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Deformity correction by Ilizarov distraction osteogenesis after distal radius physeal arrest

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Objective: The aim of this study was to evaluate the results of osteotomy and distraction osteogenesis using Ilizarov circular external fixator to treat radial shortening and severe wrist deformity due to neglected post-traumatic distal radius physeal arrest.

Methods: The study retrospectively reviewed 4 patients (4 males; average age: 16 years; range: 14 to 19 years) who underwent osteotomy and distraction osteogenesis to treat radial shortening and severe wrist deformity due to neglected distal radius physeal arrest. Mean interval between trauma and surgical intervention was 8 (range: 4 to 12) years and mean follow-up time was 83 (range: 40 to 126) months. Patients were evaluated with radiographic measurements (shortening and lengthening ratio, radioulnar joint leveling, distal radioulnar joint congruency), objective functional measurements (grip and pinch strength, range of motion measurements [ROM]) and subjective functional measurements (Disabilities of the Arm, Shoulder and Hand [DASH] questionnaire and Mayo wrist score). Statistical analysis was made using the Mann-Whitney U non-parametric test.

Results: Radiographic measurements were obtained preoperatively and at the final follow-up. The mean shortening ratio of the radius was 14.6% (range: 9.3% to 18.7%) and mean lengthening ratio was 15.9% (range: 13.2% to 18.3%). Normal distal radioulnar joint leveling and distal radioulnar congruency resembling a joint was established in all but one patient with four millimeters of ulna plus deformity. According to the Mann-Whitney U non-parametric test, there was no statistical difference in grip and pinch power, ROM on flexion/extension, and ulnar/radial deviation axis between the operated and non-operated sides. There was statistically significant pronation/supination restriction between the operated and non-operated sides ($p<0.04$). Mean DASH score was 2.07 (range: 0.0 to 8.3) and the mean Mayo wrist score was 89 (range: 75 to 100) points. According to the Mayo wrist score, results were excellent in one patient, good in two patients, and satisfactory in one patient.

Conclusion: The use of distal metaphyseal osteotomy and Ilizarov distraction osteogenesis is a viable treatment method for neglected physeal fractures of the distal radius as it establishes acceptable deformity correction and a functional wrist joint.

Key words: Distal radius fracture; distraction osteogenesis; growth plate; Ilizarov technique; Salter-Harris fracture.

Physeal injuries compromise approximately 30% of long bone fractures in children and are twice as common in the upper extremity.[1] Seventy-five percent of forearm fractures in children take place in the distal third, including physeal fractures of the distal radius and ulna.[2] A Salter-Harris Type 5 fracture is a compression fracture of the physis, in which the cartilage cells of the physis are injured, producing permanent

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damage.[2] Growth disturbance usually occurs despite the treatment method. The incidence rate of post-traumatic distal radius physeal arrest is reported to be 1% to 7%.[3] No dependable radiographic prognostic criteria exist to predict the amount of physeal disturbance at the time of injury and these fractures can usually be recognized retrospectively after growth disturbance develops.[2,3] As 85% of radius growth occurs at the distal physis, injuries involving radial physis can lead to considerable shortening and deformity.[2,3] In neglected cases, severe length discrepancy develops between the radius and ulna when the ulna stays normal in length and position and forces radial deviation of the carpal bones and hand. Despite the deforming forces, carpal bones usually stay aligned centrally over the radius. This form of deformity usually creates a painful and non-functional wrist joint and hand. Supination, pronation, ulnar deviation and dorsiflexion movements of the wrist joint are especially limited.

Although a number of surgical techniques have been described for the treatment of length discrepancy between the radius and the ulna, there is a limited number of reports in the literature concerning the treatment of forearm length discrepancies solely based on post-traumatic physeal arrest. In this study, we retrospectively reviewed the long-term follow-up results of gradual distraction and Ilizarov external fixator treatment of forearm length discrepancies resulting from post-traumatic physeal arrest.

Patients and methods

We retrospectively evaluated the results of distal radial osteotomy and distraction osteogenesis in the treatment of neglected post-traumatic distal radius physeal arrest. Four patients, (4 males; average age: 16 years; range: 14 to 19 years) with severe wrist deformity resembling radial club hand, were operated by the same senior surgeon between 2000 and 2007 at two different hospitals. All patients were already following a yearly follow-up protocol. Consent was obtained from the patient or legal guardian at the final follow-up. Two junior colleagues were assigned to perform programmed standard protocol in two different hospitals independent of the senior surgeon.

