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ARTICLE

How long does it to achieve sagittal realignment of the displaced epiphysis in Salter-Harris type II distal radial fracture when treated by manual reduction?

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ABSTRACT

This study aimed to investigate how long it takes for the dorsally displaced distal radial epiphysis to achieve realignment. We retrospectively reviewed 56 patients with dorsally displaced Salter-Harris type II distal radial epiphyseal fractures who were aged ≤15 years at the time of injury. All fractures were treated with closed reduction and immobilised using a sugar tong splint for 6 weeks. We evaluated the change in the displaced epiphysis position (%) until 12 weeks and the long-term clinical and radiological outcomes. We analysed significant differences in demographic factors and epiphyseal displacement according to the required period for epiphyseal realignment. The estimated area of the receiver operating characteristics (ROC) curve was calculated, and cut-off values were suggested to predict the required period for epiphyseal realignment. Sixteen (28.6%) and 42 (75%) patients achieved realignment of the epiphysis within 8 and 12 weeks, respectively. The cut-off values of 13.1 and 22.9% displacement at the 1-week follow-up were the best predictors of epiphyseal realignment within 8 and 12 weeks, respectively. Patients with a residual displacement of up to 51.3% in the sagittal plane at the 1-week follow-up achieved complete realignment of the epiphysis at the 6-month follow-up. From this study, we could predict the timing of epiphyseal realignment, and expect epiphyseal realignment even if re-displacement occurred up to 51.3% at the 1-week follow-up.

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IV; case series

Introduction

Forearm fractures are known to account for 40% of all paediatric fractures, and the distal radius is the commonly affected site [1]. Fifteen percent of these fractures involve the physis [2], of which the Salter-Harris type II (SH II) fractures are the most common [3]. However, there is a paucity of studies about the natural history and treatment guidelines for paediatric patients compared to those for adult patients [4]. A recent systematic review concluded that no recommendations can be made about an acceptable reduction or surgical indication of SH type II distal radial fractures in children [4].

SH II distal radial fractures are generally treated non-operatively and some authors have reported related long-term outcomes [1,4,5]. However, there is a paucity of studies describing the normal recovery process of non-operative treatment of SH II distal radial fractures [4–9]. In 1935, Aitken [6,7] described the recovery process of distal radial epiphyseal fractures in two aspects. One was the realignment of the displaced distal radial epiphysis, which means that a displaced epiphysis achieved its normal relationship to the radius shaft, and the other was the remodelling of residual angulations of the radius, such as volar tilt. He reported that the displaced distal radial epiphysis realigned within 1 year and that remodelling of residual angulation progressed within 2 years of follow-up unless complication-related physis occurred. However, to the best of our knowledge, studies examining the process of epiphyseal realignment are lacking, as most have focused on the remodelling of residual angulation. For the sake of both clinical practice and building upon research knowledge, we sought to understand the epiphyseal realignment process and its characteristics, as well as gain the ability to explain the process to parents and inform them as to whether their children's recovery process differs from that of others.

Therefore, this study aimed to investigate the process of realignment of the displaced distal radial epiphysis, meaning that the displaced epiphysis achieved a normal relationship to the radius [6,7], by addressing the following research question: how long does it take to achieve realignment of a displaced distal radial epiphysis?

Materials and methods

Patients

We retrospectively reviewed 72 patients with SH type II distal radial epiphyseal injury who presented to our institution between 2005 and 2019. We obtained approval from the institutional review board. The inclusion criteria were SH type II distal radial fractures with dorsally displaced epiphysis and patient age ≤15 years at the time of injury. Patients who were followed up for <12 weeks, underwent operative treatment and presented at >7 days after injury were excluded. Finally, 56 patients with SH type II distal radial fractures of the displaced epiphysis were analysed. The mean age at the time of fracture was 10.7 years (range, 5–15 years). There were 41 boys (mean age: 11.3 ± 2.4 years) and 15 girls (mean age: 9.0 ± 2.4 years). The mean time from the occurrence of fracture to closed reduction was 1.4 days (range, 0–7 days), and the mean follow-up period was 20.1 months (range, 3–96 months). The injury mechanisms were as follows: fall-down

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($n = 25$), soccer ($n = 7$), skate ($n = 7$), swing ($n = 6$), bicycle ($n = 6$), slip-down ($n = 3$), and ski ($n = 2$).

