

# Factors Responsible for Redisplacement of Pediatric Forearm Fractures Treated by Closed Reduction and Cast

## Role of casting indices and three point index

### Abstract

**Background:** Pediatric forearm fractures are still considered an enigma in view of their propensity to redisplace in cast. The redisplacement may be a potential cause for malalignment. We prospectively analyzed the role of risk factors and above casting indices in predicting significant redisplacement of pediatric forearm fractures treated by closed reduction and cast. **Materials and Methods:** 113 patients of age range 2–13 years with displaced forearm fractures, treated by closed reduction and cast were included in this prospective study. Prereduction and postreduction angulation, translation, and shortening were noted. In addition, for distal metaphyseal fractures, obliquity angle was noted. In postreduction X-ray, apart from fracture variables, casting indices were also noted (cast index [CI] for all patients with three-point index [TPI] and second metacarpal radius angle in addition for distal metaphyseal fractures). In 2<sup>nd</sup> week, X-rays were again obtained to check for significant redisplacement. These patients were managed with remanipulation and casting or were operated if remanipulation failed. Comparison of various risk factors was made between patients with significant redisplacement and those which were acceptably reduced. A subgroup analysis of patients with distal metaphyseal fractures was done. **Results:** Thirteen (11.5%) patients had significant redisplacement; all of them required remanipulation. No association with respect to age, sex, level of fracture, side of injury, surgeon's experience, number of bones fractured, and injury to definitive cast interval was seen. The presence of complete displacement in any of the plane in either of the bones was seen to be highly significant predictor of redisplacement ( $P < 0.001$ ). Postreduction angulation more than  $10^\circ$  in any plane in either of the bone and fracture obliquity angle in distal metaphyseal fracture also had a highly significant association with redisplacement. There was a significant difference in the mean values of all three casting indices assessed. TPI was the most sensitive casting index (87.5%). **Conclusions:** Conservative management with aim of anatomical reduction, especially in patients with complete displacement, should be the approach of choice in closed pediatric forearm fractures. Casting indices are good markers of quality of cast.

**Keywords:** Cast index, casting indices, closed reduction and cast, pediatric forearm fractures, redisplacement, second metacarpal radius angle, three-point index

**MeSH terms:** Pediatrics, forearm, fracture, bone, plaster cast

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### Introduction

Forearm fractures are among the most common injuries seen by a pediatric orthopedician.<sup>1,2</sup> The favored treatment for these fractures is conservative, i.e., closed reduction and cast immobilization.<sup>3</sup> The most common complication seen with this conventional management is “redisplacement” or loss of reduction (10%–39%).<sup>4–8</sup> Redisplacement frequently leads to malunion,<sup>9</sup> causing cosmetically and/or functionally poor results.<sup>10</sup> Knowledge of the risk factors responsible for redisplacement can help in

early identification of high-risk unstable fractures and their management by operative intervention primarily. For the past two decades, multiple studies (mostly retrospective) have tried to identify the risk factors responsible for redisplacement.<sup>4,11–23</sup> They have classified them into fracture-related, surgeon/treatment-related and patient-related factors<sup>24</sup> [Table 1]. The previous series have objectively used several radiographic indices (called as “casting indices”<sup>24</sup>) to assess cast quality and fracture reduction for pediatric forearm fractures [Table 2]. The commonly used indices are cast index (CI) [Figure 1], three-point index (TPI) [Figure 2], and second metacarpal index angle [Figure 3].

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There still remains doubt on their validity as they were retrospective and lacked homogeneity.

We prospectively analyzed the role of risk factors and above casting indices in predicting significant redisplacement of pediatric forearm fractures treated by closed reduction and cast.

**Table 1: Factors held to be responsible for redisplacement of pediatric forearm fractures<sup>24\*</sup>**

Fracture related
Initial displacement <sup>3,16</sup>
Translation (AP and lateral views)
Angulation (AP and lateral views)
Rotation of the distal segment
Shortening
Obliquity angle <sup>16</sup>
Site of injury (epiphyseal/metaphyseal/diaphyseal)
Distance of fracture from physes <sup>16</sup>
Bones involved (isolated radius or ulna/both bones) <sup>16</sup>
Treatment related
Surgeon's experience (trainee/qualified orthopedician) <sup>3,7,12</sup>
Quality of reduction (anatomical/good/fair) <sup>16</sup>
Quality of cast i.e., casting indices <sup>24</sup>
Cast Index <sup>13</sup>
Padding Index <sup>14</sup>
Canterbury Index <sup>14</sup>
Gap Index <sup>15</sup>
Three-Point Index <sup>16,23</sup>
Second metacarpal - radius angle <sup>18</sup>
Type of anesthesia (GA/conscious sedation) <sup>4</sup>
Patient related <sup>24</sup>
Sex
Side of injury
Muscle atrophy
Resolution of initial soft-tissue swelling while in cast

\*This table is not comprehensive, includes major factors which have been studied/proposed as risk factors for redisplacement. AP=Anteroposterior, GA=General Anaesthesia

## Materials and Methods

After approval from the Ethical committee of the Institution, 118 children of 2–13 years of age with closed forearm fractures requiring reduction and cast application, treated in the department were enrolled in this study. Patients with unacceptable primary fracture reduction, open fractures, physal injuries, closed physes, fractures >7 days old, impending/active compartment syndrome, associated vascular injury/joint dislocations/ipsilateral fracture of the same extremity, segmental fractures, and pathological fracture were excluded from the study. In all, three patients were lost to followup and other two of them failed to achieve primary acceptable closed reduction. Hence, in all 113 patients who satisfied the inclusion criteria, finally, were assessed.