Patients presented to the clinic with the main complaint of hand deformity. Other common complaints included the inability to do daily activities, limitation of wrist motion and pain on supination/pronation. In all patients, there was a history of a fall on an outstretched hand with pain and swelling at the wrist joint. No patient had medical attention at the time of the injury and no radiographs were available from the time of initial injury. In all patients, preoperative radiographs revealed total destruction of the distal radius physis. Although classification was impossible due to the lack of initial radiographs, the injuries resembled Salter-Harris Type 5 physeal fractures. The proximal radioulnar joint was normal in all patients. Because of the arrest in longitudinal growth of the radius, all patients had wrist deformities resembling radial club hand. In all cases, there was considerable length discrepancy distally between the radius and ulna. The ulna was normal in length and position, forcing radial deviation of the carpal bones and hand. Despite the deformity, the carpal bones were centrally well-aligned over the radius in all patients. Mean interval between trauma and surgical intervention was 8 (range: 4 to 12) years. There was no additional bone or soft tissue pathology on the same extremity. Mean follow-up time was 83 (range: 40 to 126) months. Demographic data is documented in Table 1.

Radiographs were used to determine the shortening ratio of the radius in the forearm, which we defined as the ratio between the amount of length discrepancy (distance between the distal ulna and distal radiocarpal joint level), to the total length of the radius (A/B x 100) (Fig. 1). We defined the lengthening ratio of the radius in a forearm as the ratio between the lengthening to the current total length of radius (B/A x 100) (Fig. 2). Radiologic parameters and data are documented in Table 2.

Table 1. Demographic data.

Case	Gender	Age at the time of injury	Delay after fracture (year)	Age at the time of surgery	Follow-up length (mo.s)	Dominance of treated hand	Fixator duration (weeks)	Occupation
1	M	10	4	14	40	Non-dominant	16	Student
2	M	14	5	19	41	Dominant	20	Soldier
3	M	4	10	14	126	Dominant	16	Worker
4	M	6	12	18	123	Dominant	20	Worker

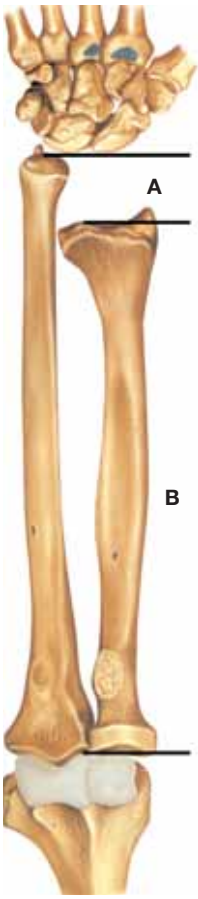

Fig. 1. Illustration for shortening ratio. *See* the text for explanation. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

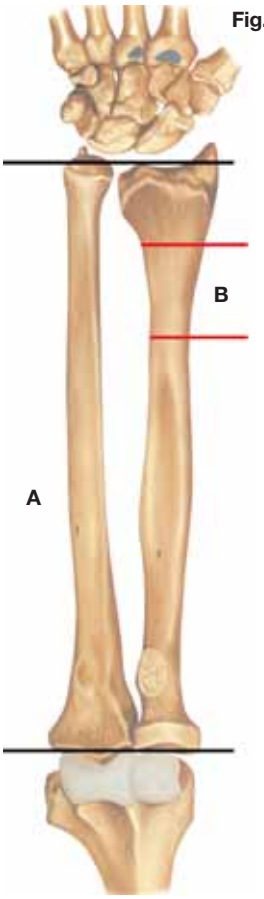

Fig. 2. Illustration for lengthening ratio. *See* the text for explanation. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Objective functional measurements consisted of active range of motion capacity (including flexion and extension, ulnar and radial deviation, and pronation and supination) measured at the final follow-up and compared to the non-operated normal extremity. Grip strength, measured with a dynamometer (Jamar®; Sammons Preston Rolyan, Bolingbrook, IL, USA), and lateral pinch strength, measured with a pinch gauge (B & L Engineering, Tustin, CA, USA), were measured at the same final postoperative examination and compared to the non-operated healthy side.