Treatment and follow-up routine

All fractures were treated with closed reduction and immobilised using a sugar tong splint for 6 weeks [9]. Closed reduction was performed with analgesia and/or sedation if needed. Gentle distraction and flexion of the wrist were used for manipulation to reduce the displaced distal radial epiphysis. An assistant supported the upper extremity in the proper position and tension for the splint. In cases wherein the residual epiphyseal displacement was >40%, the manual reduction was performed again. We accepted residual epiphyseal displacement after two trials of reduction regardless of the degree of residual epiphyseal displacement. Four patients required two trials of reduction. The fractures were monitored at 1, 3–4, 6–8, and 12 weeks. After 6 months of follow-up, we recommended annual follow-up until maturity.

Measurement

We measured the percentage of the degree of distal radial epiphyseal displacement in the sagittal plane on the lateral wrist radiographs (Figure 1) [10]. As there was a metaphyseal fracture in the SH type II distal radius fracture, we measured the length of epiphysis (A) instead of the length of the metaphysis (C) to avoid overestimation of the entire length, and the displaced distance of the epiphysis (B) (Figure 1). The degree of displacement of the distal radial epiphysis is expressed as a percentage according to the following calculation formula: displacement (%) = (B/A) × 100 (Figure 1). The changes in the displacement of the distal radial epiphysis (%) at pre-reduction (or initial), post-reduction, and at the 1-, 3–4-, 6–8-, and 12-week follow-up were evaluated (Figures 2(A–F)). The patients were classified according to the period required for a complete realignment of the displaced epiphysis. Long-term clinical and radiologic outcomes were evaluated in patients who were followed up for >1 year as a final evaluation (Figures 2(G–L)). The criteria for normal radiologic alignment by comparing the abnormal and normal sides were as follows [10,11]: (1) difference in radial inclination of <3°, (2) difference in the volar tilt of <5°, and (3) ulnar positive variance of <1 mm. A patient that satisfied all the criteria was defined as having a normal radiologic alignment. The criteria for acceptable clinical outcomes were defined as follows: (1) normal or near the normal range of motion of the wrist joint, (2) no or slight wrist pain, (3) no or slight subjective weakness of grip strength, and (4) no gross deformity of the wrist. A patient who satisfied all these criteria was defined as an acceptable clinical outcome.

Statistical analysis

Statistical analyses were performed using SPSS for Windows (ver. 20.0 SPSS Inc., Chicago, IL, USA) and MedCalc Statistical Software ver. 19.8 (MedCalc Software Ltd., Ostend, Belgium). Descriptive statistics, including the mean and standard deviation, were determined. The Kolmogorov-Smirnov test was used to verify the normality of the distributions of continuous variables. Continuous variables were compared using the Student's *t*-test. We compared the displacement of the epiphysis at pre- and post-reduction and the 1-week follow-up according to the required period for the realignment of the epiphysis. Receiver operating characteristic (ROC) curve analysis was performed to determine the estimated area and sensitivity and specificity of the cut-off values of the displacement of the epiphysis (%) to predict the period required for the realignment of the displaced epiphysis. The De-Long test was used to detect the significance of the area under the curve (AUC) at each measurement. All statistics were two-tailed, and a *p*-value <0.05 was considered significant.

