ABSTRACT: Supination contracture in patients with obstetrical brachial plexus paralysis (OBPP) results in severe functional limitation of daily activities. Forearm pronation osteotomy has been used to address this problem, although the functional benefit over nonoperative management has not yet been clearly defined. Material and methods: This is a retrospective chart review of children with OBPP who underwent a pronating forearm osteotomy for their supination contracture at our institution between 2007 and 2014. Patients were evaluated for resting forearm position, forearm passive and active pronation and supination, preoperatively and at their last follow-up. Age correlation to outcomes was also tested. A subjective assessment tool for improvement was also used to evaluate patient-oriented outcomes. Results: Eighteen patients with a mean age of 8.5 years (3.7-17) and a mean follow-up of 55 months (24-100) were included. Preoperatively, patients had a forearm resting position of 90°. Mean passive pronation was -45° (-30° to -60°). All patients had no active pronation. At their last follow-up, mean forearm resting position was -4° (-45° to +10°; p < 0.001), mean active pronation reached +26° (0° to +60°; p < 0.001), mean passive pronation was +76° (+50° to +90°; p < 0.001), mean active supination was -37° (-50° to -25°; p < 0.001) and mean passive supination was -80° (-90° to -73°; p < 0.001). There were no correlation between age at surgery and final outcomes. Subjective self-assessment tool showed a mean partial improvement in all five tested headings. Discussion: Pronation osteotomy in OBPP patients with supination contracture is an effective reliable procedure with reproducible results. It seems to be associated with partially improved functional results in the postoperative period. While recurrence is possible, age at surgical intervention does not seem to affect the final outcome.

Keywords: obstetrical brachial plexus palsy; supination contracture; pronation osteotomy; functional improvement.

INTRODUCTION

Obstetric brachial plexus paralysis (OBPP) results from excessive stretching of the brachial plexus during difficult labor [1]. It occurs in 0.38 to 3 cases per 1000 live births [2]. The main risk factors for OBPP include: birth weight > 4 kg, shoulder dystocia, breech presentation, gestational diabetes mellitus and the use of a vacuum or of a forceps during delivery [3-6]. Although the majority of patients recover spontaneously, others retain severe functional impairment [7].

Roots C5 and C6 are the most commonly affected in OBPP leading to internal rotation and adduction contracture of the shoulder [8]. Forearm supination occurs when...
C8 and T1 roots are affected, either alone or as a part of total brachial plexus injury with or without functional recovery of proximal roots [9]. In its early stages, the resulting supination deformity is flexible, but this deformity becomes progressively static with years due to interosseous membrane contracture and paralyzed muscles shortening [10]. The resulting limitation in the forearm’s arch of motion leads to severe functional deficiency as fixed supination is often associated with suboptimal hand position for activities on a desk and for use of tools [9]. Moreover, this deformity leads to major aesthetic impact, as the normal resting position of the upper limb during standing or walking is usually in slight pronation [9].

Various surgical techniques have evolved to obtain a pronation position of the hand. Soft tissue procedures include biceps Z-lengthening and rerouting to transform it into a pronator, interosseous membrane release, brachioradialis rerouting and others are indicated for early, and flexible supination deformity [11]. Bony procedures include forearm osteoclasis or osteotomies (Radius and/or ulnar pronation osteotomy) and are indicated in stiff deformities [9,12]. Eligible patients for surgical treatment are those with possible active wrist extension, otherwise, limb function will be affected negatively by the surgical intervention with maintained wrist flexion due to gravity [12].

In this article, we review the mechanical and functional patient-centered outcomes of forearm pronating osteotomy for the correction of forearm supination deformity secondary to obstetric brachial plexus palsy in 18 children treated at our institution over seven years.

MATERIALS AND METHODS

This is a retrospective study of the children with OBPP who underwent a pronating forearm osteotomy at our institution between 2007 and 2014. All children with OBPP aged between 3 and 17 years with forearm supination contracture were included. Patients with deficient active wrist extension and fingers flexion were excluded from the study. This work was unanimously approved by the institutional review board of our institution.