Subjective functional measurements consisted of the Mayo wrist score and the Disabilities of the Arm, Shoulder and Hand (DASH) outcome measure. The DASH is a 30-item, self-reported questionnaire designed to measure physical function and symptoms in people with any of several musculoskeletal disorders of the upper limb. The tool gives clinicians and researchers the advantage of having a single, reliable instrument that can be used to assess any or all joints in the upper extremity. The comparison of the objective and subjective functional measurement

Table 2. Radiological and clinical parameters.

Case	Age	Age at the time of injury	Delay after fracture (year)	Shortening ratio	Lengthening ratio	DRUJ congruency	Radioulnar joint level	DASH score	Mayo wrist score
1	14	10	4	9.3%	13.2%	+	Normal	0.0	100
2	19	14	5	12.9%	17.5%	+	Normal	0.0	90
3	14	4	10	18.7%	18.3%	+	Normal	0.0	90
4	18	6	12	17.6%	14.7%	-	Ulna plus deformity (4 mm)	8.3	75

DRUJ: Distal radioulnar joint

values of the normal and operated sides is documented in Table 3.

All patients were operated by the senior author. The distal radius was exposed through a five centimeters longitudinal dorsal incision. The extensor tendons were retracted. The level of osteotomy was estimated by direct visualization, comparing the sagittal and horizontal angulations of the distal radius joint line with the plane of the proposed osteotomy site. Osteotomy was performed at the metaphyseal region of the radius. A pre-assembled Ilizarov circular external fixator with two rings, with two pins on each ring, was used for fixation after osteotomy. In one patient, two longitudinal Schanz screws were used to establish better rotational control of the proximal and distal parts of the radius. All patients were discharged the next day after instructions about pin site care and distraction mechanism. In all patients, the external fixator was removed after solid callus formation. External fixators remained in place for an average of 5 (range: 4 to 6) months. A short arm cast was used for three weeks following the removal of the device. No rehabilitation was instituted and patients were given instructions on self-exercises and encouraged to return normal daily living conditions.

The Mann-Whitney U non-parametric test was used for statistical analysis. A p value of ≤ 0.05 was reported as statistically significant.

Pictures of Case 3 are given below for illustrative purposes (Fig. 3).

Results

Mean follow-up time was 83 (range: 40 to 126) months. No early or late neurovascular compromise was seen in any patient. One patient had a superficial pin tract infection which was managed with oral antibiotics and frequent pin site care. There were no deep pin tract infections. All patients experienced discomfort and slight pain during the first three weeks of lengthening. Breaks of one to three days were exercised during the painful early phases of distraction.

The objective functional measurements of active and passive range of motion (ROM) capacity and grip and pinch strength of the index and normal side were recorded. According to the Mann-Whitney U test, there were no statistical differences in grip and pinch power, ROM measurements on flexion/extension and ulnar /radial deviation axis between the operated and non-operated sides. There was a statistically significant restriction on motion at pronation/supination axis between the operated and non operated sides ($p<0.05$).

Mean DASH score was 2.07 (range: 0.0 to 8.3) and mean Mayo wrist score was 89 (range: 75 to 100) points. According to the interpretation of the Mayo wrist score, one excellent, two good and one satisfactory results were obtained (Table 3). All patients were able to return to active regular employment status. There were no subjective complaints about the appearance or functions of the operated wrist. One patient (Case 4) who experienced post-treatment pain in supination refused to undergo a salvage procedure for the distal radioulnar joint.

Mean shortening ratio of the radius was 14.6% (range: 9.3% to 18.7%). The mean lengthening ratio was 15.9% (13.2 % to 18.3 %). In all but one patient a distal radioulnar congruency resembling a joint was established and a normal distal radioulnar joint level was established in 3 of the 4 patients. In one patient, the distal radioulnar joint was not well-aligned (four millimeters of ulna plus deformity) because of limitations due to aggravated pain and clawing tendency.

The good objective results, subjective measurements (DASH and Mayo wrist score) and radiograph-

Table 3. Comparison of objective and subjective measurements of the healthy and operated sides.

