Bone discrepancy as a powerful indicator for early surgery in obstetric brachial plexus palsy

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Published online: 18 May 2010
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Abstract

Objectives One of the unfortunate sequelae in obstetric brachial plexus palsy (OBPP) is upper limb length discrepancy. However, the influence of primary nerve reconstruction remains undetermined. In this study, the resultant discrepancy in children with OBPP who underwent primary reconstruction was analyzed in relation to the severity of the lesion, the timing of surgery, and the functional outcome following surgery.

Methods Fifty-four patients that met the inclusion criteria were included in this study. Preoperative and postoperative bilateral scanograms were obtained to document the effect of reinnervation on bone growth. The length of the humerus, ulna, third metacarpal, third proximal phalange, and total limb length were measured and the percentage between the affected and normal side were accessed. Correlations between all the measures of limb length and measures of active motion (i.e., three different classification systems) were performed.

Results Spearman's rank correlation coefficients revealed significant correlations between limb length discrepancies and nearly all measures of active upper extremity movement. The timing of surgery and the severity of the lesion significantly influenced the resultant limb length discrepancy.

Conclusions The prevention of a non-acceptable upper limb discrepancy is fundamental for both the patient and family. The extent of the resultant discrepancy appeared to be strongly related to the time between injury and surgery, degree of severity, and the outcome of surgery. Patients with better functional recoveries of the affected upper extremities showed smaller differences in limb length.

Keywords Limb length discrepancy · Obstetric brachial plexus palsy · Primary reconstruction · Functional outcome

Introduction

Upper extremity length discrepancy in children may result from congenital, developmental, and post-traumatic conditions [4, 5, 9, 25, 46]. Residual limb shortening is common after obstetric brachial plexus palsy (OBPP) but the exact length discrepancy remains undetermined. McDaid et al. [25] studied the resultant discrepancy in children with OBPP and found significant shortening of the limb at both humerus and forearm level, especially in global lesions. However, in their study, the length discrepancy in the hand was not addressed. Moreover, none of their patients underwent plexus exploration and nerve reconstruction, and several children had previously undergone tendon transfers.

Despite some conflicting reports [2, 17, 21], probably more than 70% of all infants presenting with OBPP will have a very good spontaneous recovery. The remaining patients are destined for poor functional outcomes and they are potential candidates for nerve surgery. If the patient does not receive early treatment, the chronic muscle imbalance results in changes to the growing skeleton and creation of fixed deformities [19, 20, 30, 44]. The severity

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of the late consequences is correlated with the type of injury and the extent of denervation time [43, 45]. The most common sequelae deformities may include [49] posterior subluxation or dislocation of the humeral head, winging of the scapula, forearm deformities—pronation or supination contractures, hand deformities, and hypoplasia of the bones in the upper extremity resulting in limb length discrepancy. Many reports have analyzed the deformities of the glenohumeral joint [20, 23, 26, 48] and the forearm and hand deformities [14, 37] but there are no studies to date, however, that focus on the etiology of limb length discrepancy and the influence of primary nerve reconstruction.

The purpose of this study was to determine the resultant limb length discrepancy in 54 children with OBPP who underwent primary nerve reconstruction and analyze the results in relation with the functional outcome of the surgery, the time between injury and surgery, the severity of the lesion (avulsed vs. ruptured roots), and the age of the patient.

This study was conducted under the guidelines and the approval of the Institutional Review Board Committee of Eastern Virginia Medical School.

Materials and Methods

Upper Extremity Development

The first evidence of the presence of the human hand in the upper limb bud occurs at 4 weeks of the embryonic period, with the appearance of protrusions in the prospective forelimbs [27, 33]. Development of the cartilage anlagen is observed at approximately 7 weeks, and growth region at each end of each carpal bone is clear. The endochondral ossification pattern is fully established by 8 weeks, setting the stage for the hand growth. This growth continues in the fetus and after birth in response to systemic hormones [33].

Normal skeletal growth may occur through either endochondral ossification (longitudinal growth) or appositional growth (diameter growth) [46]. Longitudinal growth occurs at the physis (growth plate). Appositional growth occurs at the primary and secondary centers of ossification. Primary centers are located in the diaphysis while secondary centers are located in the epiphysis of the bone. When cartilaginous anlage of primary or secondary centers of growth ossifies, they become radiographically evident [28]. At birth, the primary centers for all long and short bones are present radiographically [46]. Secondary centers in the epiphyses of the long and short bones as well as primary centers of the carpal bones ossify and become radiographically evident with skeletal maturation.