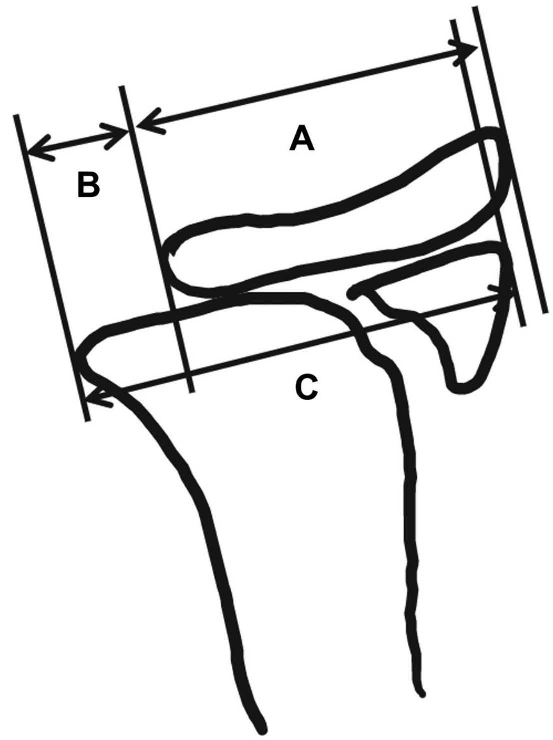

Figure 1. Illustration for the measurement of the degree of displacement of the distal radial epiphysis in the sagittal plane on the lateral wrist radiographs. As there was a metaphyseal fracture in the Salter-Harris type II distal radius fracture, we measured the length of the epiphysis (A) instead of the length of the metaphysis (C) to avoid overestimation of the entire length, and the displaced distance of the epiphysis (B). The degree of displacement of the distal radial epiphysis is expressed as a percentage according to the following calculation formula: displacement (%) = (B/A) × 100.

Results

How long does it take to achieve realignment of the displaced distal radial epiphysis?

Overall, 16 (28.6%) and 42 (75%) patients achieved realignment of the epiphysis within 8 and 12 weeks, respectively. There were significant differences in epiphyseal displacement at pre-reduction and the 1-week follow-up between patients who achieved epiphyseal realignment within 8 weeks and those with residual epiphyseal displacement at 8 weeks (Table 1). Additionally, significant differences were noted in the epiphyseal displacement at pre-reduction, post-reduction, and 1-week follow-up between patients with epiphyseal realignment within 12 weeks (including patients with epiphyseal realignment within 8 weeks) and those with residual epiphyseal displacement at 12 weeks (Table 2).

Among 56 patients, 43 were followed up until 6 months. All patients achieved realignment of the epiphysis. Among the 43 patients, 11 patients (25.6%) achieved realignment of the epiphysis between 12 weeks and 6 months. The residual displacement at the 1-week follow-up was 15.2–51.3% in patients who achieved complete epiphyseal realignment between 12 weeks and 6 months. Patients with 51.3% of the residual displacement at the

Figure 2. Radiographs of an 8-year-old girl showed a displaced epiphysis due to an SH II distal radial fracture, which was treated with closed reduction and maintained using a sugar-tong splint. (A,B) Initial radiographs before closed reduction. There was 38% epiphyseal displacement in the sagittal plane [A = 16.3 mm, B = 6.2 mm, displacement (%) = (6.2/16.3) × 100 = 38%]. (C) There was 15.4% residual epiphyseal displacement in the sagittal plane after one trial of closed reduction. (D) At the 1-week follow-up, the residual epiphyseal displacement increased to 27.5% in the sagittal plane. (E) There was 14.5% of residual epiphyseal displacement in the sagittal plane at the 8-week follow-up. (F) Epiphyseal realignment was achieved at 12 weeks of follow-up. (G,H) Radiographs of the unfractured side after 7 years and 4 months, at the age of 16 years. The physis was closed. The radial inclination was 24.2°, volar tilt was 13.1°, and positive ulnar variance was 2.2 mm. (I,J) Radiographs of the fractured side after 7 years and 4 months at the age of 16 years. The physis was closed. The radial inclination was 26.8°, volar tilt was 17.3°, and positive ulnar variance was 3.5 mm. The patient showed abnormal radiologic alignment with a positive ulnar variance of more than 1-mm. (K,L) The medical photographs after 7 years and 4 months of follow-up at the age of 16 years. The full range of motion was achieved without gross wrist deformity. She showed acceptable clinical outcomes at the final follow-up.

Figure 2. Continued

Table 1. Comparison between patients who achieved and who did not achieve realignment of the displaced epiphysis within 8 weeks.

	Realignment within 8 weeks ($n = 16$)	Residual displacement at 8 weeks ($n = 40$)	p-Value
Age (years)	11.7 ± 2.4	10.3 ± 2.6	0.069
Mean time from the occurrence of fracture to closed reduction	1.0 ± 1.5	1.5 ± 2.2	0.402
Initial displacement (%)	20.6 ± 9.1	46.9 ± 31.7	0.002
Displacement at post-reduction (%)	12.2 ± 5.8	16.5 ± 10.0	0.108
Displacement at 1-week follow-up (%)	11.6 ± 5.8	21.2 ± 11.8	0.003

Results are expressed as mean ± standard deviation.

Table 2. Comparison between patients who achieved and who did not achieve realignment of the displaced epiphysis within 12 weeks.