Postclinical evaluation and fracture splinting, good quality, nondigital, prereluction anteroposterior (AP) view, and

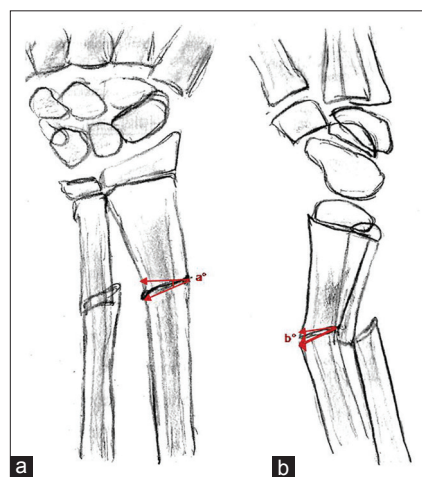


Figure 1: Diagrammatic representation of fracture obliquity angle was calculated by maximum fracture-line angle in either the transverse or the sagittal plane - i.e., the lines between the fractured medial and lateral cortices on anteroposterior view (a) and those between the fractured dorsal and volar cortices on the lateral view (b) and the larger angle was selected as the fracture obliquity angle

**Table 2: Summary of various casting indices on standard X-rays**

Index	Author	How to calculate	Cutoff value
Cast Index <sup>13</sup>	Chess <i>et al.</i>	Inner diameter of cast on lateral view (at fracture site)/inner diameter of cast on AP view (at fracture site)	<0.81
Padding Index <sup>13</sup>	Bhatia and Housden	Dorsal gap on the lateral view (at fracture site)/maximum interosseous distance on AP view	<0.3
Canterbury Index <sup>13</sup>	Bhatia and Housden	Cast index + padding index	<1.1
GAP Index* <sup>15</sup>	Malviya <i>et al.</i>	([Radial gap [fracture site] + ulnar gap [fracture site]]/inner diameter of cast in AP view) + ([Dorsal gap [fracture site] + volar gap [fracture site]]/inner diameter of cast in lateral view)	<0.15
Three Point Index* <sup>#16</sup>	Alemdaroğlu <i>et al.</i>	([Distal radial gap+ulnar gap [at fracture site] + proximal radial gap]/transverse distance of cortical contact on AP view) + ([distal dorsal gap+volar gap [at fracture site] + proximal dorsal gap]/transverse distance of cortical contact on lateral view)	<0.8
Second Metacarpal Radius Angle* <sup>18</sup>	Edmonds <i>et al.</i>	Angle between the second metacarpal and the long axis of the radius in AP view	>0°

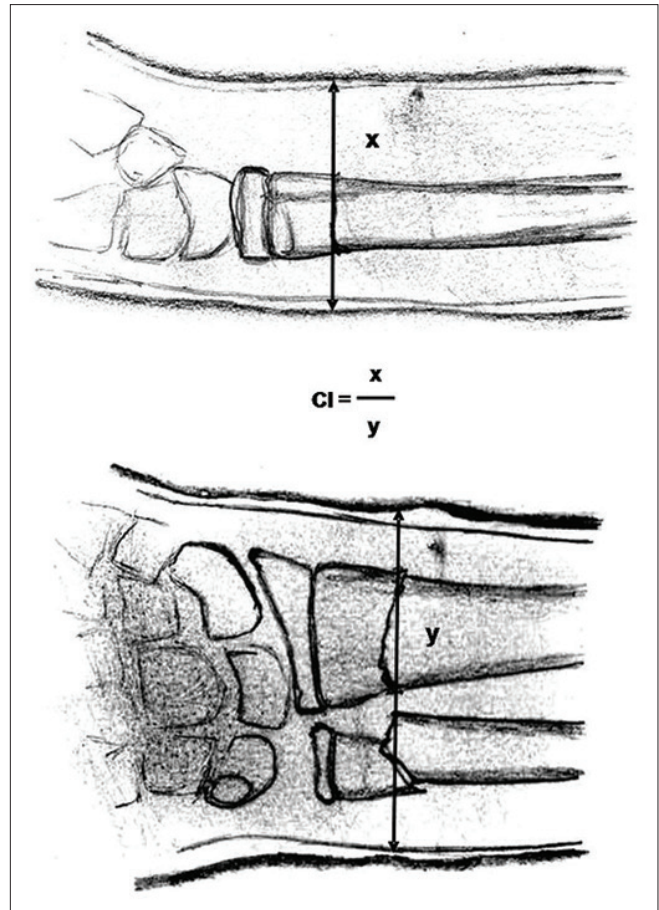
\*For distal metaphyseal fractures only, \*#For distal metaphyseal fractures but recently studied for diaphyseal fractures<sup>23</sup> also



**Figure 2:** Clinical photographs showing the technique of traction and casting. (a) Traction technique using two assistants. Note that fifth finger has been left free. (b) Uniform cotton wool padding applied. Note extra padding over wrist and olecranon to avoid pressure sore. (c) Application of below-elbow component of the cast with interosseous molding. (d) Extension of the cast to above elbow level with posterior humeral molding. (e) Well molded above elbow cast with 90° flexion at elbow in midprone position

lateral view radiographs of the forearm including elbow and wrist were obtained. These X-rays were assessed for fracture displacement in terms of angulation, translation (measured in terms of percentage of displacement as a proportion of the breadth of the bone at the fracture site), shortening (amount of overlap in millimeters), and fracture obliquity angle<sup>16</sup> (for distal metaphyseal fractures only) [Figure 4], site of injury-metaphyses/diaphyses, and bones involved-single or both bones. We also noted the value of fracture site angulation of highest magnitude in either of two bones in any of the X-ray view is called as maximum angulation for that patient. For example: A patient with radial angulation of 10°/26° (AP view/lateral view) and ulnar angulation of 12°/20° (AP view/lateral view) will have maximum angulation value of 26°.

