

# Treatment of Diaphyseal Forearm Defects Caused by Infection Using Ilizarov Segmental Bone Transport Technique

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## Research article

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# Abstract

**Background** The Ilizarov segmental bone transport technique can be applied in the reconstruction of the bone defects with less invasive fashion and more versatility compared to other methods, while most studies were focused on the lower extremity. The purpose of this study was to evaluate the effectiveness of the Ilizarov segmental bone transport technique in the treatment of diaphyseal forearm bone defects caused by infection.

**Methods:** This study included 12 patients with diaphyseal forearm bone defects caused by infection, who underwent bone transport procedures using the monolateral external fixator at our institution from January 2010 to January 2018, including 10 males and 2 females with a mean age of 39 years (range 23-57 years). Patient's demographic data and clinical outcomes at least two years follow-up after removing the external fixator were collected and retrospectively analyzed. The functional results were evaluated by the questionnaire of Disability of Arm, Shoulder and Hand (DASH) and the modified Mayo wrist score (MWS) at the final follow-up.

**Results:** There were 10 radii and 2 ulnae bone transport procedures collected. The average defect size was 5.1 cm (4-6.5 cm). All patients were successfully followed up with a mean period of 28.2 months (24 to 36 months) and achieved infection-free union. There was no recurrence of infection observed. The mean external fixation time was 232.6 days (182 to 276 days), and the mean external fixation index was 46.3 days/cm (40.9 to 61.8 days/cm). The mean DASH score was 30.6(18 to 49) preoperative, while 13.8 (5 to 26) at the final follow-up. The average modified MWS improved from 68.8 (55 to 80) pre-operatively to 83.8 (65 to 90) at the final follow-up. All the differences between the preoperative and final scores were statistically significant ( $p < 0.05$ ). Almost all the patients achieved satisfactory clinical outcomes and were able to perform activities of daily living.

**Conclusion:** Ilizarov segmental bone transport technique is an alternative and effective method for the treatment of diaphyseal forearm bone defects caused by infection, and this method acquired satisfactory clinical outcomes.

## Background

Bone defects in the diaphyseal forearm may occur due to high-energy injury, the removal of contaminated and devascularized bony fragments in open fractures, resection of a bone tumor, or radical debridement of infected nonunion<sup>1,2</sup>. The management of bone defects in the diaphyseal forearm is a real challenge for the restoration of the biomechanics of the elbow and wrist due to the close proximity of vital neurovascular structures and the necessity to maintain supination, pronation, and range of motion of the adjacent joints<sup>3</sup>. The different technical options for the reconstruction of diaphyseal bone defects are shortening, nonvascularized autografts, vascularized autografts, allografts, bone substitutes, and induced membrane technique<sup>4-11</sup>, but the subsequent results are not completely satisfying. Another

option is bone transport with distraction osteogenesis<sup>12-14</sup>. The variety of reconstruction methods reflects the complexity in achieving healing in the gap left by the bone defects.

The Ilizarov segmental bone transport technique can be applied in the reconstruction of the bone defects of any length theoretically with less invasive fashion and more versatility compared to other methods, especially for massive bone defects > 6 cm. Most studies about applying the Ilizarov technique in the treatment of bone defects were focused on the lower extremity<sup>12-19</sup>, and there are few published data reported in upper extremity<sup>1,3,20-23</sup>. Compared with the lower limbs, the upper limbs require more function than weight-bearing. The forearm with higher functional requirements is vital for daily activities, especially for pronation and supination. The complexity of the bone transport procedure and for fear of functional loss may contribute to the rarely use in the forearm. The purpose of our study was to evaluate the effectiveness of the Ilizarov segmental bone transport technique in the treatment of diaphyseal forearm bone defects caused by infection.