Determination of the appropriate appearance of primary and secondary centers in the hand is commonly referred to

as bone age. Longitudinal studies have well documented the means and standard deviations for onset and completion of ossification for each of the 29 growth centers in the hand and wrist [18]. Most hand ossification centers become radiographically evident between 0 and 3 years of age in girls and 0 to 4 years of age in boys. Growth plate closure clusters between 13 and 16 years of age in girls and 15 to 17 years of age in boys.

Patient Population

Between 1979 and 2006, a total of 175 patients with obstetric brachial plexus palsy were examined in our center. Of these, 104 patients (106 extremities) underwent primary reconstruction and/or secondary procedures. Ninety-nine patients had unilateral paralysis and five had bilateral paralysis. Of all 104 patients operated on, 54 patients were included in our study. Inclusion criteria were the following: (1) all patients with a minimum follow-up of 36 months after primary reconstruction, (2) patients with unilateral paralysis only, and (3) patients with accurate plain X-ray films (scanograms) of bilateral extremities.

The mean time between birth and surgery (i.e., denervation time) was 2.2 years (range, 2 months to 9 years). Twenty-nine (54%) of the patients were female and 25 (46%) were male. Fifty patients had vertex presentation, and three patients were delivered via breech presentation. One patient had been born by cesarean delivery. In 25 (46%) cases, the right brachial plexus was injured, and in 29 (54%) cases the left side was involved. Twelve (22%) patients had a diagnosis of Erb palsy with C7 involvement (C5–C7), and 42 (78%) patients were diagnosed with global palsy (C5–T1).

Type of Reconstruction

In most cases, a neuroma in continuity was found in the spinal nerves and/or trunks. Depending on the clinical signs and the operative findings, the neuroma was excised and reconstruction by nerve grafting along with intraplexus and/or extraplexus nerve transfers was performed. In all cases, the assessment of the severity and extent of the lesion was supported by intraoperative neurophysiological and histological investigations [43, 44]. The number of grafts and their length depended on the type and severity of the lesion. The reconstruction of the brachial plexus included a combination of different techniques (Table 1). Neurolysis was performed only for elements of the plexus that had suffered a mild traction injury without disruption of the perineurial sheath. Grafting procedures (intraplexus neurotizations) were always needed. The most commonly used donor nerves were the proximal stumps of the C5 (44 neurotizations) and C6 nerve roots (26 neurotizations). In

Table 1 Type of nerve reconstruction according to type of injury.

Type of surgery	C5–C7	C5–T1	Total
Grafting	9	15	24
Grafting+neurolysis	1	7	8
Grafting+nerve transfers	2	20	22
Total	12	42	54

the presence of multiple root avulsions, extraplexus motor donors were used. Extraplexus donors included the distal spinal accessory nerve, which was used to reconstruct the suprascapular nerve in 17 cases, the cervical plexus, the intercostal nerves, and the contralateral C7. All nerve coaptations were executed with 10-0 or 11-0 sutures under high magnification of the operating microscope.

Measurements

A scanogram was obtained with the central X-ray beam positioned sequentially including the acromion, arm, forearm, wrist, and hand to the tips of the fingers. A radioopaque metallic ruler was placed adjacent to the extremity and the entire upper extremity projected on a long-leg X-ray cassette. Using standardized anatomic landmarks, measurements of each limb segment were obtained. *Humeral* length was measured from an anteroposterior radiograph from the top of the humeral head to the most distal portion of the humerus, which varied with skeletal maturity. Some patients had the arm internally rotated and the elbow in flexion contracture and therefore additional scanograms with parental help were obtained for accurate measurements. At the forearm level, the length of the *ulna* was measured from the tip of the olecranon to the ulnar styloid on the supinated anteroposterior radiograph. At the level of the hand, the length of the *third metacarpal* and the length of the *third proximal phalange* were measured individually on an anteroposterior scanogram.

The amount of shortening from all these four levels was expressed as an absolute limb length discrepancy (in centimeters) and as a percentage of the uninvolved humerus, ulna, third metacarpal, third proximal phalange, and total limb length. The same physician (Z.T.K.) studied all roentgenograms and recorded all the measurements. Scanograms were obtained on a preoperative basis to measure existing bone length discrepancies and to document the effect of reconstruction on bone growth. Follow-up visits included repeated scanograms (every 6–12 months) of both extremities. The mean patient age at the date that had the first scanograms was 2.2 ± 2.4 years (range, 2 months to 9 years), and the age that had the last scanograms (follow-up age) was 8.0 ± 4.05 years (range, 3.3 to 24 years).

