Distal forearm fractures in children: Cast index as predictor of re- manipulation

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ABSTRACT

Background: Displaced distal forearm fractures in children have been treated in above-elbow plaster casts since the last century. Cast index (CI) has been proposed as a measure to indicate how well the cast is molded to the contours of the forearm. In this study the CI in post-manipulation radiographs were analyzed to evaluate its relevance to re-angulation of distal forearm fractures in children in different age-groups.

Materials and Methods: Out of 174 consecutive cases treated during the study period, 156 patients (114 male and 42 female) with a mean age of 9.8 years (range: 2–15 years) were included in this retrospective radiographic analysis; 18 patients were excluded for various reasons. All patients were manipulated in the operation theater under general anesthesia and a molded above-elbow cast was applied. The CI was measured on immediate post-manipulation radiographs. Children were divided into three groups according to age: group 1: <5 years, group 2: 5–10 years, and group 3: >10 years.

Results: Angulation of the fracture within the original plaster cast occurred in 30 patients (19.2%): 22/114 males and 8/42 females. The mean CI in these 30 patients who required a second procedure was 0.92±0.08, which was significantly more than the mean CI in the other children (0.77±0.07) (P<.001). The mean CI in children who underwent re-manipulation in the group 1 was 0.96, which was significantly higher than that of the other two groups, i.e., 0.90 in group 2 and 0.88 in group 3 (P<.05). A receiver operating characteristics (ROC) curve estimated the cutoff point for intraoperative CI of 0.84 when both the sensitivity and specificity of CI was high to predict re-manipulation for re-displaced fractures of the distal forearm in children in any age-group.

Conclusion: The CI is a valuable tool to assess the quality of molding of the cast following closed manipulation of forearm fractures in children. A high CI (≥0.84) in post-manipulation radiographs indicates increased risk of re-displacement of the fracture in children, especially in those under the age of 5 years and over the age of 10 years.

Key words: Children, cast index, conservative treatment, forearm fracture

INTRODUCTION

Fractures of the distal forearm constitute 35%–45% of all pediatric long bone fractures. Application of a molded long-arm plaster cast with the elbow in 90° flexion has been common practice for treatment of displaced distal forearm fractures in children since the last century. The success of a manipulative reduction is dependent on the maintenance of the corrected position within the plaster cast. The risk of re-angulation of the fracture is dependent on the molding. The cast index (CI), an index for molding of the plaster cast in forearm fractures, was advocated by Chess et al. (1994). Chess used a short-arm cast and calculated the CI as the ratio of the internal width of the forearm cast in the sagittal plane to the internal width in the coronal plane at the fracture site. This indicates how well the cast is molded to the contours of the forearm.

The purpose of this study was to evaluate the value of CI for predicting re-angulation of distal forearm fractures following manipulation in children of different age-groups.

MATERIALS AND METHODS

We retrospectively reviewed the radiographs of 174 consecutive closed pediatric distal forearm fractures treated at our hospital between July 2003 and July 2005. These children were identified from the operating theater logbook. All angulated fractures of the distal third of the forearm (either radius alone or combined radius and ulna) that required a
Cast index as predictor of re-manipulation in distal forearm fractures in children

Debnath, et al: Cast index as predictor of re-manipulation in distal forearm fractures in children

Closed manipulation were included in the study. The data was recorded from a review of hospital records, operating theater notes, and radiographs. The preoperative, intraoperative, and follow-up radiographs (1, 3, and 6 weeks) were also reviewed. The exclusion criteria were: 1) unsatisfactory initial reduction, 2) pathological or open fractures, 3) incomplete series of X-rays, 4) patients lost to follow-up before healing, and 5) bilateral fractures. Fifteen children had incomplete series of radiographs and three patients were followed up elsewhere, and these patients were therefore excluded from the study. Thus, 156 children (114 male and 42 female) between 2–15 years of age (mean age: 9.8 years) were included in the study. All preoperative radiographs were assessed for angulation.

All patients with clinical deformity and angulation of more than 20° on plain radiographs (lateral views) were manipulated under general anesthesia. A below-elbow plaster cast was applied and molded over stockinette and single-layer padding as described by Charnley. The reduction was confirmed with portable fluoroscopy in both planes. The reduction was deemed satisfactory by the surgeon when there was no evidence of displacement (i.e., <5 mm) on both planes and angulation was corrected to near anatomical position (i.e., <5°). The short cast was subsequently completed to a long-arm plaster with the elbow in 90° flexion. Patients were followed up at the first and third weeks to check the position of fractures radiologically. Standard anteroposterior (AP) and lateral radiographs were used in all initial and subsequent radiographic examinations. All patients had final review at 6 weeks.