## Methods

This retrospectively study included 12 patients with diaphyseal forearm bone defects caused by infection, who underwent bone transport procedures using the monolateral external fixator (Limb Reconstruction System, LRS, Orthofix, Verona, Italy) at our institution from January 2010 to January 2018. There were 10 males and 2 females with a mean age of 39 years (range 23–57 years). Patients older than 18 years with bone defects larger than 4 cm in the diaphyseal forearm were included. We excluded patients with pathological fracture, bilateral fracture, fracture associated with vascular and nerve injury, age > 65 years, poor compliance, and any other illness (such as diabetes, hypertension, osteoporosis, kidney disease, etc.) that can affect bone healing. Informed consent was obtained from all patients for their data to be recorded in our study (including hospital data, radiographs, and photographs). This study was approved by the Ethical Committee of our institution.

The bone transport procedure involved 10 radii (left in 6, right in 4) and 2 ulnae (left in 2). The etiology of bone defect included osteomyelitis(primary or posttraumatic osteomyelitis) in 9 (7 radii and 2 ulnae) and infected nonunion in 3 (3 radii). For the location of bone defect, proximal 1/3 of the diaphysis in 3 cases (2 in radii, 1 in ulna), middle 1/3 in 7 cases (6 in radii, 1 in ulna), and distal 1/3 in 2 cases (2 in radii). The mean number of operations before presenting to our institution was 2.2 (0–4 operations). The average defect size was 5.1 cm (4-6.5 cm) measured intraoperatively after radical debridement. There were 7 limbs in an active infected state with sinus and drainage. Samples obtained from drainage or deep tissue at the infected site were cultured and conducted antibiotic susceptibility tests in all patients. The results showed 8 patients infected with *Staphylococcus aureus*, 2 patients with *Pseudomonas aeruginosa*, Methicillin-resistant *Staphylococcus aureus* and *Escherichia coli* infected one patient respectively.

## Surgical technique

### Stage I (eradication of infection)

The patients were positioned supine or laterally on a radiolucent table under continuous general or brachial plexus block anesthesia. The operative incisions were performed in accordance with previous surgical incisions when possible. With the sufficient exposure of the infectious site or complete removal of hardware, the devitalized or infected bone and soft tissue were radically resected. Cortical bleeding, described as the so-called paprika sign, was accepted as an indication of vital osseous tissue<sup>24</sup>. At least 6 suspected tissues taken from multiple sites were sent for culture in all patients for the postoperative antibiotics. Sufficient irrigation with hydrogen peroxide, iodine liquid, and physiological saline during and after debridement is essential.

Antibiotic-impregnated cement spacer was used for the stability of the injured bone. The incision was closed with drainage tubes or vacuum sealing drainage (VSD) for which could not be closed at the initial management or there was a severe active infection. Intramedullary Kirschner wire and plaster cast were used to align the bone ends and preserve the length and orientation of the forearm. (Fig. 1)

Antibiotics that are suitable according to the results of cultures and antibiotic susceptibility tests are applied intravenously for at least 3 weeks or until the ESR (erythrocyte sedimentation rate) and CRP (C-reactive protein) levels return to normal limits.

## **Stage Ⅱ (application of monolateral external fixator and osteotomy)**

The antibiotic cement spacer and Kirschner wire were removed when clinical manifestations and laboratory indicators showed the infective process had resolved. Local tissue flap or directly suture without tension was performed to reconstruct the small soft tissue defects, and flap transfer or free skin grafting was used to cover the large wound. Preoperative anteroposterior and lateral X-rays were used to plan the placement of the monolateral external fixator.

The length and alignment of the injured bone were restored firstly reference to the contralateral uninjured side. In the neutral position of the forearm and the elbow positioned at 90°, the injured bone was fixated by a monolateral external fixator. Under image intensifier control, two or three hydroxyapatite-coated Schanz screws were inserted on each planned bony fragment, ensuring that every pin was on the same coronal plane. A percutaneous minimally invasive cortical osteotomy was performed at the appropriate site using Gigli saw technique, and care was given to preserving as much periosteum as possible. All the procedures were performed by the same surgical team.