Active motion was assessed using a modified Mallet scale [41] with a grading of I to IV for evaluation of shoulder abduction; shoulder external rotation; and hand to nape, hand to back, hand to pocket, and hand to mouth position. Aggregate Mallet scores were calculated by summing the six individual scores (maximum score 24 points). Elbow function was assessed using the Gilbert scale [16, 19]. This scale provides an assessment of active elbow flexion, elbow extension, and extension deficit (flexion contracture); the latter reduces the score. The scale has a maximum score of 5 (range –1 to 5). Hand function was evaluated by using a modified Gilbert–Raimondi hand scale [40] (ranging from 0, which equals total palsy, to 6, which represents a nearly normal functioning hand). A consensus grade of the hand scale for each patient was produced quoting all the clinical data (i.e., grading of the individual muscle groups of the hand, range of motion, pronosupination, and grip and pinch strength).

Statistical Analysis

Statistical analysis was performed in the Biostatistics Department of Eastern Virginia Medical School. One-way analysis of variance was used to assess the relationship

Table 2 Limb length discrepancy in all levels: preoperative and postoperative results.

Mean age	Preoperative		Postoperative	
	2.2 ± 2.4 years		8.0 ± 4.05 years	
	Absolute difference (cm)	Percentage of contralateral limb (%)	Absolute difference (cm)	Percentage of contralateral limb (%)
Humeral length	0.84	95.0	1.77	93.0
Ulna length	0.88	93.2	2.26	88.3
Third metacarpal length	0.24	93.4	0.47	90.3
Third proximal phalange length	0.15	93.8	0.25	92.5
Total limb length	1.9	94.2	4.77	91.0

Table 3 Spearman's rank correlation coefficients between measures of active upper limb motion (modified Mallet classification, Gilbert scale, and modified Gilbert–Raimondi hand scale) and measures of upper limb length discrepancies (*p* value in parenthesis).

	Modified Mallet classification [41]	Gilbert scale [16]	Modified Gilbert–Raimondi hand scale [40]
Humeral length (%)	0.381 ^a (0.004)	0.17 (0.21)	0.398 ^a (0.002)
Ulna length (%)	0.561 ^a (<0.0001)	0.422 ^a (0.001)	0.618 ^a (<0.0001)
Hand (MT+PP) length (%)	0.671 ^a (<0.0001)	0.337 ^a (0.012)	0.632 ^a (<0.0001)
Total limb length (%)	0.578 ^a (<0.0001)	0.36 ^a (0.007)	0.625 ^a (<0.0001)

MT third metacarpal, PP third proximal phalange

^a Significant difference

among denervation time and absolute limb length difference (humerus, ulna, third metacarpal, third proximal phalange, total), and percentage; if significance was found, the Scheffe's pairwise test was performed. For data in which the assumption of normality was not met, a Kruskal–Wallis test, followed by pairwise Dunn's multiple comparisons test, was used. Pearson correlation coefficient was used for the correlation between follow-up age and all the measures of limb length. Correlation between all the measures of limb length and measures of active motion were assessed using Spearman's rank correlation coefficient. All the analysis was performed in SAS 9.1.3 (Cary, NC, USA). The significance level was set at 0.05.

Results

Forty-two (78%) of 54 children had some discrepancy of the limb at all four levels (humerus, ulna, third metacarpal, and third proximal phalange). Preoperative and postoperative results of the total population (*n*=54) for humerus, ulna, third metacarpal, third proximal phalange, total limb length difference, and percentage are presented in Table 2. At the final follow-up, the involved limb averaged 91% of the uninvolved limb (range 79–99%), and the difference was significant (paired *t* test, *p*<0.001). The absolute mean difference between the involved (45.8 cm, range 30–63 cm) and uninvolved (50.6 cm, range 31–73.6 cm) extremities was 4.77 cm (paired *t* test, *p*<0.001).

There was a significant correlation between follow-up age (i.e., final postoperative measurements) and the absolute difference in total limb length (Pearson correlation, *r*=0.65, *p*<0.01); however, no significant correlation was found between follow-up age and percentage of the total length (*r*=−0.23, *p*=0.082).