Details recorded were age, gender, fracture type (transverse or oblique) and side, bones involved, grade of surgeon (i.e., consultant or registrar), and whether re-manipulation was required, with or without supplementary stabilization. A few patients who required re-manipulation were noted to be unstable and only these needed supplementary stabilization. The CI was measured on the intraoperative films as well as the 1-week post-manipulation follow-up radiographs. CI was measured as ratio a/b in which ‘a’ is the internal cast width in the lateral view and ‘b’ is the internal cast width in the AP view at the fracture site. Angulation was also measured at the fracture site. We have concentrated mainly on the angulation to avoid confounding factors. Younger et al., on the other hand, measured axis deviation (AD), which is the calculated distance between the anatomic and deformed axes of the radius. We also stratified the patients into groups based on the age, as follows: group 1: <5 years, group 2: 5–10 years, and group 3: >10 years. Only when fractures required re-manipulation was it considered as failure of treatment. The decision to re-manipulate was based on standard guidelines (i.e., re-angulation of more than 20°).

Inter-observer variation was determined by having two of the authors (ARG and SD) independently calculate the CI in 10 sets of radiographs randomly selected. Intra-observer variability was estimated by having one of the authors (ARG) calculate the CI in the same radiographs after an interval of 6 weeks. Statistical analysis was performed using SPSS® software v. 12.5 (Chicago, Illinois). We used the Pearson correlation coefficient, with scores between 0.61 and 0.80 representing good correlation and those greater than 0.81 representing excellent correlation. The mean CI in the non-manipulation and the re-manipulation groups were recorded and compared. The primary outcome measure was re-manipulation. Continuous variables were tested using the Student’s t-test. P<.05 was deemed significant. A receiver operating characteristics (ROC) curve was analyzed to estimate the cutoff point for the CI for predicting re-manipulation. The ROC curve was constructed by calculating the sensitivity and specificity of the cutoff point for each of the possible CI values. An index of ‘goodness’ of the predictor variable, i.e., CI, is the area under the curve (AUC).

RESULTS

Re-angulation of the fracture within the original plaster cast occurred in 30 children (19.2%): 22/114 males and 8/42 females. The mean ages in the non-re-manipulated and the re-manipulated groups were 9.9 and 10.2 years, respectively. The mean CI in the non-re-manipulated children (n=126) [Figure 1a–e] was significantly lower than the mean CI in children requiring re-manipulation (n=30) (0.77±0.07 vs 0.92±0.08; P<.001). All the re-manipulations were carried out for re-angulation. Among the 30 fractures needing re-manipulation, 18 fractures required stabilization with K-wires, while the rest (n=12) were stable with plaster cast alone [Table 1].

Table 1: Patient demographics in non-re-manipulation and re-manipulation groups

| Factor                  | Non-re-manipulation group | Re-manipulation group | P value |
|-------------------------|---------------------------|-----------------------|---------|
| Age                     | 9.9 years (mean)          | 10.2 years (mean)     | .68     |
| Gender                  | 92M:34F                  | 22M:8F                | .8      |
| Laterality              | 66R:60L                  | 16R:14L               | .9      |
| Initial angulation       |                           |                       |         |
| 20°–25°                 | 71                        | 2                     |         |
| 25°–30°                 | 45                        | 13                    | <.05    |
| >30°                    | 10                        | 15                    |         |
| Cast index              | 0.77 (SD 0.07)            | 0.92 (SD 0.08)        | <.05    |
primary manipulation. The CI was measured again for the re-manipulated group and was found to be lower (mean CI: 0.72) in the second cast. This correlated well with the lack of re-angulation in the re-manipulated group [Table 2].

After stratifying the children into different age-groups, we observed that re-manipulation was required (i.e., when there was angulation >20° and clinically evident deformity) in 6/16 (37%) children in group 1 (<5 years), in 6/58 (10.3%) children in group 2 (5–10 years), and in 18/82 (22%) children in group 3 (>10 years) [Table 2]. The mean CI in children who underwent re-manipulation in group 1 was 0.96 [Figure 2a–e], which was significantly higher than that of the other two groups (0.90 in group 2 and 0.88 in group 3) (P<.05) [Graphs 1 and 2]. One hundred and six (68%) children had only distal radius fracture, while 50 (32%) children had combined radius and ulna fractures. Re-manipulation was necessary in 16/106 (15%) patients with only distal radius fracture and in 14/50 (28%) patients with combined distal radius and ulna fracture. There was no difference in the mean CI between the two groups [Table 2]. The grade of the surgeon (consultant vs registrar) did not have any significant influence on CI (P=.64).