## **Postoperative management**

All patients were encouraged to do isometric muscle motion and adjacent joint range of motion exercise within the tolerance of pain on the second day after surgery. Pushing a wall as stress simulation was an ideal option. Pin site care was performed by medical alcohol or iodophors every day.

According to the reference data<sup>25, 26</sup>, after a latency period of 7 to 10 days, bone transport started at a rate of 1 mm daily, 0.25 mm per 6 h, 4 times a day. The rate of bone transport was adjusted according to

patients' tolerance and the quality of the regenerate bone. All patients were required to stay in the hospital at least one week after osteotomy to learn about the pin track care and the regulation of the external fixation for bone transport. The procedure of bone transport continued for 4 or 5 days to compress the docking site after the docking.

Radiographic evaluation and clinical follow-up were conducted every 2 weeks during the bone transport period and monthly in the consolidation phase. The external fixator was dynamized before removal. The removal of the external fixator was conducted when the standard orthogonal radiographs showed sufficient consolidation of the distraction zone (dense bone formation) and docking site union (corticalization in 3 of 4 cortices). Additionally, all patients were put on the functional brace for 4–6 weeks for the protection of refracture. All patients were closely followed up at least two years after removing the external fixator. The functional results were evaluated by the questionnaire of Disability of Arm, Shoulder and Hand (DASH) and the modified Mayo wrist score (MWS) at the final follow-up.

## Statistical analysis

Statistical analysis was performed with the SPSS 22.0(IBM Corp, USA). Continuous variables were analyzed by paired-samples T-tests and expressed as the mean and range. Statistically significant difference was set at  $P < 0.05$ .

## Results

The clinical results are shown in Tables 2 and 3. All patients were successfully followed up with a mean period of 28.2 months (24 to 36 months) and achieved infection-free union (Fig. 1–3). There was no recurrence of infection observed. The mean external fixation time was 232.6 days (182 to 276 days), and the mean external fixation index was 46.3 days/cm (40.9 to 61.8 days/cm). The wound healed by themselves, and no patient required flap coverage.

The average degree of wrist flexion improved from  $39.2^\circ$  (20 to  $55^\circ$ ) pre-operatively to  $48.3^\circ$  (20 to  $65^\circ$ ) at the final follow-up, wrist extension from  $38.3^\circ$  (20 to  $50^\circ$ ) to  $46.7^\circ$  (25 to  $60^\circ$ ), elbow flexion from  $118.8^\circ$  (110 to  $130^\circ$ ) to  $130^\circ$  (125° to  $145^\circ$ ), elbow extension from  $0.4^\circ$  (-10 to  $10^\circ$ ) to  $4.2^\circ$  ( $0^\circ$  to  $10^\circ$ ), pronation from  $44.6^\circ$  (35° to  $60^\circ$ ) to  $59.2^\circ$  (50 to  $75^\circ$ ) and supination from  $36.7^\circ$  (20 to  $65^\circ$ ) to  $47.1^\circ$  (25 to  $65^\circ$ ).

The mean DASH score was 30.6(18 to 49) preoperative, while 13.8 (5 to 26) at the final follow-up. The average modified Mayo wrist score improved from 68.8 (55 to 80) pre-operatively to 83.8 (65 to 90) at the final follow-up. All the differences between the preoperative and final scores were statistically significant ( $p < 0.05$ ). Almost all the patients achieved satisfactory clinical outcomes and were able to perform activities of daily living. The grip strength was markedly improved, and few patients feel pain.

## Complications

Oral analgesics was required for the complaint of pain during the transport period in almost all patients. The most common complication was pin site infection (66.67%), which was managed by daily pin site care and oral antibiotics. One patient (8.33%) suffered deep pin tract infection and pin loosening, successfully treated by pin replacement and intravenous antibiotics. Axial deviation occurred in one patient (8.33%), modification of the apparatus and an open reduction was required before the end of the treatment. Soft tissue incarceration was noted in one case (8.33%), which was managed by freshening the bone ends, reopening the medullary canal, and excising the invaginated soft-tissue; any malalignment was corrected simultaneously. Delayed union of the docking site occurred in two patients (16.67%) and successfully treated by the “accordion” technique. Nonunion was noted in one case (8.33%), and autologous ipsilateral iliac grafting was conducted to obtain union. None of neurovascular injury or psychological problems were observed.