	Realignment within 12 weeks ($n = 42$)	Residual displacement at 12 weeks ($n = 14$)	p-Value
Age (years)	11.0 ± 2.3	9.9 ± 3.2	0.163
Mean time from the occurrence of fracture to closed reduction	1.6 ± 2.2	0.6 ± 0.9	0.123
Initial displacement (%)	34.5 ± 29.0	54.2 ± 27.4	0.030
Displacement at post-reduction (%)	12.8 ± 6.5	22.6 ± 11.9	<0.001
Displacement at 1-week follow-up (%)	14.5 ± 6.8	30.2 ± 14.0	<0.001

Results are expressed as mean ± standard deviation.

Table 3. Characteristics of 11 patients who achieved epiphyseal realignment between the 12-week and 6-month follow-up.

	Mean ± standard deviation	Range
Age (years)	9.8 ± 3.1	5–15
Mean time from occurrence of fracture to closed reduction	0.6 ± 1.0	0–3
Initial displacement (%)	53.6 ± 28.5	10.1–100
Displacement at post-reduction (%)	34.2 ± 11.6	8.9–43.1
Displacement at 1-week follow-up (%)	36.1 ± 23.4	15.2–51.3

1-week follow-up also achieved complete realignment of the epiphysis at the 6-month follow-up (Table 3, Figure 3).

Twenty-six patients were followed up for >1 year. Among them, 53.8% (14 patients) achieved normal radiologic alignment. The ulnar positive variance was the most common abnormal radiologic outcome, which was observed in 10 patients. The other outcomes were as follows: decreased volar tilt ($n = 1$) and physeal bar formation, ulnar positive variance, and increased volar tilt ($n = 1$). There were no significant differences in demographics and epiphyseal displacement between patients with normal and abnormal radiologic alignment (Table 4). There were two patients with unacceptable clinical outcomes: one patient underwent ulnar shortening osteotomy due to ulnar impaction symptoms with ulnar positive variance and the other underwent physeal bar resection due to wrist pain and gross deformity.

What factors influence the period required for the realignment of the displaced distal radial epiphysis?

The ROC curve analysis revealed that the residual displacement at the 1-week follow-up was the best predictor of realignment of the epiphysis within 8 and 12 weeks, showing the highest AUC values (Figures 4(A,B), Tables 5, 6). The cut-off values of 13.1 and 22.9% of residual epiphyseal displacement at the 1-week follow-up were predictors for epiphyseal realignment at 8 and 12 weeks, respectively (Figures 4(A,B), Tables 5, 6). When the residual epiphyseal displacement was <13.1%, 50% of the patients achieved epiphyseal realignment within 8 weeks, but when the displacement was >13.1%, only 12.5% of the patients achieved epiphyseal realignment within 8 weeks (Figure 5(A)). When the residual epiphyseal displacement was <22.9%, 90.7% of the patients achieved epiphyseal realignment within 12 weeks, but when the displacement was >22.9%, only 23.1% of the patients achieved epiphyseal realignment within 12 weeks (Figure 5(B)).

Discussion

The residual displacement of the epiphysis at the 1-week follow-up can be a useful parameter to predict the realignment of the epiphysis in SH type II distal radial fractures with dorsally displaced epiphysis. When the residual epiphyseal displacement was <13.1% at the 1-week follow-up, half of the patients achieved