Mean aggregate modified Mallet classification score was 19.23±3.5 (range 10 to 24) out of a maximum score of 24. Mean Gilbert scale score was 4.09±0.9 (range 2 to 5) out of a maximum score of 5. Mean modified Gilbert–Raimondi hand scale score was 3.9±1.6 (range 1 to 6) of a maximum score of 6. Spearman's rank

correlation coefficients revealed significant correlations between limb length discrepancies and nearly all measures of active upper extremity movement, as shown in Table 3.

The effect of timing of primary nerve reconstruction was analyzed. Six of 54 patients underwent early nerve reconstruction within 3 months of life (group A), 20 had reconstruction between 4 and 6 months (group B), and the remaining 28 patients had nerve reconstruction later than 7 months (group C). Early surgery (≤3 months) significantly affected the absolute total limb length as compared with the other two groups (groups B and C) (*p*=0.0003) (Fig. 1). Also, denervation time significantly affected percentage of the humerus (*p*<0.0001), ulna (*p*=0.0014), third metacarpal (*p*=0.0022), third proximal phalange (*p*=0.0006), and total length (*p*<0.0001) (Fig. 2). Comparison between subgroups revealed that early surgery (≤3 months) significantly affected the hand length (third metacarpal

Figure 1 The effect of the denervation time (DT) on the absolute difference of the total limb length (*p*=0.0003).

Figure 2 The effect of the denervation time (DT) on the of the total limb length (%) ($p < 0.0001$).

and third proximal phalange), and surgery less than 6 months (groups A and B) significantly affected the humerus and ulna length as compared with the late surgery group (group C). Descriptive statistics are presented in Table 4. Three exemplary cases are presented in Figs. 3, 4, and 5.

The bone discrepancy in relation to the status of each root lesion was also studied. The intraoperative findings of the 54 reconstructed plexuses are shown in Table 5. We should note that most of the cases (78%) were global plexus lesions and a combination of avulsions and

ruptures existed in the same plexus. The results were the following:

1. When C8 and/or T1 roots were avulsed (in 21 of 54 cases both roots were avulsed and in only three cases was C8 or T1 individually avulsed), bone discrepancy significantly affected both the ulna (84.8% of the uninvolved limb) and the hand (third metacarpal and the third proximal phalange, average 88.05%) as compared to the humerus length (92.6%) ($p < 0.0001$).
2. When C7 root was avulsed (22 cases), bone discrepancy mainly affected the ulna (85.4%) as compared to the hand (89%) and the humerus length (93.4%) ($p < 0.001$).
3. When C5 and C6 roots were involved (upper plexus lesions, 12 cases) bone discrepancy significantly affected the humerus length (94.6%) and the ulna (95.6%) as compared to the hand (98.5%) ($p = 0.0004$).

In summary, the hand and the ulna were most affected in lower root avulsions (C8 and T1), while in C7 root avulsions the ulna was the most affected bone. In upper plexus lesions, the humerus length was mainly affected.

Discussion

Despite advances in prenatal care and childbirth, the incidence of obstetric brachial plexus palsy has not changed dramatically over the years [26]. Prevention remains problematic and the natural history of the condition remains

Table 4 Comparisons of variables between patients with different denervation times (DT).

Variables	DT (months)	No.	Mean value (SD)	<i>p</i> value
Humeral length (%)	≤3	6	96.7±1.3	<0.0001 ^a
	4–6	20	94.2±3.3	
	>7	28	91.2±2.7	
Ulna length (%)	≤3	6	96.7±1.5	0.0014 ^a
	4–6	20	89.5±5.7	
	>7	28	85.5±7.5	
Third MT length (%)	≤3	6	98.4±2.7	0.0022 ^a
	4–6	20	91.4±5.8	
	>7	28	87.7±7.6	
Third PP length (%)	≤3	6	98.8±1.8	0.0006 ^a
	4–6	20	94.0±4.6	
	>7	28	90.0±5.8	
Total limb length difference (cm)	≤3	6	1.3±0.6	0.0003 ^a
	4–6	20	3.9±2.3	
	>7	28	6.1±2.8	
Total limb length (%)	≤3	6	97.1±0.9	<0.0001 ^a
	4–6	20	92.2±3.6	
	>7	28	88.7±4.1	