## Discussion

The forearm is a complex joint mechanism and not just two separate bones. The integrity of the anatomical structures is vital for a comprehensive function and synergistic effect, especially for the pronation and supination<sup>22</sup>. There is no doubt that the management of a segmental diaphyseal defect in the forearm is a difficult task for surgeons, especially combined with deep infection. It is so important to reconstruct the forearm function and control the infection process simultaneously.

Various methods have been proposed to treat bone defects in the forearm, including corticocancellous bone graft, nonvascularized fibular graft, vascularized fibular graft, Masquelet’s induced membrane technique, and bone transport<sup>4-6, 9, 10, 12, 20, 21, 27</sup>. Prasarn et al.<sup>28</sup> conducted iliac crest graft in 12 cases with the average defects measured 2.1 cm in the forearm and achieved union in all patients. Although bone graft is an effective method for bone defects, it is not recommended for the defects exceeds 5 cm due to the risk of resorption<sup>29</sup>, nonunion, and fracture of the graft<sup>30</sup>. Vascularized fibular graft has a high rate of success, but it is technically demanding and has potential donor site morbidity. Adani et al.<sup>31</sup> performed vascularized fibular graft in 10 patients with an average forearm bone defect of 8.4 cm and achieved union in 9 of 10 patients, whereas Gore et al.<sup>32</sup> reported there was mild muscle weakness after partial fibula removed and Gonzalez et al.<sup>33</sup> declared that there was statistically link between valgus and the removal of the partial fibula. The Masquelet technique has the advantage for management of the segmental bone defects and required no advanced skills in microvascular surgery, but the outcome is difficult to predict, especially in post-infective defects<sup>34</sup>.

Ilizarov bone transport technique, which is characterized by rapid, effective, minimally invasive, and can preserve the biomechanical microenvironment needed for fracture healing, is the preferable option for the treatment of massive bone defect<sup>12, 13, 15, 16, 19</sup>. Although the treatment of bone defect using bone transport technique has been used widely, inevitable difficulties as complications that may affect the procedure have been reported by many studies<sup>14, 19, 35</sup>. Pain and pin site infection are common in our study as expected. The other complications, as pin loosening, axial deviation, soft tissue incarceration,

delayed union, and nonunion, are also observed. They are all successfully treated with kinds of methods. The key factors we realized to prevent or minimize complications are particular attention, patient compliance, and experience of the surgeon. The complexity of this procedure and for fear of functional loss may contribute to the rarely use in the upper extremity.

In the present study, the external fixation index (mean 46.2 days/cm, range 40.9 to 61.8 days/cm) was higher than that in previous study<sup>13, 19-21</sup> (mean 45.4 days/cm, range 42 to 48.9 days/cm). This can be explained by the mechanism of bone defect in our study, which is mostly caused by an infection that requires repeated debridement before the initiation of bone transport, the microenvironment for bone regeneration may be destroyed, both docking union and regenerate maturation become a time-consuming process. Although the range of motion of the wrist, elbow, and forearm are not back to normal, especially for the pronation and supination in the forearm, the functional results were satisfactory with a mean DASH score of 13.8 (5 to 26) and a mean modified Mayo wrist score 83.8 (65 to 90) in our study. There is only a moderate disability in activities of daily life. To recover the forearm function in our experience, intensive physiotherapy should be emphasized during the whole procedure.