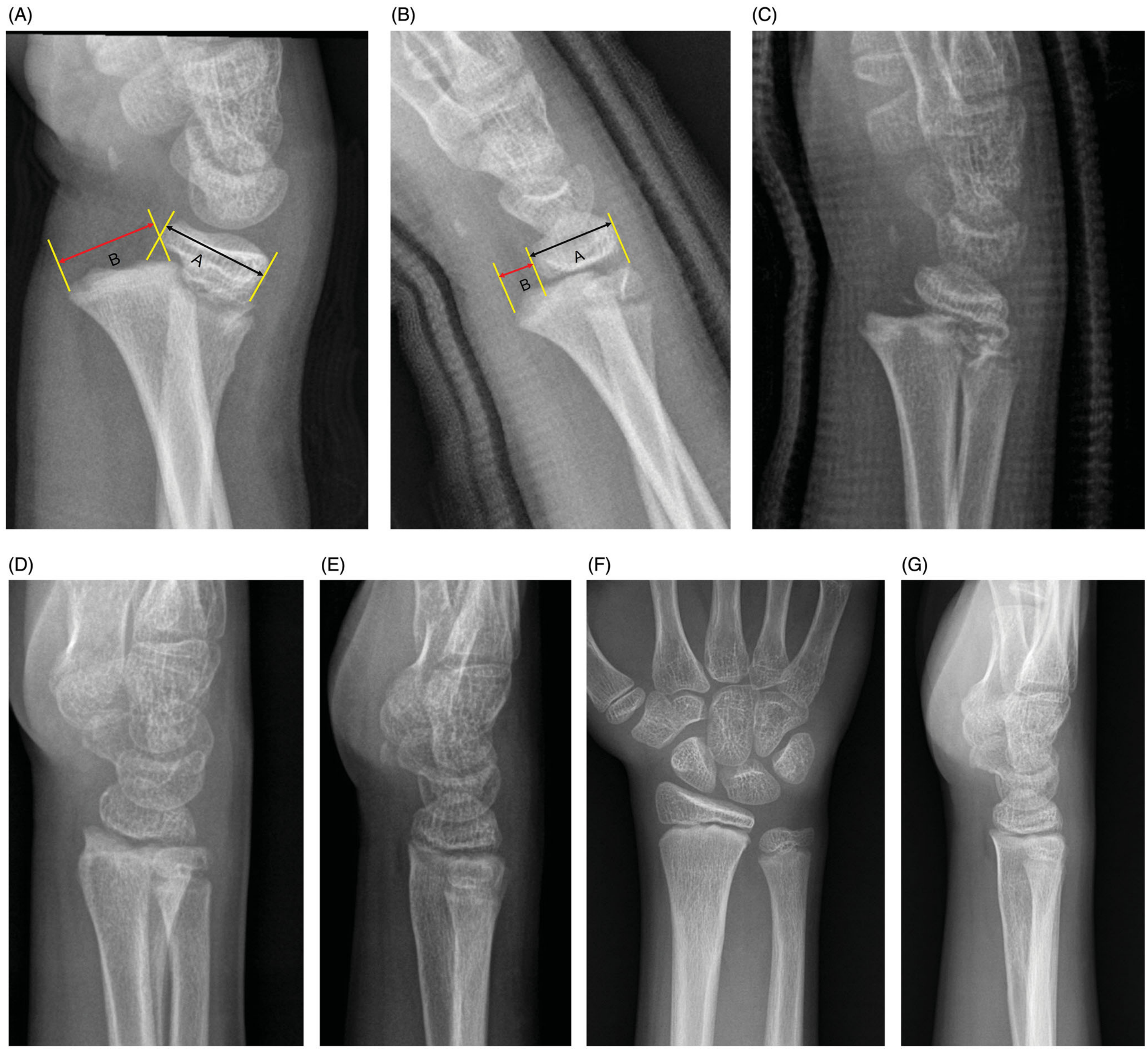

Figure 3. Radiographs of a 10-year-old boy showed a displaced epiphysis due to an SH II distal radial fracture, which was treated with closed reduction and maintained using a sugar-tong splint. (A) Initial radiographs before closed reduction. There was 99% epiphyseal displacement in the sagittal plane. (B) There was 40.5% residual displacement in the sagittal plane after one trial of closed reduction. (C) At the 1-week follow-up, the residual epiphyseal displacement increased to 51.3%. (D) At 12 weeks of follow-up, the residual epiphyseal displacement decreased to 7%. (E) Epiphyseal realignment was achieved at 6 months of follow-up. (F,G) The radiographs of the fractured side after the 1-year follow-up at the age of 11 years. Acceptable radiologic alignment was achieved.

epiphyseal realignment within 8 weeks. When the residual epiphyseal displacement was <22.9% at the 1-week follow-up, 90.7% of the patients achieved epiphyseal realignment within 12 weeks. All patients achieved epiphyseal realignment at 6 months of follow-up, including those with up to 51.3% of epiphyseal displacement at the 1-week follow-up in a subgroup analysis of patients who were followed up until 6 months. There was an abnormal radiologic alignment in approximately half of the patients at the final follow-up in a subgroup analysis of patients who were followed up for >1 year. The ulnar positive variance was the most common abnormal finding. Among them, only two patients underwent additional surgery due to unacceptable clinical outcomes.