After an informed consent from parents/care providers, an attempt of closed reduction was given by the orthopedic surgeon on duty (trainee/qualified) under conscious sedation and immobilized in an above elbow plaster of Paris (POP) cast using cotton wool for padding in 90° of



**Figure 3:** A line diagram showing that the CI is inner diameter of cast on lateral view (at fracture site)/inner diameter of cast on AP view (at fracture site). It is determined by dividing the sagittal cast width (x) by the coronal cast width (y) at the fracture site ( $CI = x/y$ ). Cut off value <0.81. CI = Cast index, AP = Anteroposterior

flexion at elbow. The cast was initially applied as below elbow cast and later extended to above elbow level. The position of forearm (regarding pronation/supination) for immobilization of forearm was based on preexisting well defined guidelines in the literature.<sup>25-27</sup> The principles of good forearm casting technique<sup>9</sup> i.e., interosseous molding, supracondylar molding, appropriate padding (ensuring at least two layers of padding material, with extra padding over bony prominences), evenly distributed cast material, straight ulnar border and flat posterior humeral borders, and three point molding were ensured [Figure 5]. Reduction was noted on check radiographs in standard AP and lateral views. Quality of reduction (assessed by checking postreduction fracture alignment regarding angulation, translation, and shortening) was noted, and casting indices of the patient were calculated at this stage (CI<sup>13</sup> [Figure 1] for all fractures and TPI<sup>16</sup> [Figure 2] and second metacarpal radius angle<sup>18</sup> (SMRA) [Figure 3] in addition for distal metaphyseal fractures. Predefined acceptability criteria of reduction were followed [Table 3]. For unacceptable reductions, the second attempt was given under general anesthesia (GA). Patients in which we were not able to

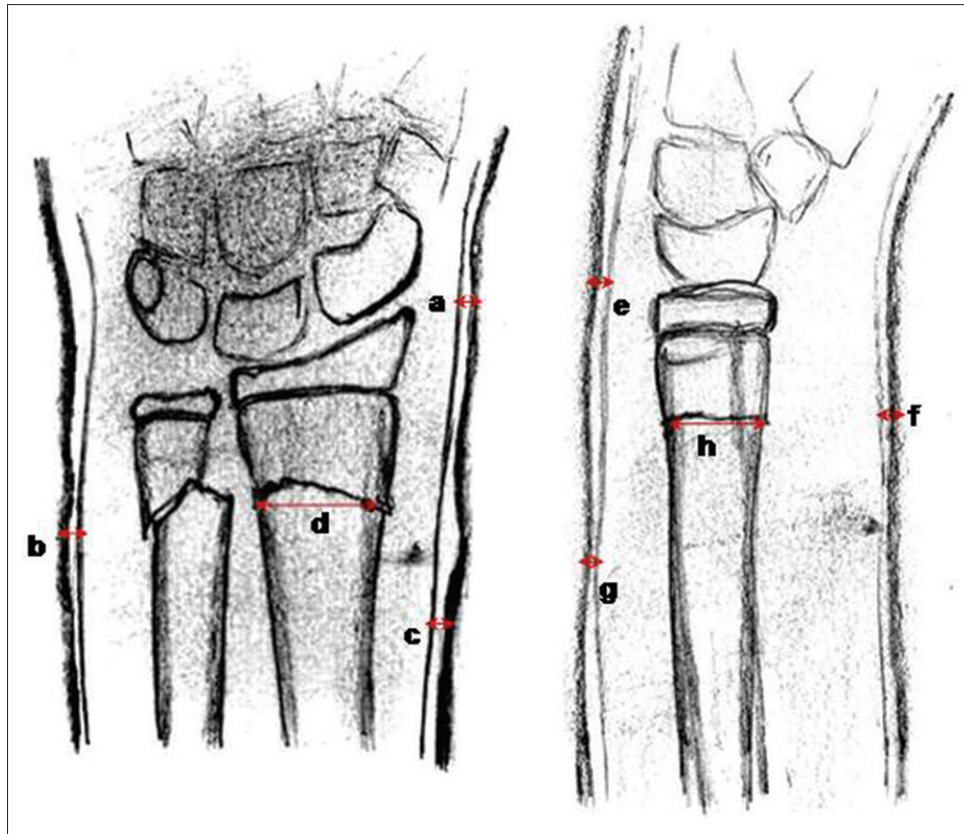


Figure 4: Diagrammatic representation of TPI. It is

$$\frac{(\text{distal radial gap} + \text{ulnar gap [at fracture site]} + \text{proximal radial gap})}{\text{transverse distance of cortical contact on AP view}} + \frac{(\text{distal dorsal gap} + \text{volar gap [at fracture site]} + \text{proximal dorsal gap})}{\text{transverse distance of cortical contact on lateral view}}$$

TPI = [(a + b + c)/d] + [(e + f + g)/h]. Cut off value <0.8. TPI = Three point index, AP = Anteroposterior

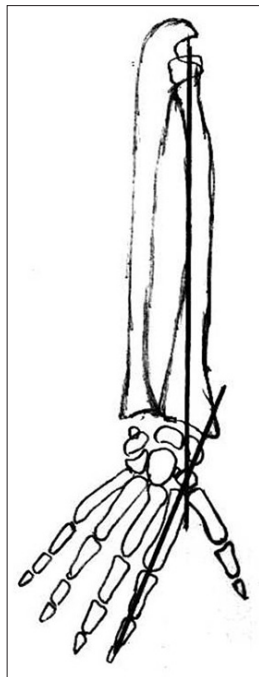


Figure 5: Diagrammatic representation of SMRA. It is angle between second metacarpal and long axis of the radius in AP view. Cut off value >0°. SMRA = Second metacarpal radius angle, AP = Anteroposterior

**Table 3: Criteria for acceptability of reduction**

**For shaft forearm fractures<sup>25</sup>**

- For <9 year old
  - Angulation <15°
  - Complete displacement
- For >9 year old
  - Angulation
    - Proximal third <10°
    - Midshaft/distal third <15°
  - Complete displacement, if shortening <1 cm

**For distal radius fractures<sup>26</sup>**

- Bayonet apposition ≤1 cm (age <9 years)
- Angulation up to 30° in sagittal plane (>5 years of growth remaining)
  - Acceptable angulation reduced by 5° for each less year of growth remaining
- Angulation up to 15° in the frontal plane

reduce fractures even after the second attempt, were then scheduled for operative management and were excluded from the study (n = 2).