Bone transport can be performed by different types of external fixation. The circular external fixator is not conducive to the functional exercise of the forearm, and the restriction of pronation and supination can exacerbate the functional impairment. Therefore, a monolateral external fixation system without tensioned transfixion wires was used in our study. It is beneficial to the rotation of the forearm, and there is less risk of neurovascular damage<sup>36</sup>. A large amount of movement in the forearm may lead to the loosening of the pins of the external fixator. We recommend using hydroxyapatite-coated Schanz screws to prevent the complications, especially for the patient with osteoporosis. For proper bone transport, the most crucial procedure is that the length and alignment of the injured bone must be restored firstly with reference to the contralateral same bone. Besides, the injured bone should be fixated at the neutral position of the forearm and the elbow positioned at 90° in our experience due to the interosseous membrane is most relaxed in this position, and it can reduce the risk of displacement caused by muscle tension.

When conduct osteotomy on the injured bone, we recommend the use of the Gigli Saw technique. The periosteum may have less regenerative and reparative potential, and the injury to the periosteum may lead to ischemia or necrosis of the underlying bone ends. The subperiosteal Gigli saw osteotomy technique is especially advantageous with bone defect cases to preserve the periosteum while completely transecting the endosteum and eliminates the possibility of an incomplete corticotomy with minimal soft tissue dissection<sup>37</sup>. Furthermore, experience has shown that the volume of antibiotic bone cement should be larger than that of the resected bony fragment to create a large enough space and reduce the risk of soft tissue incarceration during the procedure of bone transport.

Our study described an effective alternative technique for the management of bone defects caused by an infection in the forearm. The consecutive stages contain eradication of infection, restoration of bone defect, proper length regain of the injured bone, union achieved and better functions of the wrist and

elbow obtained. The most crucial step is radical debridement of the infectious tissues as a priority to establish mechanical stability of the bony fragments and biological stimulation of the bone in our experience. The procedure is lengthy, with a considerable risk of complications. Appropriate insertion of pins, stability of the transport system, meticulous care, and careful attention contribute to ensuring satisfactory results.

The present study had several limitations. Longer follow-up is necessary to evaluate the clinical efficacy better. Considering its retrospective nature and relatively small sample size, a prudent attitude should be adopted regarding the interpretations of our outcomes. Further investigations, especially multi-centered trials with larger sample size, should be conducted to overcome the limitations of our study.

## **Conclusion**

Ilizarov segmental bone transport technique is an alternative and effective method for the treatment of diaphyseal forearm bone defects caused by infection, and this method acquired satisfactory clinical outcomes.

## **Abbreviations**

DASH: the questionnaire of Disability of Arm, Shoulder and Hand

MWS: the modified Mayo wrist score

VSD: vacuum sealing drainage

ESR: erythrocyte sedimentation rate

CRP: C-reactive protein

## **Declarations**

### **Ethics approval and consent to participate**

This retrospective study was approved by the Ethics Committee of The First Affiliated Hospital of Xinjiang Medical University. Written informed consent was obtained from all patients for their data to be recorded in our study.

### **Consent for publication**

Written informed consent was obtained from all patients for their data to be published in our study.

### **Availability of data and materials**

The datasets analyzed during the current study are available from the corresponding author on reasonable request

### **Competing interests**

The authors declare that they have no conflict of interest.

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### **Authors' Contributions**

YSL: Conducted the study. Collected, analyzed and interpreted the data. Wrote the manuscript.

MY: Designed the study. Interpreted the data. Edited the manuscript.

ZHL: Collected and interpreted the data.

JLL: Created and statistical analyzed the data.

CM: Planned the project. Reviewed the manuscript.

AY: Planned the project. Reviewed the manuscript.