Table 2: Comparison of cast index

| Age-groups | Radius (16) : Radius and ulna (14) | 2nd Cast in re-manipulated group |
|------------|-----------------------------------|----------------------------------|
| Male : Female | 0.99 : 0.90 (P<.05) | 0.96 : 0.88 (P<.05) | 0.94 : 0.92 (P=.80) | 0.72 |

Figure 1: (a) Pre-manipulation lateral view; (b) pre-manipulation AP view; (c) post-manipulation AP view, with moulded cast showing coronal plane dimension; (d) post-manipulation lateral view, with moulded cast showing sagittal plane dimension (CI = 0.67); (e) 3-weeks post-manipulation showing union in good alignment

Figure 2: (a) Initial AP radiograph in a poorly moulded plaster cast showing coronal plane dimension (CI = 0.96); (b) initial lateral radiograph in a poorly moulded plaster cast showing sagittal plane dimension; (c) post-manipulation AP radiograph in well-moulded cast showing coronal plane dimension (CI = 0.74); (d) post-manipulation lateral radiograph in well-moulded cast showing sagittal plane dimension; (e) lateral radiograph at 3 weeks showing maintenance of alignment
The initial angulations for all fractures averaged 26° (range: 20°–44°). Fifty percent (n=78) of fractures with premanipulation angulation of more than 30° had to be re-manipulated. As assessed on intra-operative films, 140 children (90%) had accurate reduction. Nineteen of the one hundred and forty (13.5%) children with accurate reduction had to undergo re-manipulation following re-angulation in the cast. Only 16 children who had residual deformity within acceptable limits were allowed to continue with the molded cast. 11 of these 16 children (6.8%) required re-manipulation.

There was good intra-observer (κ=0.75) and inter-observer (κ=0.91) agreement for the CI in non manipulation and re-manipulation groups, with 95% of the observed differences being less than two standard deviations in magnitude.

The ROC has a large area under the curve (AUC), i.e., 0.91 (CI: 0.87 to 0.96; \( P < .001 \)). From the ROC graph and the coordinates, the cutoff point for CI was estimated to be 0.84. At this coordinate of CI, the sensitivity was 85% and the specificity was 81% for predicting re-manipulation in forearm fractures of children [Graph 3].

**DISCUSSION**

There is an inherent capacity for spontaneous correction of residual angulation and quick fracture healing in children.\(^2\) Nevertheless, orthopedicians have a natural tendency to try and achieve near anatomical reduction of each fracture. Acceptable alignment following forearm fractures has been defined.\(^12\) Sometimes an external deformity is obvious even with minimal angulation and can cause parental anxiety. Manipulation of these fractures involves general anesthesia with its attendant risks to the patient. A re-manipulation doubles this risk, and the patient and family are subjected to more anxiety. Besides, re-manipulation and internal fixation adds to the morbidity.\(^13\)

Boyer et al. (2002) suggested that all displaced fractures with an angulation of more than 15° require closed reduction.\(^14\) In this series, all children with angulation of more than 20° were advised closed reduction and cast molding. Complete initial displacement has been identified as a significant risk factor for re-displacement.\(^4,15,16\) Non-anatomical reduction of a fracture has been previously reported as an independent risk factor for re-displacement.\(^4,17\) It has also been confirmed that an anatomical reduction is a prerequisite to a successful outcome.\(^18\) In the present series 90% of the children had anatomical reduction of their fracture. Only 13.5% of these anatomically reduced fractures required re-manipulation. Younger et al. recommend re-manipulation if the axis deviation was more than 5° in younger patients or more than 3° in patients close to or after growth plate closure.\(^8\) Loss of reduction was more common in combined fractures
of radius and ulna than in isolated fractures of the radius alone (28% vs 15%). Some studies have highlighted the higher risk of loss of reduction in combined radial and ulnar fractures.\textsuperscript{15,17}

Loss of position of the fracture in the plaster cast is the most important predictor of malunion.\textsuperscript{8} The rate of re-manipulation following closed reduction of forearm fractures in children has been reported to be necessary in 7%–25% of cases.\textsuperscript{3,15,18–20} The re-manipulation rate of 19.2% in this series is similar to that reported in the literature. Completely displaced fractures have the highest risk for further manipulation or open reduction; translation of the radius of more than half the diameter of the bone was associated with a risk of failure of 60%.\textsuperscript{21} Angulated fractures with relatively less displacement may also re-displace. One reason for re-angulation in such fractures is poor cast molding, which leads to inadequate three-point fixation after an anatomical reduction.\textsuperscript{3,8} The key factors for good plaster application are good molding, thin and uniform padding, and adequate three-point fixation.