Surgical technique

Patients were operated by a senior pediatric orthopedic surgeon, using an anterior (Henry) approach to the radius and a posterior direct approach to the ulna (Figure 1). Open osteotomy of the radius, then of the ulna were performed at the mid diaphysis of each bone. The deformity is corrected to an angle of 20 to 30° of pronation, and the fragments were fixed using a locking compression straight plate with 6 screws (3 proximal and 3 distal to the osteotomy site) on each bone. Postoperatively, all patients had a long arm cast in the corrected pronation position for three weeks. After cast removal, all patients followed a one-year protocol of functional rehabilitation of the forearm.

Data collection

For each patient, forearm resting position as well as passive and active range of motion in pronation and supination were noted preoperatively and at last follow-up. The minimum follow-up is of 24 months. Measurements

**FIGURE 1.** Anterior Henry approach to the radius with a template plate in place. A mark is made at the location of the osteotomy, and two K-wires are inserted in the proximal and distal fragment prior to performing the osteotomy, to control rotational correction
were performed by the senior orthopedic surgeon and one senior resident. The effect of age at surgery on the obtained outcomes was also analyzed. Forearm a/p and lateral X-rays were performed at last follow-up for all patients as part of routine follow-up (Figure 2).

**Statistical analysis**
The preoperative and postoperative values for the five tested variables (forearm resting position (°), forearm passive pronation (°), forearm active pronation (°), forearm passive supination (°), forearm active supination (°)) were compared using a paired student “t” test. Effect of age at surgery on the surgical outcome was analyzed through a logistic regression by univariate analysis. All analysis was performed using SPSS 16.0 statistical software (SPSS Inc., Chicago Illinois, USA).

A p-value less than 0.05 was considered statistically significant.

**Subjective evaluation**
A subjective assessment tool for the improvement perceived by the patient or his/her parents was developed at our institution.

This tool is based on five headings: Aesthetic, wrist and finger motion, grasping, daily use of hand and quality of life improvements. Patients or their parents were asked to fill the assessment with the help of an author of this manuscript using, for each heading, 0 when there was no subjective improvement, 1 when the improvement was moderate and 2 when the improvement was subjectively complete or near complete (Table I).

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SUBJECTIVE SELF-ASSESSMENT TOOL FOR EVALUATION OF IMPROVEMENT GIVEN TO PATIENTS OR THEIR CAREGIVERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement</td>
<td>None (0)</td>
</tr>
<tr>
<td>Aesthetic improvement</td>
<td></td>
</tr>
<tr>
<td>Grasping force</td>
<td></td>
</tr>
<tr>
<td>Grabbing ability</td>
<td></td>
</tr>
<tr>
<td>Finger mobility</td>
<td></td>
</tr>
<tr>
<td>Quality of life</td>
<td></td>
</tr>
</tbody>
</table>
RESULTS

Eighteen patients were initially included in the study. One of these was lost to follow-up, ending with 17 patients who were followed for at least 24 months. The mean follow-up is of 55 months postoperatively with a maximum recorded follow-up reaching 100 months. Mean age at surgery was 8.5 years, ranging from 3.7 to 17 years. Supination deformity occurred on the left side in 78% of patients and on the right side in 22% of patients.

Preoperatively, all patients had a forearm resting position of -90° (full supination). Mean passive pronation averaged 45° (-30° to -60°). All patients had no active pronation.

At their last follow-up, mean forearm resting position was about 4° (-45° to +10°). Mean active pronation was 26° (0° to +60°) and mean passive pronation reached 76° (+50° to +90°). Mean active supination was -37° (-50° to -25°) and mean passive supination was -80° (-90° to -73°) (Table II).

Interobserver and intraobserver reliability were tested between both authors who took the necessary measures. Interobserver reliability was found to be 0.67 and intraobserver reliability was 0.70.