Case	1	2	3	4	5	6	7	8	9	10	DASH score	Mayo wrist score
1	90	85	7.3	7.1	70°/70°	40°/70°	90°/90°	60°/30°	40°/20°	15°/20°	0.0	100
2	130	110	9.4	9.2	80°/70°	60°/60°	90°/90°	60°/70°	40°/20°	25°/20°	0.0	90
3	140	80	9.2	8.2	90/80	80°/70°	90°/90°	90°/90°	30°/20°	30°/20°	0.0	90
4	125	90	9.5	9.1	80/80	70°/40°	90°/90°	60°/30°	30°/20°	30°/20°	8.3	75

1. Grip strength (healthy side), 2. Grip strength (operated side), 3. Pinch strength (healthy side), 4. Pinch strength (operated side), 5. Flexion/extension (healthy side), 6. Flexion/extension (operated side), 7. Supination/pronation (healthy side), 8. Supination/pronation (operated side), 9. Ulnar/radial deviation (healthy side); 10. Ulnar/radial deviation (operated side)

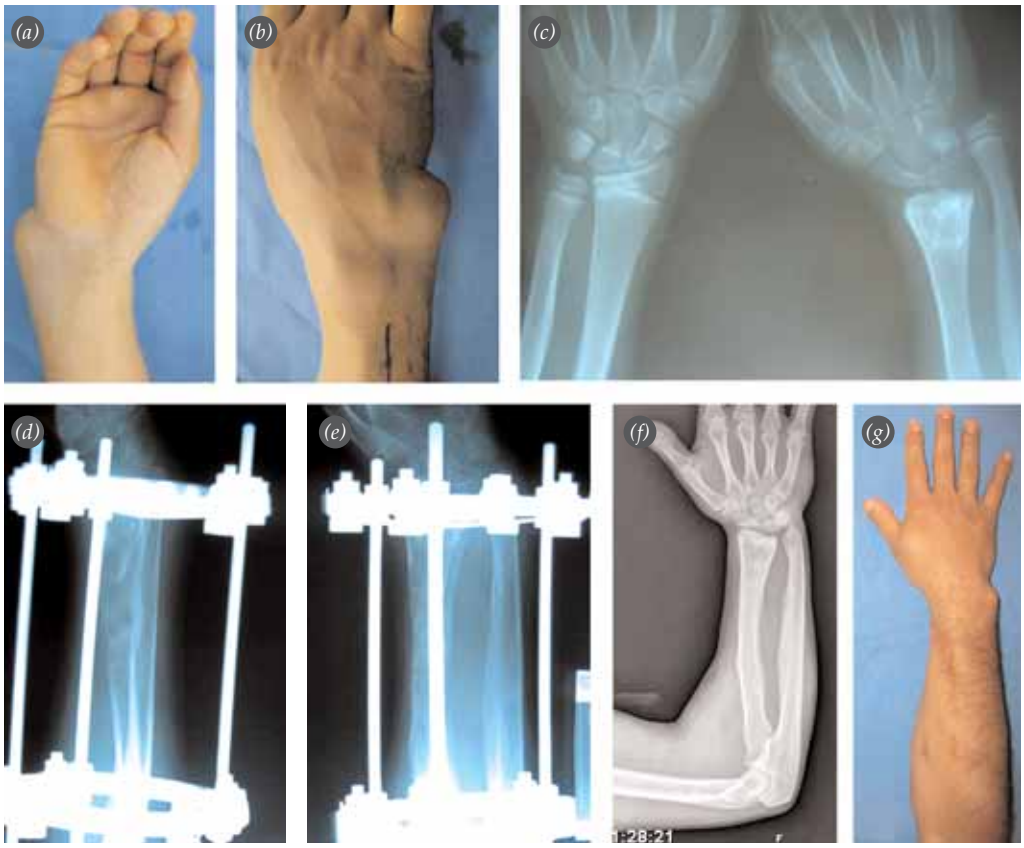

Fig. 3. **(a, b)** A 14-year-old patient who sustained a possible Salter-Harris Type 5 fracture of distal radius ten years previously. Note the dramatic radial deviation of the hand and prominent distal ulna. **(c)** Distal ulna and physis are normal in alignment and appearance. Distal radial physis was totally compressed. There was 19% shortening. Despite the abnormal biomechanics, the carpus aligned well with the distal radius. **(d, e)** After four months, there was a visible consolidation of the callus at the osteotomy site. Distal radioulnar joint appeared well-aligned. Radius was lengthened to the total amount of shortening, despite open physis (18%). There were limitations due to aggravated pain and clawing tendency. **(f, g)** Distal ulna and radius appear well-aligned at the last follow-up (126 months after surgery). [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

ic findings were consistent. Because of the low number of subjects in the study, this observation was statistically evaluated using the Mann-Whitney U nonparametric test.