Patients with acceptable reduction were followed up weekly. Radiographs were again obtained in the 2<sup>nd</sup> week postreduction<sup>12,28</sup> and checked for any redisplacement of

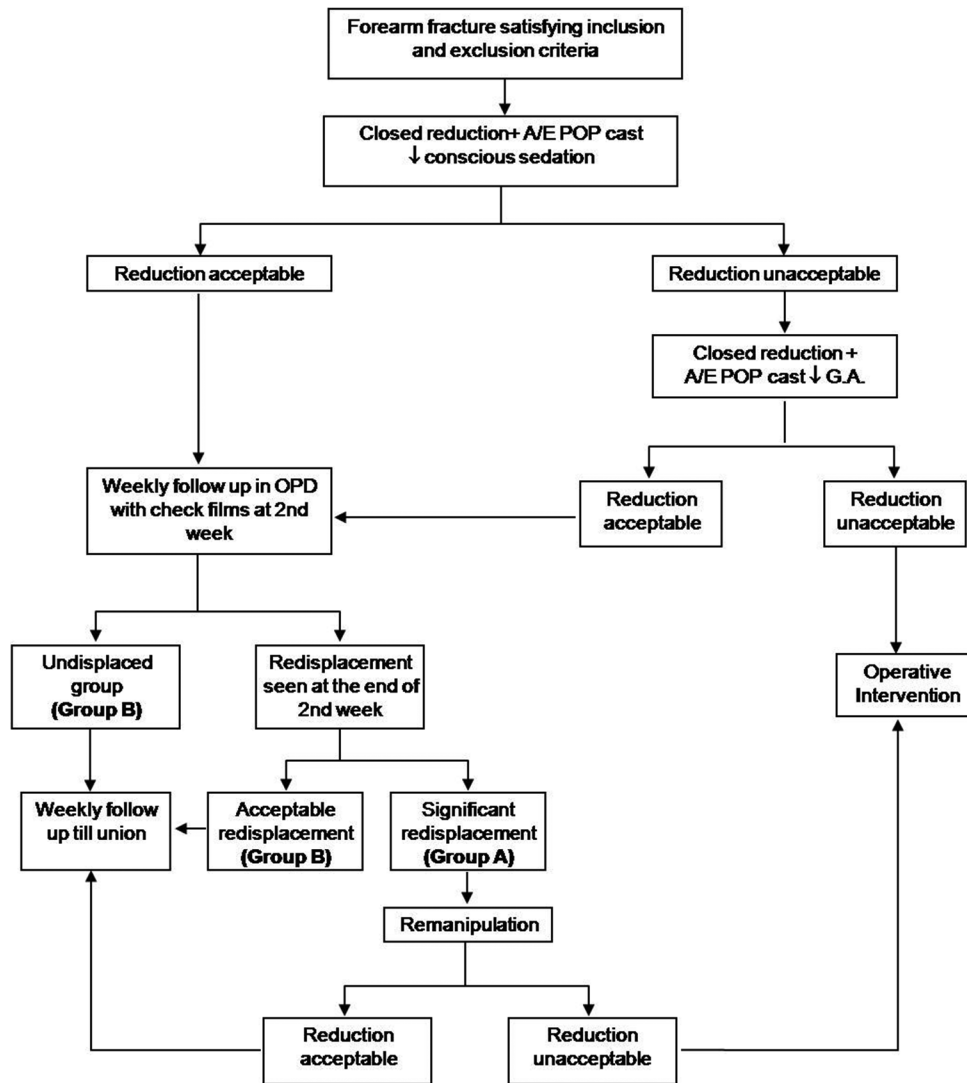


Figure 6: Flowchart showing the management protocol of the study, A/E= Above elbow, POP= Plaster of Paris, GA= General anaesthesia

reduction. If present, the displacement was measured, and remanipulation was done if displacement was beyond the criteria of acceptability. If the reduction was deemed acceptable, the patient was managed conservatively. For unacceptable reductions, operative methods were offered. These subjects requiring operative reduction were labeled as “significantly redisplaced” group (Group A). In participants where fracture remained undisplaced/nonsignificant redisplacement occurred; continued treatment till 6<sup>th</sup> week with X-rays after cast removal and were labeled as “acceptably reduced” group (Group B) [Figure 6].

Since distal end forearm fractures differ from diaphyseal forearm shaft fractures in terms of anatomy, mechanism, indications for management, and method of management,<sup>29</sup> a subgroup analysis of 37 patients with distal metaphyseal fractures (Group M; significantly redisplaced fractures – Group MA; acceptably reduced fractures – Group MB) was also done.

Data analysis was done using SPSS for windows v 17.0 software (SPSS Inc., Chicago, IL, USA). Apart from the

demographic data and descriptive statistics, for continuous variables with parametric data, unpaired *t*-test was used, while for those with nonparametric data, Mann–Whitney U-test was used. For categorical variables, Chi-square/Fisher exact test was used. Data which were recorded as percentage such as translation at fracture site, in order to show the distribution of the data and especially the fact that the measurements were 0.00% for several of the participants, their median values with the interquartile ranges (instead of mean) were used for statistical analysis. To study the association between redisplacement and various factors, multivariable logistic regression analysis was done. For all tests, *P* < 0.05 was considered to be statistically significant.

## Results

Out of these 113 patients, 13 patients (11.5%) had unacceptable/significant redisplacement (Group A) for which they were advised remanipulation or were remanipulated. Of these 13 patients, five belonged to

subgroup of diaphyseal fractures (total  $n = 76$ ) and eight had distal metaphyseal fractures (total  $n = 37$ ). Three patients, out of these 13, who failed to achieve acceptable reduction even after remanipulation, underwent operative fixation with K-wires [Figure 7].