Final approval of the version to be submitted: YSL, MY, ZHL, JLL, CM, AY

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Not applicable

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## Tables

Table 1  
Details of the patients

Case	Sex	Age (years)	Disease	Location	Defect size(cm)	Previous operation time(s)	Infecting organism
1	Female	41	O	L, Radius, middle	5	2	SA
2	Female	34	IN	L, Radius, distal	4	3	SA
3	Male	43	O	R, Radius, middle	4.5	1	PA
4	Male	25	O	L, Radius, middle	4.5	0	SA
5	Male	38	IN	L, Radius, proximal	4	4	SA
6	Male	46	O	R, Radius, middle	5	3	MRSA
7	Male	57	O	R, Radius, distal	4.5	2	SA
8	Male	43	IN	L, Radius, middle	6	2	SA
9	Male	51	O	L, Radius, middle	5.5	3	E. coli
10	Male	41	O	R, Radius, proximal	6.5	3	SA
11	Male	23	O	L, Ulna, proximal	6	1	SA
12	Male	31	O	L, Ulna, middle	5.5	2	PA

O: Osteomyelitis; IN: Infected nonunion; SA: Staphylococcus aureus; MRSA: Methicillin-resistant Staphylococcus aureus; PA: Pseudomonas aeruginosa; E. coli: Escherichia coli; L: Left; R: Right

Table 2  
Details of the treatment outcomes

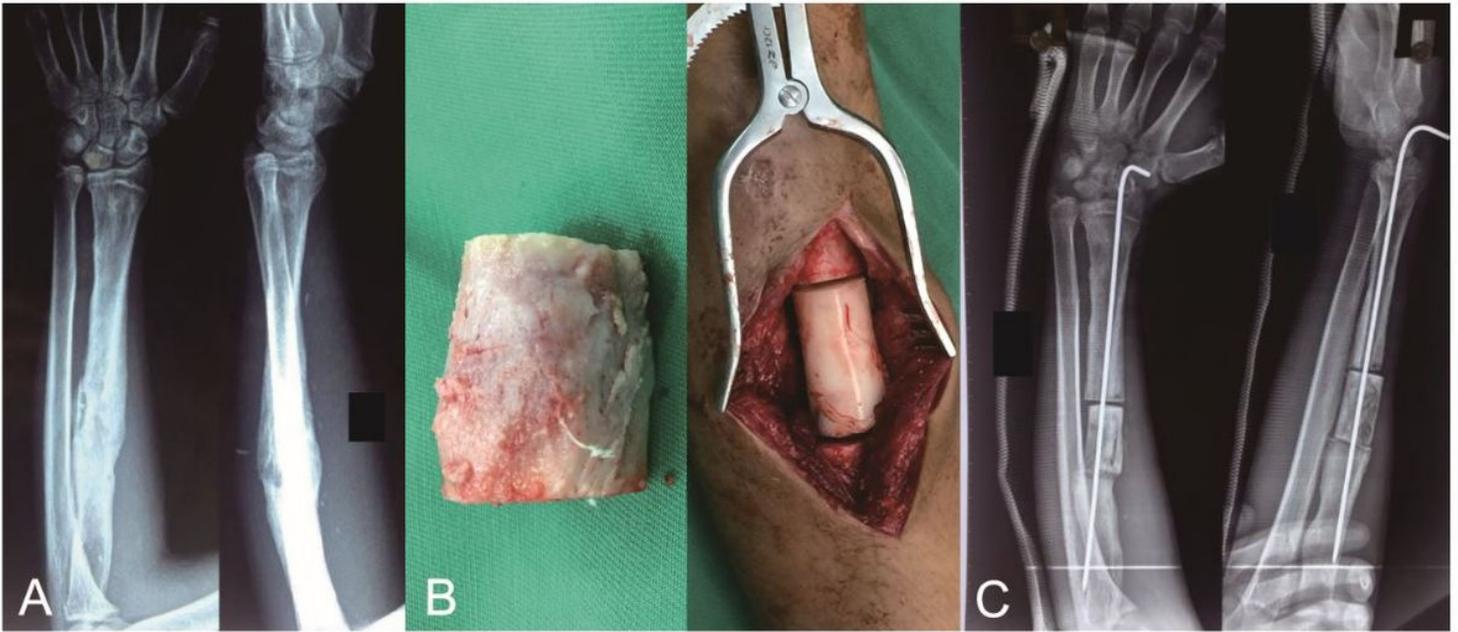
Case	EFT (days)	EFI (days/cm)	WF/WE(°)		EE/EF(°)		FP/FS(°)		Follow-up(months)
			Pre-op	Follow-up	Pre-op	Follow-up	Pre-op	Follow-up	
1	232	46.4	35-0-40	45-0-45	0-0-110	5-0-125	40-0-20	55-0-35	28
2	247	61.8	30-0-40	50-0-55	0-0-125	10-0-130	40-0-25	55-0-40	24
3	196	43.6	40-0-45	50-0-60	-10-0-115	0-0-125	45-0-30	60-0-45	30
4	253	56.2	20-0-20	20-0-25	5-0-110	5-0-125	35-0-25	50-0-25	24
5	182	45.5	45-0-40	45-0-50	10-0-130	10-0-130	50-0-40	65-0-50	36
6	223	44.6	55-0-50	55-0-50	0-0-125	0-0-125	70-0-65	70-0-65	24
7	184	40.9	40-0-40	50-0-45	0-0-125	5-0-140	40-0-30	50-0-45	32
8	251	41.8	45-0-30	65-0-55	-5-0-110	0-0-145	60-0-55	75-0-65	26
9	239	43.5	30-0-25	45-0-40	0-0-115	5-0-125	35-0-35	50-0-45	24
10	276	42.5	40-0-40	40-0-40	0-0-110	0-0-125	40-0-45	50-0-50	32
11	259	43.1	45-0-45	55-0-50	0-0-120	5-0-135	35-0-40	70-0-55	30
12	249	45.3	45-0-45	60-0-45	5-0-130	5-0-135	45-0-30	60-0-45	28