MT third metacarpal, PP third proximal phalange, SD standard deviation

^a Significant difference

Figure 3 A girl presented at 3 months of age with right obstetric brachial plexus palsy (a). Preoperatively, there was no bone discrepancy between the affected and normal side (b). She underwent early nerve reconstruction (DT=3 months) and the intraoperative

findings were as follows: C5, C6—rupture; C7—traction; C8, T1—spared. At 7 years of age, the limb length discrepancy was indistinguishable (c and e). The absolute difference in total limb length was 0.9 cm and the percentage was 99% (d and f).

controversial although the majority of cases achieve a satisfactory and useful recovery without surgical intervention [31]. When spontaneous reinnervation fails to restore normal function by 6 to 8 weeks, and surgery is delayed, this invariably leads to the development of bony deformities and joint contractures caused by asymmetric muscle forces [6]. In severe cases of OBPP where no evidence of functional recovery is plausible, surgical intervention is indicated [19, 43, 44]. While controversies exist regarding

the treatment strategies, the broad principles of management of OBPP are clear: early diagnosis, early assessment of function, early surgical intervention, and aggressive physical therapy punctuated by secondary reconstruction for residual deformities [35]. In patients who present late for nerve reconstruction, irreversible changes have taken place in skeletal muscles and established upper limb length discrepancy is present, highlighting the importance of early referral and treatment [29, 34].

Figure 4 A boy presented at 6 years of age with a diagnosis of right obstetric brachial plexus palsy (**a**). The preoperative lengths were for the humeral 95%, ulna 89%, third metacarpal 88%, third proximal phalange 91%, and total length 92%, respectively. The absolute difference in total length was 3.7 cm. He underwent nerve reconstruction at that time (DT=73 months). The intraoperative findings were as follows: C5—rupture; C6—avulsion; C7, C8, T1—avulsion/rupture. However, the discrepancy was progressive and 2 years later the absolute difference in total length was 8.4 cm (**b**). The percentage was for the humerus 92%, ulna 72%, third metacarpal 90%, third proximal phalange 91%, and total length 84%, respectively (**c** and **d**).

The results of the current study indicate that children with OBPP will have some degree of limb length discrepancy of the affected side, and the majority of them (78% in our series) will have some discrepancy of the limb at all levels (arm, forearm, and hand). However, the majority of the cases were global lesions, since infants with severe lesions were much more likely to be referred to our center than infants with Erb palsy. In the patients with global palsy, the lower roots were mostly avulsed while the upper roots were ruptured. It is very interesting that the ulna was the most affected bone regarding each root level injury especially in lower root avulsions (C8 and T1). Nonethe-

less, it should be pointed out that in 16 out of 21 (76%) cases of both C8 and T1 root avulsions, the C7 root was also avulsed.

It is of great importance to identify the severity of brachial plexus injury as early as possible, especially if there is minimal recovery in the early weeks of follow-up. Some authors suggest that if surgical exploration is to be undertaken, it should be performed within the first 6 months of life [3, 8, 15]. Haerle and Gilbert [19] recommend that, if at 3 months of life an infant with global palsy and Horner's syndrome shows no recovery of the forearm and hand, the baby should be operated on, even with signs of upper root

Figure 5 A girl presented at 11 months of age with right obstetrical brachial plexus palsy (a). The preoperative lengths were for the humerus 96%, ulna 96%, third metacarpal 87%, third proximal phalange 89%, and total length 94%, respectively. The absolute difference in total length was 1.4 cm (b). She underwent primary reconstruction at that time and the intraoperative findings were as

follows: C5—rupture; C6, C7, C8—avulsion; T1—avulsion/rupture. Seven years later, the limb length discrepancy was cosmetically noticeable and objectionable (c). The absolute difference in total length was 9.6 cm. The percentage was for the humerus 89%, ulna 78%, third metacarpal 76%, third proximal phalange 84%, and total length 83%, respectively (d and e).

recovery or biceps function. Our strategy is timely nerve reconstruction, earlier than 3 months for global palsies, and at 3 months in Erb palsy patients without biceps or deltoid recovery [39, 40, 43, 44]. According to the current study, the extent of the limb length discrepancy does appear to be strongly related to the time between injury and nerve reconstruction. The children that underwent early nerve surgery (within 3 months) had total limb length 97.1% of

the unaffected side, those that underwent nerve reconstruction between 4 and 6 months had total length 92.2%, and those that had primary reconstruction later than 6 months had total limb length 88.7% of the unaffected side ($p < 0.0001$). Also, the absolute difference in total limb length was 1.3 cm, 3.9 cm, and 6.1 cm, respectively ($p = 0.0003$). Certainly, the type of reconstruction (e.g., length of the nerve graft), degree of severity,

Table 5 Type of lesion for each root in 54 reconstructed brachial plexuses.