The mean age of the patients was 8.62 years (range 3–13 years; male:female = 67:33) with right sided predominantly injured in 64.6% ( $n = 73$ ). In the distal forearm subgroup ( $n = 37$ ), there were 23 males (62%) and 14 females (38%). Injury was right sided in 20 (54%) patients. Sixty-six patients (58.4%) were given cast by a trainees and the remaining 47 (41.6%) by qualified surgeons, while in patients with distal metaphyseal fractures, 20 patients (54%) were given cast by trainee surgeons and the remaining 17 (46%) were given by qualified surgeons. The frequency of fractures requiring remanipulation was 11.5%. None of the patients developed compartment syndrome or any significant cast related complications requiring change of treatment plan. One patient developed postreduction posterior interosseous nerve palsy which fully recovered at 3 weeks followup.



**Figure 7:** X-ray of both bones forearm of a twelve year old boy, anteroposterior and lateral views showing (a) diaphyseal fracture of both bones Prereduction, (b) postreduction CI = 0.79, (c) at second week, fracture was acceptably reduced, (d) at 6<sup>th</sup> week post injury shows bony union. CI=Cast index

The fracture was most common in the middle third (54.9%) followed by distal third (40.7%). Proximal third (4.4%) fractures were less common. The mean injury to definitive cast interval (the time gap between injury and definitive cast application) for all patients was 48.31 h ( $\pm 33.20$  h) (range 2–124 h). No association of age, sex, level of fracture, side of injury, number of bones fractured, injury to definitive cast interval, and surgeon's experience with redisplacement was seen when group as whole, and subgroup distal third was undertaken [Table 4]. The only exception was significant difference in Group MB and MA were seen in injury to definitive cast interval ( $P = 0.021$ ).

Mean values of prereduction and postreduction fracture site angulation of both bones were also compared [Table 5]. There was no significant difference was seen between the two groups regarding prereduction angulation. The postreduction angulation of ulna (both AP and lateral view) was significantly more ( $P = 0.010$  and  $P = 0.002$ , respectively) in patients of Group A as compared to Group B. Similar difference was seen in distal metaphyseal fractures ( $P = 0.005$  and  $P = 0.006$ , respectively).

The presence of prereduction complete displacement, (i.e., 100% translation in either of the bones in any of the two views) was found to be a good predictor of significant redisplacement. Similarly, prereduction shortening showed significant difference between Group A and Group B when both quantitative ( $P = 0.001$ ) and qualitative ( $P = 0.002$ ) analysis was done [Table 5].

For distal metaphyseal fractures, fracture obliquity angle was measured in prereduction AP and lateral views of radiograph. Greater of the two was taken to be the "fracture obliquity angle" for that patient. Significant difference was found to be present among both the groups when their means were compared using *t*-test ( $P = 0.009$ ). On further classifying patients into three subgroups ( $<10^\circ$ ,  $10^\circ$ – $20^\circ$ , and  $>20^\circ$ ), a significant difference was seen among them ( $P < 0.001$ ) [Table 5].

Patients of both main group and subgroup with distal metaphyseal fractures (were sub grouped on the basis of prereduction maximum angulation values (i.e.,  $<10^\circ$ ,  $10^\circ$ – $20^\circ$ ,  $>20^\circ$ ), but there was no significant difference in the distribution of patients of both groups (Group A and Group B) into these three subgroups of angles. Patients were again subgrouped into two groups, on the basis of postreduction maximum angulation value of the patient (i.e.,  $<10^\circ$ ,  $\geq 10^\circ$ ) and qualitative analysis was done. There was a statistically significant difference in distribution of patients with significant redisplacement and those with acceptably reduced fracture in both main group of all patients ( $P = 0.010$ ) and patients with distal metaphyseal fractures ( $P = 0.008$ ) [Table 5].

Significant association of all casting indices in both main and distal metaphyseal fractures subgroup was shown in Table 6. Except SMRA, TPI, and CI proved to be

**Table 4: Comparison of various parameters between groups**

Characteristics	All patients (n=113)			Distal metaphyseal subgroup (n=37)		
	Group B (n=100)	Group A (n=13)	P	Group MB (n=29)	Group MA (n=8)	P
Age (years)	8.54±2.98	9.27±2.65	0.403*	9.05±3.21	8.56±2.70	0.696
Sex (%)						
Males	66 (66)	10 (76.9)	0.541 <sup>#</sup>	17 (58.6)	6 (75)	0.683
Females	34 (34)	3 (23.1)		12 (41.4)	2 (25)	
Side (%)						
Right side	66 (66)	7 (53.8)	0.539 <sup>#</sup>	18 (62.1)	2 (25.0)	0.109
Left side	34 (34)	6 (46.2)		11 (37.9)	6 (75.0)	
Level (%)						
Proximal third	5 (5)	0	0.308 <sup>#</sup>	-	-	-
Middle third	57 (57)	5 (38.5)		-	-	
Distal third	38 (38)	8 (61.5)		-	-	
Number of bones fractured <sup>s</sup>						
One	5 (5)	1 (7.7)	0.528 <sup>#</sup>	2 (6.9)	1 (12.5)	0.530
Two	95 (95)	12 (92.3)		27 (93.1)	7 (87.5)	
Injury to definitive cast interval (hours)						
Median values (IQR)	48.00 (24.00-77.00)	12 (6.00-76.00)	0.069 <sup>^</sup>	50.00 (29.00-76.00)	9.00 (6.00-60.00)	0.021
Surgeon's experience (%)						
Qualified	41 (41)	6 (46.2)	0.771 <sup>#</sup>	14 (48.3)	3 (37.5)	0.701
Trainee	59 (59)	7 (53.8)		15 (51.7)	5 (62.5)	

\*Unpaired *t*-test, <sup>#</sup>Fischer exact test, <sup>s</sup>Based on additional ulnar fracture, <sup>^</sup>Mann-Whitney U-test. IQR=Interquartile range

significant risk factors when above their cutoffs [Table 7]. Multivariable logistic regression analysis possible only for the whole sample size [Table 8] indicated most significant role of presence of complete displacement in prediction of significant redisplacement requiring remanipulation ( $P < 0.001$ ). This model correctly classified 89% of participants and the Nagelkerke  $R^2$  of the model was 0.380 [Table 8].

