.

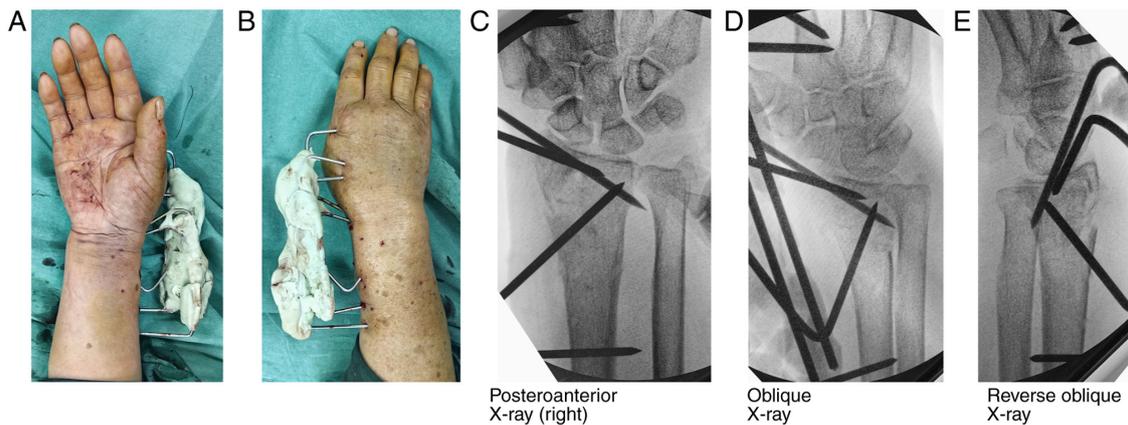


Figure 8. Completed combined external fixation in the same patient as in Fig. 7. (A) Volar view. (B) Dorsal view. (C) Posteroanterior X-ray. (D) Oblique X-ray. (E) Reverse oblique X-ray.

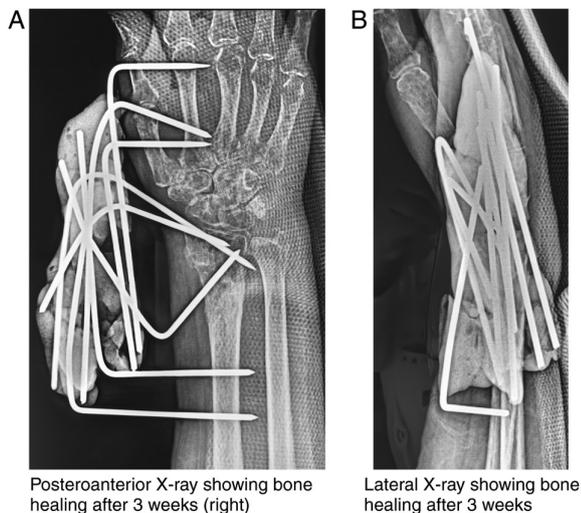


Figure 9. Bone healing after 6 weeks in the same patient as in Fig. 7. (A) Posteroanterior X-ray. (B) Lateral X-ray.

diseases, such as diabetes, hyp immunity, hypoproteinemia and infection of other body parts.

The most common reason for distal radial malunion is improper treatment, with an incidence rate of 33% (31). Malunion is defined as one of the following: Radial inclination <15° on posteroanterior view; radial length >5 mm shortening on posteroanterior view; radial tilt >15° dorsally or 20° volar tilt on lateral view; or articular incongruity >2 mm of step-off (30). When the DRF is less shortened, bone grafting may not be necessary if the DRF is stable and some anterior cortical contact remains. When intraoperative reduction creates a large space with a loss of cortical contact, the risk of malunion is greater, and bone grafting is required to avoid postoperative fracture non-union. Allogeneic bone grafts, including corticocancellous or cancellous bone, may be suitable candidates; however, autogenous iliac grafts remain the optimal selection both mechanically and biologically. During the postoperative follow-up, high-resolution peripheral CT is

feasible to further the evaluation of bone healing in DRF (32). In the present study, all patients in both groups showed satisfactory bone healing, and no postoperative fracture non-union was observed.

The present study had some limitations. First, the treatments could not be performed in blinded manner due to the nature of the study, which may have resulted in a selection bias. Second, the manoeuvres and assessments were performed at different time points, and the surgeons' experience improved with time, thereby influencing the ascertainment of the effects of the techniques. Third, the biomechanics of fixation were not assessed and should be investigated in future studies and in randomised controlled multicentre clinical trials to further determine the efficacy of the treatments.

In conclusion, CEF may be as effective as BEF in preventing RHL in older patients with DRF. Percutaneous bony distraction may prove more effective than conventional distraction manoeuvres in achieving anatomical reduction with minor morbidity. The two techniques demonstrate a similar ability for bone remodeling. Further studies are needed to explore the therapeutic advantages of CEF over BEF, especially considering its lower cost when compared with BEF.

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#### Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

#### Authors' contributions

JL and WD were involved in the study conception, design, implementation, data analysis and interpretation, as well as the writing of the paper. XZ and YPY contributed to the collection, analysis and interpretation of data. DZ and YY participated in implementation of the surgery and data collection. RC was involved in the study conception and design. All listed authors have made significant contributions to the development and writing of this article. All authors have read and approved the manuscript. JL and WD confirm the authenticity of all the raw data.

#### Ethics approval and consent to participate

The research protocol was approved by the Investigational Review Board of Jingxing County Hospital (Shijiazhuang, China; approval no. 2017005), and written informed consent was obtained from all participants prior to the study.

#### Patient consent for publication

The patients involved in this study consented to the publication of their images.

#### Competing interests

The authors declare that they have no competing interests.

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