Root	Type of lesion						No. of plexuses
	A	A/R	R	R/T	T	N	
C5	1	1	46	1	5		54
C6	14	4	33		3		54
C7	22	5	15	1	11		54
C8	24	4	5	2	10	9	54
T1	21	4	3	3	13	10	54
Total	82	18	102	7	42	19	

A avulsion injury, *A/R* avulsion/rupture, *R* rupture, *T* rupture/traction, *C* traction, *N* normal

and concomitant problems are all factors that might influence the final outcome. However, as shown in the recently published series from our center [39, 40, 42], there is a direct relationship between timing of surgery and the functional outcome. Patients who underwent early surgery showed better functional recoveries of the affected upper extremities.

In the current study, significant correlations were detected between upper limb length discrepancies and measures of upper limb motion (modified Mallet classification, Gilbert scale, and modified Gilbert–Raimondi hand scale). This finding suggests that patients with more limited active upper extremity function may have greater differences in limb length. Bae et al. [1] have recently published their analysis of 48 patients with brachial plexus birth palsy who underwent measurements of the bilateral upper extremities. All patients were treated conservatively and had persistent neurological deficits with upper extremity weakness. Interestingly, despite the small but significant limb length and girth differences, no meaningful correlations were detected between the magnitude of limb size difference and standardized measures of upper limb motion. The degree of severity in our study (78% of the cases were global plexus lesions with multiple root avulsions) and the relative large limb length differences among patients might explain this inconsistency.

Mechanobiologic factors strongly influence skeletal ossification and regulate changes in bone geometry and apparent density during ontogeny [10, 13]. Carter et al. [11] concluded that cartilage growth and chondroosseous development is extremely susceptible to extrinsic factors from the immediate environment. Examples of such factors are the influence of adjacent tissues, vascularity, the concentration of nutrients and hormones, and mechanical movement and forces [33]. Mechanical stresses acting on bone growth constitute a major extrinsic influence in early

skeletal development [12]. Changes in mechanical stresses prenatally, postnatally, and in the growing child will result in bone and joint deformities and limb length discrepancy. Several investigators have studied the growth of long bones after the attached muscles have been denervated and found bone growth was retarded after denervation [24, 38]. Dysart et al. [7] postulated that muscle pull affects periosteal tension and consequently bone growth in length. In patients with obstetric brachial plexus palsies, weak or absent muscle function in the affected upper extremity due to prolonged denervation leads to diminished mechanical stresses that are critical to longitudinal growth of the long bones. Therefore, the earlier the upper extremity musculature is returned to function, the less the limb length discrepancy.

Limb lengthening procedures in the upper extremity are indicated in fewer instances than in the lower extremity because moderate discrepancies in the upper limb do not produce functional or cosmetic problems. Those equal or greater than 5 cm are cosmetically noticeable and those greater than 7 cm are objectionable [4]. Length discrepancies of more than 5 cm result in impairment of reach and cosmetically unappealing clothing difficulties and appearance. Significant progress in upper-extremity lengthening has occurred with the introduction of the Ilizarov method [22, 47]. However, lengthening with the Ilizarov technique is a demanding process that is influenced by a multitude of factors [32]. Problems, obstacles, and complications during limb lengthening include muscle contractures, joint subluxation, axial deviation, neurological or vascular insult, premature consolidation, delayed consolidation, refracture, pin-site infection, and difficulties with psychological adjustment [36]. Therefore, the prevention of a non-acceptable upper limb discrepancy is fundamental for both the patient and family.

The current study has some inherent limitations including its retrospective nature. It is a non-comparative study without a control (no surgical treatment) group. The authors do acknowledge that there were difficulties in arriving at solid conclusions as there were many variables involved such as timing of surgery, degree of severity, and follow-up duration. The sample size included 54 patients of varying ages, and many subjects were not followed to skeletal maturity. Hence, additional prospective, randomized studies will be necessary in order to assess the definitive validity of this study.

In summary, by closely reviewing the results attained in this series of patients, a better understanding was gained on the specific degree of upper limb shortening and the specific bones involved in relation to the severity of the lesion, the timing of surgery, and the functional outcome of surgery.

Disclaimer None of the authors received financial support for this study and all authors have no conflict of interest.

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