## Discussion

Out of the total 113 patients analyzed in the study, 13 (11.5%) patients had significant redisplacement and required remanipulation. This rate of redisplacement was comparable to previous studies on the subject,<sup>4,15-23</sup> however, these studies had different criteria to define redisplacement.<sup>22</sup> Hence, comparison with such studies is not of much significance. We used remanipulation as the rescue therapy for significantly redisplaced fractures which proved to be an effective measure as shown in previous studies.<sup>6</sup> Pin fixation was kept as a backup for patients who failed to achieve acceptable reduction even after remanipulation.

No significant association was seen between age, sex, or side of injury with redisplacement as has been seen in previous studies.<sup>15-22</sup> Iltar *et al.*<sup>23</sup> had shown that children <7 years of age have more chance of redisplacement due to their small forearm, leading to difficulty in application of a well-molded cast. Although technically correct, this was not supported in our study. Although right-sided injuries were more common as compared to left in our study, results did

not show any association between right-sided injury and redisplacement which was shown by Younger *et al.*<sup>30</sup>

Initial angulation or prereluction angulation has been reported as a risk factor by Pretell Mazzini *et al.*<sup>22</sup> However, for current series, no difference was seen between the patients with acceptably reduced fractures and significantly redisplaced fractures as also seen previously by most authors.<sup>3,11,12,14,17-21</sup> Angulation only suggests bending of bones without complete disruption of periosteum. Due to this intact periosteal sleeve, intrinsic stability of fracture is maintained. Hence, there is less chance of redisplacement.

The presence of complete displacement in any of the radiographic views irrespective of the site predisposes to redisplacement. This risk factor proposed by previous studies<sup>16,17,19</sup> has been reaffirmed by our study. Possible reason is that complete displacement indicates complete disruption of periosteal sleeve; hence, fracture has lost its intrinsic stability. Hence, we suggest that patients with complete displacement should receive proper attention during followup and may be considered for primary operative intervention especially so if nearer to physal closure.

The presence of prereluction shortening indicates complete displacement, which has been shown to be an important predictor in this study and many previous studies.<sup>16,17,19</sup> Small number of patients in distal radial metaphyseal fracture group can plausibly explain the lack of significance for this predictor for these fractures.

In our study, none of the patients which redisplaced belonged to proximal one-third of the forearms. In

**Table 5: Comparison of fracture angulations between groups**

Characteristics	All patients (n=113)			Distal metaphyseal subgroup (n=37)		
	Group B (n=100)	Group A (n=13)	P	Group MB (n=29)	Group MA (n=8)	P
Prereduction fracture configuration- (angulation in degrees)						
Radius AP	8.47±5.89	8.46±9.76	0.328 <sup>^</sup>	5.97±5.89	8.88±10.30	0.704
Radius lateral	17.61±8.30	18.00±12.70	0.889 <sup>^</sup>	19.62±8.39	21.00±13.81	0.731
Ulna AP	8.21±7.35	11.00±9.70	0.307 <sup>^</sup>	8.03±7.52	10.38±7.39	0.299
Ulna lateral	15.92±10.87	18.77±17.07	0.811 <sup>^</sup>	18.24±12.00	22.13±19.43	0.599
Postreduction fracture configuration- (angulation in degrees)						
Radius AP	2.61±2.8	2.77±2.94	0.798 <sup>^</sup>	2.21±3.12	2.50±3.55	0.871
Radius lateral	4.43±3.52	7.92±4.57	0.010 <sup>^</sup>	3.97±3.51	9.50±5.04	0.006
Ulna AP	1.75±2.72	5.23±4.48	0.002 <sup>^</sup>	1.66±2.02	6.13±4.26	0.005
Ulna lateral	2.86±2.98	5.77±5.48	0.075 <sup>^</sup>	3.41±2.91	5.63±5.76	0.435
Maximum angulation (prereduction) in percent						
<10°	8 (8)	2 (15.4)	0.326 <sup>#</sup>	3 (10.3)	1 (12.5)	0.98 <sup>#</sup>
10°-20°	47 (47)	4 (30.8)		8 (27.6)	2 (25)	
>20°	45 (45)	7 (53.8)		18 (62.1)	5 (62.5)	
Maximum angulation (postreduction) in percent						
<10°	81 (81)	6 (46.2)	0.010 <sup>#</sup>	23 (79.3)	2 (25)	0.008 <sup>#</sup>
>10°	19 (19)	7 (53.8)		6 (20.7)	6 (75)	
Prereduction translation at fracture site, median (IQR) (percent)						
Radius AP	0.00 (0.00-21.25)	0.00 (0.00-30.00)	0.327 <sup>^</sup>	0.00 (0.00-30.00)	5.00 (0.00-42.50)	0.649
Radius lateral	0.00 (0.00-45.50)	30.00 (0.00-100)	0.030 <sup>^</sup>	33.00 (0.00-100)	18.75 (0.00-100)	0.989
Ulna AP	0.00 (0.00-5.00)	30.00 (0.00-100)	0.006 <sup>^</sup>	0.00 (0.00-0.00)	100 (7.50-100)	<0.001
Ulna lateral	0.00 (0.00-27.50)	0.00 (1.00-6.50)	0.046 <sup>^</sup>	0.00 (0.00-37.50)	10.00 (0.00-100)	0.214
Postreduction translation at fracture site, median (IQR) (percent)						
Radius AP	0.00 (0.00-0.00)	0.00 (0.00-20.00)	0.043 <sup>^</sup>	0.00 (0.00-11.50)	0.00 (0.00-17.50)	0.998
Radius lateral	0.00 (0.00-10.63)	0.00 (0.00-30.00)	0.470 <sup>^</sup>	0.00 (0.00-15.00)	0.00 (0.00-25.00)	0.766
Ulna AP	0.00 (0.00-0.00)	10.00 (0.00-20.00)	0.005 <sup>^</sup>	0.00 (0.00-0.00)	0.00 (0.00-7.50)	0.494
Ulna lateral	0.00 (0.00-0.00)	0.00 (0.00-30.00)	0.779 <sup>^</sup>	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.353
Prereduction complete fracture site displacement in either of the two bones (%)						
Absent	80 (80)	2 (15.4)	<0.001 <sup>#</sup>	18 (62.9)	0	0.003
Present	20 (20)	11 (84.6)		11 (37.1)	8 (100)	
Prereduction shortening (cm)						
Median (IQR)	0.00 (0.00-2.25)	3.00 (1.00-6.50)	0.001 <sup>^</sup>	2.00 (0.00-5.00)	3.50 (0.50-6.75)	0.355
Postreduction shortening (cm)						
Median (IQR)	0.00 (0.00-0.00)	0.00 (0.00-1.00)	0.297 <sup>^</sup>	0.00 (0.00-0.00)	0.00 (0.00-0.00)	0.913
Prereduction shortening in significant redisplacement (%)						
Absent	70 (70)	3 (23.1)	0.002 <sup>#</sup>	14 (48.2)	2 (25)	0.423
Present	30 (30)	10 (76.9)		15 (51.8)	6 (75)	
Fracture obliquity angle (°)						
-	-	-	-	11.71 (3.89)	25.38 (10.97)	0.009 <sup>*</sup>
Fracture obliquity angle						
<10°	-	-	-	7 (24.1)	1 (12.5)	<0.001 <sup>#</sup>
10°-20°	-	-	-	22 (75.9)	1 (12.5)	
>20°	-	-	-	0	6 (75)	