EFT: external fixation time, EFI: external fixation index, WF: wrist flexion, WE: wrist extension, EF: elbow flexion, EE: elbow extension, FP: forearm pronation, FS: forearm supination

Table 3  
Functional results

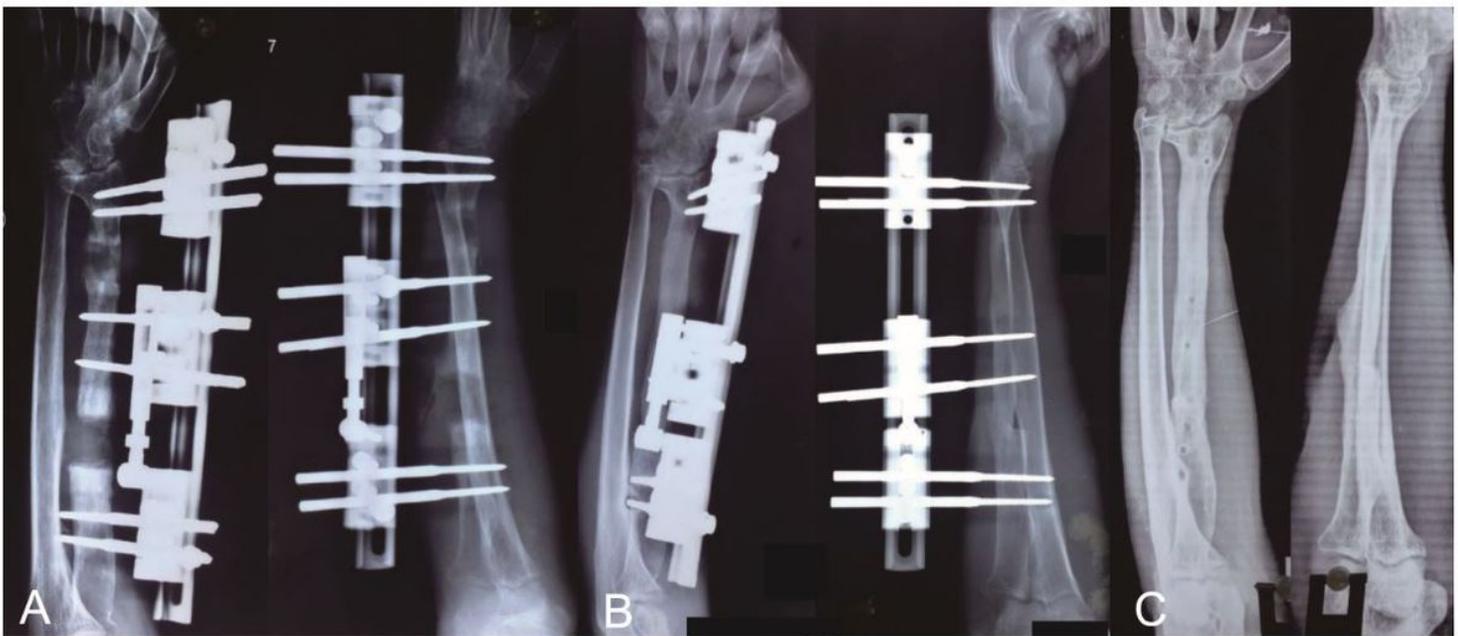
Case	DASH		MWS	
	Pre-op	Follow-up	Pre-op	Follow-up
1	34	11	55	85
2	18	5	75	90
3	31	18	70	85
4	49	26	50	65
5	25	10	70	90
6	22	13	80	85
7	26	16	70	80
8	29	12	75	85
9	37	15	60	85
10	30	17	75	80
11	34	12	75	85
12	32	10	70	90
Mean	30.6	13.8	68.8	83.8
t	10.955		-6.760	
P-value	P < 0.001		P < 0.001	
DASH: the questionnaire of Disability of Arm, Shoulder and Hand.				
MWS: the modified Mayo wrist score.				