Few studies have reported on epiphyseal realignment and its significance in SH II distal radial fractures. In 1935, before the introduction of the Salter-Harris classification, Aitken suggested four key findings after observing about 60 cases of distal radial epiphyseal injury [6,7]. First, the displaced epiphysis achieved realignment within a maximum period of 2–3 years (usually 5–8 months). Second, the process of epiphyseal realignment included absorption of the volar portion and production of the bone on the dorsum of the distal radius. Third, although the temporary growth retardation was commonly noticed, it had no clinical importance. Fourth, the reduction occurred at any age, regardless of the proximity to the normal ossification time. In 1965, Bragdon [9] treated 31 patients with Aitken type I distal radial epiphyseal fractures, which corresponded to SH type II, and supported the findings of Aitken's study [6,7]. He suggested that repeated manipulation might be harmful and is not necessary if at least 50% apposition was obtained, and the sugar-tong splint was a satisfactory and safe method to immobilise this injury [9]. In 1984, Lee et al. [5] also found that there was a correlation

Table 4. Comparison between patients with normal and abnormal radiologic alignment at the final follow-up.

	Normal radiologic alignment group ($n = 14$)	Abnormal radiologic alignment group ($n = 12$)	p-Value
Age (years)	9.9 ± 3.2	11.1 ± 2.1	0.297
Mean time from the occurrence of fracture to closed reduction	0.6 ± 1.1	1.0 ± 1.6	0.505
Initial displacement (%)	44.9 ± 34.3	33.5 ± 17.5	0.309
Displacement at post-reduction (%)	19.0 ± 12.2	15.7 ± 8.3	0.426
Displacement at 1-week follow-up (%)	21.6 ± 14.9	17.4 ± 10.0	0.415

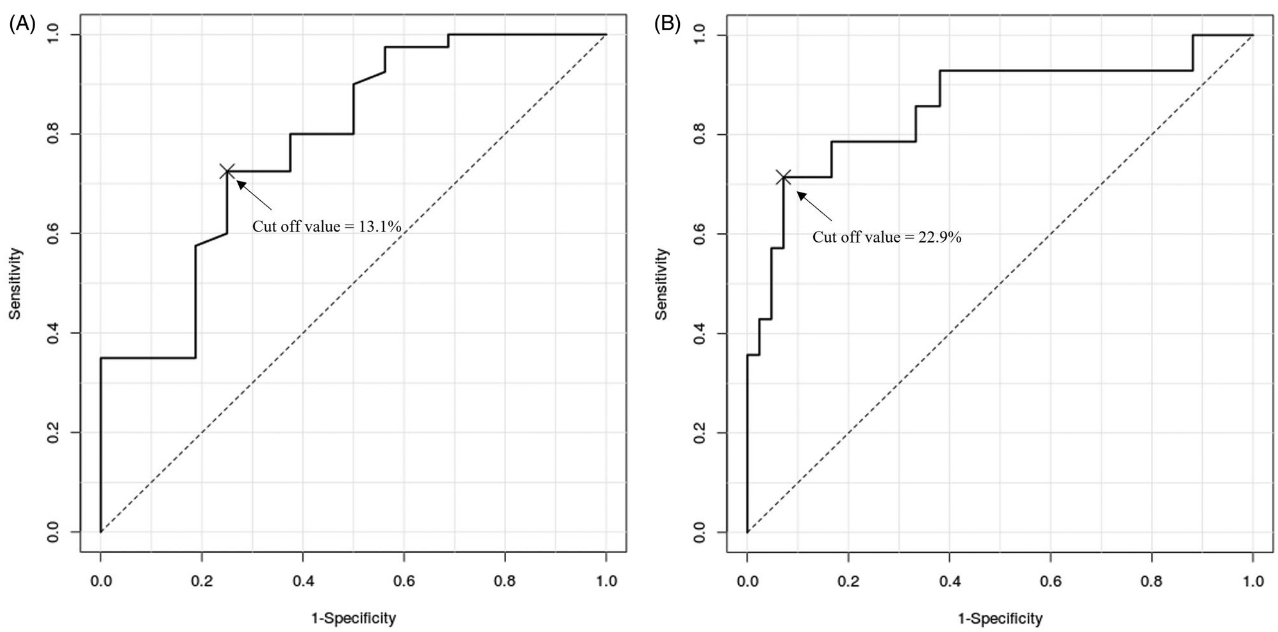

Figure 4. Receiver operating characteristics (ROC) curve analysis. (A) ROC curve analysis to determine the predictive cut-off value of the residual epiphyseal displacement at the 1-week follow-up for complete epiphyseal realignment within 8 weeks. (B) ROC curve analysis to determine the predictive cut-off value of the residual epiphyseal displacement at the 1-week follow-up for complete epiphyseal realignment within 12 weeks.