\*Unpaired t-test, #Fischer exact test, ^Mann-Whitney U-test. IQR=Interquartile range, AP=Anteroposterior



**Table 6: Comparison of cast indices between groups**

Cast indices	All patients (n=113)			Distal metaphyseal subgroup (n=37)		
	Group B (n=100)	Group A (n=13)	P	Group MB (n=29)	Group MA (n=8)	P
Cast index (overall)	0.78 (0.08)	0.83 (0.07)	0.016*	0.74 (0.06)	0.82 (0.05)	0.006
Three-point index	-	-		0.76 (0.14)	1.30 (0.57)	0.035
Second metacarpal radius angle (°)	-	-		4.82 (5.19)	-0.75 (4.4)	0.009
Cast index						
≤0.81	76 (76)	4 (30.8)	0.002#	25 (86.2)	3 (37.5)	0.012
>0.81	24 (24)	9 (69.2)		4 (13.8)	5 (62.5)	
Three-point index						
≤0.8	-	-	-	21 (77.8)	1 (12.5)	0.002
>0.8	-	-	-	6 (22.2)	7 (87.5)	
Second metacarpal radius angle						
≥0°	-	-	-	26 (89.7)	5 (62.5)	0.101
<0°	-	-	-	3 (10.3)	3 (37.5)	

\*Unpaired t-test, #Fischer exact test

**Table 7: Diagnostic value of various casting indices**

Casting index	Sensitivity	Specificity	Positive predictive value	Negative predictive value	OR	Accuracy
All patients						
Cast index	69.2	76	27.3	95.0	9	3.03
Distal metaphyseal group						
Cast index	62.5	86.2	55.6	89.3	10.4	4.28
Three-point index	87.5	77.8	53.8	95.5	24.5	4
Second metacarpal radius angle	37.5	89.7	50.0	83.9	5.2	3.62

OR=Odds ratio

**Table 8: Risk factors for remanipulation**

Risk factor for remanipulation	Unadjusted OR	95% CI for OR	P	β*	AOR	95% CI for OR	P
Prereduction complete displacement	22.000	4.51-107.27	<0.001	2.909	18.336	3.678-91.407	<0.001
Prereduction shortening*	7.778	1.998-30.281	0.003	-	-	-	-

\*Due to high correlation (phi coefficient=0.784) between prereduction shortening and prereduction complete displacement, the prereduction shortening was excluded from the multivariable logistic regression analysis. Due to the small number of cases of significant redisplacement (only 8 out of 37), this test could not be used in distal metaphyseal fractures subgroup. OR=Odds ratio, AOR=Adjusted odds ratio, CI=Confidence interval

addition, there was no association between the level of fracture and redisplacement ( $P = 0.308$ ) as shown by Iltar *et al.* (2013)<sup>23</sup> However, Price *et al.* (1990) has shown a higher incidence of redisplacement in proximal forearm fractures.<sup>31</sup> This difference could not be seen due to inadequate representation of such injuries as only 5 patients belonged to proximal forearm group. Furthermore, in our study, the presence of single bone or both bones fracture did not had any influence over redisplacement as had been shown by Iltar *et al.*<sup>23</sup> Similarly, for distal radius metaphyseal fractures, the presence of associated ulnar fracture showed no influence over redisplacement as shown by other authors.<sup>3,16</sup>

Obliquity of the fracture line has been studied only for distal metaphyseal fractures till date. Hence, we assessed its role only in patients with distal metaphyseal injuries ( $n = 37$ ). Authors have shown it to increase (Alemdaroğlu *et al.*<sup>16</sup>) as well as decrease (Hang *et al.*<sup>20</sup>) the chances

of redisplacement. Our result favored the findings by Alemdaroğlu *et al.*<sup>16</sup> which suggested that with increase in the obliquity of the fracture line, the fracture stability is decreased. Hence, patients with fracture obliquity angle of more than 20° should receive special attention, if are being managed conservatively.

The mean values of postreduction angulation or residual angulation deformity of radius (in lateral view) and ulna (in AP view) were significantly more in significantly redisplaced Group A when compared with acceptably reduced Group B. These findings were seen both when all patients were being studied as well as for distal metaphyseal fractures.

To further assess the role of postreduction angulation, we studied “maximum angulation” of all patients in postreduction films of both the bones in both views. It showed that 81/100 of acceptably reduced patients had maximum angulation <10°, while 7/13 patients with

significant redisplacement had maximum angulation  $>10^\circ$ . There was a significant difference both in group of all patients and that of distal fractures. This indicated that residual deformity of  $>10^\circ$  in any plane of any bone indicates less than satisfactory reduction. In other words, patients with such a postresidual deformity were prone to redisplace. Hence, patients with postreduction deformity of  $>10^\circ$  should be kept under special observation and regular followup.