## Figures



**Figure 1**

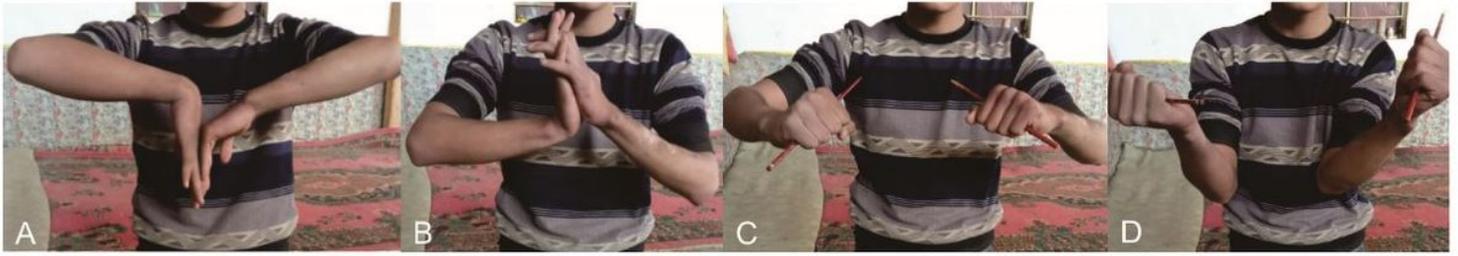
A 25-year-old man who suffered osteomyelitis in his left radius and treated by bone transport technique. a Preoperative AP and lateral views of X-rays. b Debridement of the infected site with a 4 cm bone defect in left radius and antibiotic bone cement was used to occupy the residual space. c Postoperative AP and lateral views of x-rays, the forearm was fixated by Kirschner wire and plaster cast.



**Figure 2**

X-rays of the bone transport procedure. a One month after the operation with bone transport. b Eight months after the operation with bone transport, consolidation of the regenerate and union at the docking

site was shown. c AP and lateral views of X-rays after removing the external fixator.



**Figure 3**

Functional assessment 24 months later, after removing the external fixator. a Wrist joint flexion was 20°. b Wrist joint extension was 25°. c Forearm pronation was 65°. d Forearm supination was 25°.