between the higher incidence of premature growth failure and multiple attempts at a closed reduction after reviewing 100 cases of distal radial epiphyseal fractures. According to the suggestions of previous studies, we performed closed reduction only up to two times; the residual displacement was accepted, and the fractures were monitored. In 2004, Houshian et al. [8] reviewed 85 cases of SH type II distal radial fractures and reported that most patients showed remodelling of the physis. They suggested that there was no impairment of wrist function in cases of epiphyseal displacement up to 40% [8]. The findings of our study are consistent with the results of the previous studies [8]. We could achieve realignment of the epiphysis within 6 months, and acceptable radiologic and clinical outcomes with limited trials of closed reduction and immobilisation using a sugar-tong splint were obtained in patients with a displacement of the epiphysis up to even >50% at the 1-week follow-up.

However, some new findings were not addressed previously. First, the residual displacement at the 1-week follow-up was the most important factor for predicting the required period of epiphyseal realignment. Second, we suggested specific cut-off values for the residual displacement at the 1-week follow-up for predicting the required period for epiphyseal realignment. As mentioned above, at the residual epiphyseal displacement cut-off values of <13.1 and 22.9%, the time required for epiphyseal realignment was 8 and 12 weeks, respectively.

The common occurrence of ulnar positive variance at the final follow-up in this study supported the previous findings that temporary growth retardation occurred commonly but had no clinical importance. Only one patient complained of ulnar wrist pain and underwent ulnar shortening osteotomy among nine patients with ulnar positive variance.

Lee et al. [5] reported no correlation between post-reduction fracture angulation or displacement and the development of premature growth plate closure. Larsen et al. [4] suggested that patients younger than 10 years were at high risk for symptomatic shortening if a growth arrest occurred. In our study, the initial displacement was 32.1% that reduced to 13.1% at the 1-week follow-up after only one trial of reduction in a patient who showed physeal bar formation and underwent physeal bar resection due to unacceptable clinical and radiologic outcomes. He had a relatively low energy injury (fall-down at ground level) and achieved epiphyseal realignment within 8 weeks. Lee *et al.* described that an epiphyseal compression injury with benign radiographic findings could also cause premature epiphyseal closure, although the majority of growth failure complications followed after repetitive, forceful manipulation. Houshian et al. [8] reported no case of premature physeal closure among 85 patients who did not undergo more than two attempts of reduction. We believe that the one patient with premature physeal closure in our study resulted from the epiphyseal compression at the time of injury, although we could not prove it. As the findings that multiple trials of reduction poorly affect the prognosis are generally accepted, the incidence of premature physeal arrest seemed to have decreased

Table 5. The area under the ROC curve, 95% confidence interval (CI), and cut-off values of epiphyseal displacement at the initial, post-reduction, and 1-week follow-up for predicting the epiphyseal realignment within 8 weeks.

Displacement (%)	AUC	*p*-Value	95% CI	Cut-off value (%)	Sensitivity (%)	Specificity (%)
Initial	0.743	0.005	0.617–0.869	35.9	100.0	52.5
Post-reduction	0.641	0.103	0.487–0.794	14.3	75.0	55.0
One week	0.784	0.001	0.649–0.920	13.1	75.0	72.5

AUC: area under the curve; ROC: receiver operating characteristic.

Table 6. The area under the ROC curve, 95% confidence interval (CI), and cut-off values of epiphyseal displacement at the initial, post-reduction, and 1-week follow-up for predicting the epiphyseal realignment within 12 weeks.

Displacement (%)	AUC	*p*-Value	95% CI	Cut-off value (%)	Sensitivity (%)	Specificity (%)
Initial	0.727	0.012	0.578–0.876	33.5	78.6	69.1
Post-reduction	0.752	0.005	0.586–0.917	18.1	64.3	85.7
One week	0.855	$<$0.001	0.723–0.988	22.9	71.4	92.9

AUC: area under the curve; ROC: receiver operating characteristic.