Postreduction translation was assessed similar to that of prereluction translation. No significant difference was noted between the two groups except for the median values of translation of radius and ulna in AP view was more in patients with significant redisplacement. No such difference was seen for distal fractures. This indicates that the anatomical reduction both regarding angulation and translation is necessary for successful management of pediatric forearm fractures, without any risk of significant redisplacement, as also shown by multiple studies.<sup>3,13,16-21</sup> However, postreduction shortening had no statistical significant difference in patients when all patients were considered or when distal metaphyseal fractures were considered.

Injury to definitive cast interval is the time gap between injury and definitive cast application. Secondary to injury, swelling appears which further aggravates when given an early definitive cast. When this swelling subsides, fracture tends to lose its position or in other words redisplaces. We hypothesized that delayed application of the definitive cast, i.e., after 48 h of injury, will ensure partial subsidence of swelling and hence allow a reduction and casting, in which there will be less chances of redisplacement. Although for all such cases, there was no intention to delay treatment, a significant difference was found in distal metaphyseal subgroup [Table 4]. Wrist region is a precarious area where swelling can have several morbid effects. It plausibly indicates that delayed casting may reduce the chances of redisplacement and should be preferred if gross swelling is present.

Treating surgeon's experience has often been correlated with redisplacement, with experienced surgeon having a lower rate of redisplacement.<sup>7,12</sup> However, our study showed that surgeon's experience to be an insignificant predictor of redisplacement both in the group of all patients as well as when only patients with distal metaphyseal fractures were studied. These results supported the findings of Proctor *et al.*,<sup>3</sup> Monga *et al.*,<sup>17</sup> Hang *et al.*,<sup>20</sup> and Yang *et al.*<sup>21</sup> As all of the doctors managing patients were orthopedic surgeons, no comparison was made between surgeons and emergency physicians as made by many studies in recent years.<sup>32</sup>

There was a significant difference between Group A and Group B ( $P = 0.016$ ) which clearly indicates that with rise of CI, chances of redisplacement increases. Further, on checking the value of 0.81 as a cutoff, we found it to be a useful index to predict redisplacement, with sensitivity of

69.2% and specificity of 76% and an odds ratio of 9. Only two studies have analyzed the role of CI in diaphyseal fractures<sup>23</sup> or considering all forearm fractures.<sup>17</sup> The latter study by Monga *et al.*<sup>17</sup> did not show any significant role of CI in prediction, whereas the former study by Iltar *et al.*<sup>23</sup> showed it to be a sensitive (83%) predictor of redisplacement with a specificity of only 40%.

Similar results were seen in distal metaphyseal fractures with the sensitivity of 62.5% while specificity rose to 86.2% (odds ratio = 10.41) when we used it as a screening test for prediction of redisplacement, which were similar to the results of multiple other studies<sup>2,14-16,19,33</sup> which assessed its role in distal forearm injuries. In spite of limitations in use of CI in cases with chubby children<sup>15</sup> and casts with nonuniform padding,<sup>2</sup> it has been shown to be an accurate and a sensitive test repeatedly.<sup>2,14-16,19,33</sup> Iltar *et al.*<sup>23</sup> doubted its validity in diaphyseal injuries where the shape of forearm in cut section changes from an elliptical (distal third) to an oval-shaped (mid or proximal third). However, increase in its cutoff from 0.7<sup>13</sup> to 0.81<sup>33</sup> allows study of diaphyseal injuries as well. Apart from its validity, it is also easy to apply clinically as compared to other indices. Therefore, for all fractures of pediatric forearm irrespective of the site, CI can be a guide to predict redisplacement, and for testing, the quality of molding of the cast. Cast index can also be one parameter of testing casting skill in trainees by using it as a yardstick.

TPI was calculated only for distal metaphyseal fractures, as it was described only for them. The mean TPI in patients with redisplaced fractures was 1.30 while for acceptably reduced fractures it was 0.76. This difference was statistically significant ( $P = 0.035$ ). When its validity was assessed as a predictor of redisplacement with a cutoff of 0.8, it proved to be a significant predictor ( $P = 0.002$ ). The sensitivity (87.5%) and specificity (77.8%) of TPI were highest of all other indices which were studied for distal metaphyseal fractures. These results supported the findings of Alemdaroglu *et al.*<sup>16</sup> and Hang *et al.*<sup>20</sup> Hence, TPI is the most sensitive predictor of redisplacement in distal metaphyseal fracture although its use is somewhat restricted by complex calculations needed. SMRA, again is useful only in distal metaphyseal fractures.<sup>18</sup> There was significant difference ( $P = 0.009$ ) between two groups (MA and MB) but not when its role as screening test using zero degree as a cutoff was assessed ( $P = 0.101$ ). This variation could be explained by the small number of patients with significant redisplacement. A study with larger number of patients may prove its role.

The present study had limitations of single-center recruitment, use of nonsynthetic padding which may have thickness variations, with no comparisons between synthetic and nonsynthetic padding material, cast material (POP vs. fiberglass), type of anaesthesia used (conscious sedation vs. GA) The strengths of the study were this

being a prospective study including both diaphyseal and metaphyseal fractures with well-defined inclusion and exclusion criteria, acceptability of reduction, redisplacement, and indications of remanipulation.

We conclude that conservative management by closed reduction and cast well molded is still the management of choice in closed pediatric forearm fractures. Significant risk factors which can possibly predict redisplacement were (a) Complete displacement at fracture site (b) Postreduction angulation  $>10^\circ$  in any plane in any view (c) Fracture obliquity angle  $>20^\circ$  (d) Our study also suggested using various casting indices especially cast index and SMRA for quantifying cast adequacy in forearm fractures.

#### Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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#### Conflicts of interest

There are no conflicts of interest.

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