Chess \textit{et al.} reported that paying particular attention to cast fit, as measured by CI, reduced the chances of re-manipulation.\textsuperscript{9} The index was predictive of maintenance of fracture reduction as it reflected the molding of the cast on the forearm. The current study included both metaphyseal and diaphyseal fractures of the distal radius, whereas the study by Chess \textit{et al.} included only diaphyseal forearm fractures. Our study demonstrates the importance of ensuring good cast molding to maintain reduction in both fracture subtypes. In addition to CI, Bhatia \textit{et al.} (2006) measured padding index on radiographs and combined these two indices to calculate the Canterbury index.\textsuperscript{5} They suggested that fractures with a cast index of more than 0.8, a padding index of 0.3, and a Canterbury index of 1.1 are more prone to re-displacement. The gap index (i.e., measured as the ratio of the space between the plaster and the skin to the inside diameter of the plaster) was suggested to be a more useful predictor of re-displacement.\textsuperscript{22} But that study did not take into account the reduction in the swelling in the immediate post-manipulation period. The authors also indicated that although the gap index was a more sensitive index, the specificity of CI was more than that of the gap index (88% vs 82%).\textsuperscript{22} The gap index may not be easy to reproduce in a busy fracture clinic. Pretell \textit{et al.} suggested that the factors responsible for re-angulation or re-displacement of distal radial fractures may be fracture related, surgeon related, and patient related.\textsuperscript{23} The quality of molding of the cast is a surgeon-related factor. They suggested that the three-point index (introduced by Alemdaroğlu \textit{et al.}) is a useful casting index for predicting re-displacement in forearm fractures.\textsuperscript{24} This is the only study which suggests that this index is sensitive one.\textsuperscript{23} The authors nevertheless opined that these casting indices should not be interpreted in isolation but should be used in conjunction with fracture characteristics and patient factors.\textsuperscript{24} The CI is a simple and reproducible method of measuring the quality of molding at the level of the fracture. It correlates well with loss of position. The other recently described indices are more difficult to reproduce.

Webb \textit{et al.} (2006) suggested that the only variables that differed significantly between the patients who lost reduction and those who maintained reduction were the cast type and CI.\textsuperscript{25} The mean CI in their study was 0.79±0.07 for children who had lost reduction and required re-manipulation. The present study was designed to validate the fact that the CI is an invaluable tool for assessing the quality of molding of the cast following closed manipulation. ROC estimation suggested that the cutoff point for CI should be 0.84 (when there is high sensitivity as well as specificity) for identifying children who require re-manipulation. All the previous reports have shown that the treatment failure group has a mean CI of 0.80.\textsuperscript{5,6,14,22,25}

This study divided the children into three different age-groups for understanding the value of the CI in each age-group. There was higher rate of re-manipulation in the <5 years age-group as well as in the >10 years age-group. It is presumed that this may be due to the fact that children below 5 years have rounded forearm contours due to excess subcutaneous fat and hence are difficult candidates for cast molding. For the children below the age of 5 years, CI is consistently high due to difficult molding of the plaster cast. This may be due to poor control over the molding in chubby forearms.\textsuperscript{22} A similar explanation is probably true for the older age-group in whom 22% had re-angulation, difficult molding in these cases probably being due to increased muscle bulk.

The strength of this study lies in the fact that this was single-center consecutive radiographic analysis over a specific period of time, i.e., 2 years. All the treating surgeons followed a strict protocol to achieve an accurate reduction before plaster application. In this study all fractures that required re-manipulation had re-angulation in the palmar/dorsal (sagittal) plane. The analysis was carried out for three different age-groups to evaluate the clinical importance of CI in each age-group. Two of the authors independently calculated the CI from a set of radiographs to check the inter-observer agreement. Also, the principal author (blinded) calculated the CI from the same radiographs on two different dates to check the intra-observer agreement.

A limitation of this study is that this was a retrospective...
analysis of radiographs and the intra-manipulative radiographs were non-standardized. However, we feel that this study does reflect situations within routine clinical management of forearm fractures.18

Higher CI (≥0.84) values in post-manipulation radiographs following forearm fractures in children increases the risk of re-angulation and re-manipulation. These children should have a well-molded cast reapplied to lower the CI. Special care should be taken to ensure proper molding of the cast in patients below 5 years and those above 10 years of age. We recommend that, to reduce the risk of loss of position of distal forearm fractures in children, the CI should be routinely calculated in post-manipulation fluoroscopy.

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