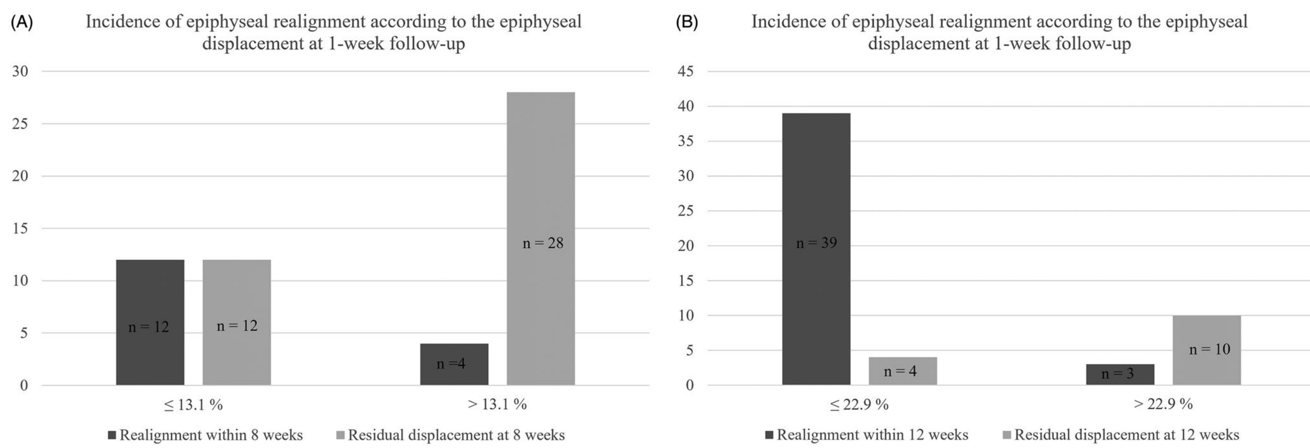

Figure 5. Bar graphs showing the incidence of epiphyseal realignment within 8 and 12 weeks. (A) Bar graphs showing the incidence of epiphyseal realignment at the 8-week follow-up according to the epiphyseal displacement at the 1-week follow-up. When the residual epiphyseal displacement was <13.1%, 50% of the patients achieved realignment of the epiphysis within 8 weeks, but when above 13.1%, only 12.5% of the patients achieved realignment within 8 weeks. (B) Bar graphs showing the incidence of epiphyseal realignment at the 12-week follow-up according to the epiphyseal displacement at the 1-week follow-up. When the residual epiphyseal displacement was <22.9%, 90.7% of the patients achieved realignment of the epiphysis within 12 weeks, but when it was >22.9%, only 23.1% of the patient achieved realignment within 12 weeks.

considerably compared to the past as shown in the recent systematic review.

There are some limitations to this study. First, this is a retrospective case-series study without a control group. Second, we focused on the epiphyseal displacement on the sagittal plane. Because the epiphyseal displacement in the coronal plane was realigned at the time of epiphyseal realignment in the sagittal plane in all cases, we did not address it in this study. Finally, there were a small number of patients who were followed up for >1 year, which resulted in a limited evaluation of the long-term effects of the required period for epiphyseal realignment. However, we can treat patients with confidence when we knew the general recovery pattern not only in the long term but also in the short term. The results of this study specifically suggested a recovery pattern in the short term when treating displaced epiphyseal injury of the distal radius, and we believed that our findings would be helpful to clinicians.

In conclusion, the residual epiphyseal displacement at the 1-week follow-up was the best predictor for the required period of epiphyseal realignment. When the residual epiphyseal displacement at the 1-week follow-up was <22.9%, about 90% of the patients achieved epiphyseal realignment within 12 weeks. Most patients with the residual displacement of up to 51.3% at 1-week follow-up achieved epiphyseal realignment within 6 months. From this study, we could predict the timing of epiphyseal realignment, and expect epiphyseal realignment even if re-displacement occurred up to 51.3% at the 1-week follow-up.

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Ethical approval

We obtained approval from the Chungnam National University Hospital Institutional Review Board (IRB No.: CNUH 2021-05-050).

Informed consent

Informed consent was obtained from all individual participants included in the study.

Author contributions

Seung Hoo Lee and Hyun Dae Shin: conception of the work, the acquisition, analysis, and interpretation of data for the work, drafting of the work and revising it critically for important intellectual content, final approval of the version to be published, and agreement to be accountable of all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Soo Min Cha and Eun-Seok Choi: acquisition, analysis, and interpretation of data for the work, drafting of the work, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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