A functional and aesthetic wrist joint with minimal pain was established in all patients despite the inability to obtain a radiographically normal distal radioulnar joint due to the unpredictable destruction of physis.

Discussion

Injuries that involve the physis and the epiphysis can cause growth arrest and resultant angular deformity. Impairment of the longitudinal growth of a specific bone depends on the age of the patient at the time of physeal injury, amount of the energy absorbed by the physis and the probable potential input of the physis to the longitudinal growth.[1,2] The most commonly used classification for physeal injuries was described by Salter and Harris, based on the radiographic appearance of the fracture.[4] Salter-Harris Type 1 and 2 fractures are common and Type 3 and 4 fractures are rare. A Salter-Harris Type 5 fracture is a compression fracture of the physis. The cartilage cells of the physis are crushed, producing permanent damage.[4] In Type 5 injury, growth disturbances usually occur regardless of the form of treatment.[2]

Physeal injuries account for approximately 30% of long bone fractures in children.[1,2] They occur twice as common in the upper extremities as in the lower extremities.[1,2] Seventy-five percent of forearm fractures in children are located in the distal third.[2] In

addition to single or both-bone fractures, physeal fractures of the distal radius and ulna also occur.[2] Post-traumatic distal radius physeal arrest incidence is reported to be 1% to 7%.[3] Because there are no reliable radiographic prognostic criteria to predict physeal disturbance at the time of injury, these fractures are often diagnosed retrospectively when a growth disturbance develops.[2,3] As approximately 85% of the growth of ulna and radius occur at the distal physis, physeal arrest at the distal radius after a Salter-Harris Type 5 fracture can lead to severe shortening and multi-planar deformity at upper extremity as ulna continues to grow longitudinally.[3,5]

A length inequality due to physeal arrest in the upper extremity is not regarded as important to function as inequality in the lower extremity and is generally considered to be better tolerated.[2] However, this is not the case for distal radial physeal injuries as the two bones are located parallel to each other, creating a biomechanical medium for supination and pronation. It has been stated that patients with forearm bone shortening of more than one centimeter are symptomatic.[3,6,7] The term "post-traumatic radial club hand" was coined by Ring et al. to describe the severe radial deviation deformity and functional impairment of the hand and wrist joint that resembles a radial club hand after distal radius fracture.[6]

A number of surgical techniques have been described, such as immediate filling of the gaps with strut bone grafts and lengthening with or without an osteotomy (with the help of epiphysiolysis) using uniplanar or circular distraction devices, for the treatment of the length discrepancy between the radius and the ulna.[3,8-11] Reports in the literature describing the treatment of radial shortening focus mainly on mixed series, such as tumors, congenital deformities, and post-traumatic defects.[12] A limited number of reports exist concerning the treatment using gradual distraction and Ilizarov external fixators of forearm length discrepancies solely resultant on post-traumatic physeal arrest in the pediatric population. As this is a relatively uncommon problem, the current study only includes four patients.[3]

Limitations of our study included the small number of patients and the lack of preoperative outcome measures for prospective comparison of treatment methods. However, this is an uncommon problem and a prospective comparison between the uniplanar and circular external fixator with the use of osteotomy would be difficult to execute.

In conclusion, distal metaphyseal osteotomy and Ilizarov distraction osteogenesis can be considered a viable treatment method for neglected physeal fractures of the distal radius because of its ability to correct deformity in multiple planes without bone grafting. Distraction osteogenesis establishes acceptable deformity correction and a functional and aesthetic wrist joint with minimal pain wrist joint despite the inability to obtain a radiographically normal distal radioulnar joint due to unpredictable destruction of physis.

Conflicts of Interest: No conflicts declared.

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