The improvement for all five tested variables when compared to preoperative values showed a p value < 0.001 for each (Table II).

Univariate analysis studying the correlation between age at surgery and the five tested variables showed the following coefficient of correlations: resting position: 0.124155, p = 0.75; active pronation: 0.153796, p = 0.69; passive pronation: -0.09598; p = 0.8; active supination: 0.040075, p = 0.91; passive supination: 0.577888, p = 0.10 (Table II).

Results for subjective self-assessment are displayed in Table III.

Radiographs showed normal bone union in all patients, with no hardware failure. One patient had a radial head dislocation and one had complete elbow dislocation, both existing preoperatively. This did not affect the outcome as both patients had +5° and -3° of resting forearm positions respectively at their last follow-up.

No wound infection, wound dehiscence or major bleeding were reported. Only two patients had a recurrence of forearm supination contracture (-45° and -20° of resting position respectively). The first was operated at age of 9.3 years and the second one at age of 4.5 years. Both patients were re-operated with final resting positions of -8° and +2° respectively.

DISCUSSION

This is the first Lebanese cohort of OBPP patients with supination deformity operated on of radius and ulnar osteotomy. This retrospective study showed that at a minimum 2-year follow-up, forearm resting position significantly improved from full supination to a near neutral position, with 86° of mean improvement. Statistically significant improvement was also shown for passive (121° of improvement) and active pronation (116° of improvement). Moreover, this study showed that diaphyseal ulna and radius osteotomy preserved passive and active supination despite operating on
patients with severe and stiff supination contracture and absent active pronation preoperatively. These results keep in line with previous cohorts in the medical literature evaluating corrective osteotomies of the forearm [9-11,13-17]. In their 23 patients operated of pronating osteotomy, Bahm and Gilbert got a final resting position in 17° of pronation of forearm at latest follow-up [15]. Van Kooten et al. had a series of eight cases operated of radial osteotomy with good functional and aesthetic results at 23 months [16]. Rolfe et al. performed a distal ulnar and mid-radial pronating osteotomy on a cohort of 14 patients with OBPP obtaining 104° of mean final correction and a final mean position of pronation of 24° [14]. Also, Gladstein et al. showed a statistically significant improvement postoperatively after pronation osteotomy in neutral standing position and in pronation ability compared to nonoperated controls [9]. In a systematic review of the literature and meta-analysis, Metsaars et al. found that pronation osteotomy resulted in 65° improvement of passive pronation, 75° gain in position at rest, with more improvement in more severe cases [17]. Improvement of active pronation from zero preoperatively to present and functional postoperatively may be explained by preoperative stiff supination contracture and a lever arm dysfunction of the pronators.

Therefore, pronation osteotomy proved its efficacy in correcting severe and rigid supination deformity in OBPP. It is associated to a more predictable outcome in terms of immediate deformity correction. It is usually foreseeable that there will be some degree of loss of correction with time which can be addressed by intentionally excessively correcting the forearm position to 20° pronation. In biceps rerouting and other soft tissues procedures, optimal muscle balance must be achieved to prevent recurrence or loss of range of motion. This is difficult to assess intraoperatively, whereas placing the forearm in 20 degrees of pronation is reproducible and easy.

Two patients (11.7%) in our series had recurrence of their supination contracture. This is better compared to the reported rate in the literature ranging between 20 and 40% [17,18]. Recurrence was thought to be associated to young age at surgery, lower function of shoulder and hand, and single bone osteotomy technique [18]. However, in our cohort, there was no statistical correlation between age at surgery and any of the variables tested for the outcomes. This is in line with results obtained from the meta-analysis performed by Metsaars et al. [17].

Functional gain achieved by forearm pronating osteotomies remains unclear in the literature partly due to lack of subjective patient centered outcome measures; we developed, at our institution, a subjective improvement assessment tool focusing on the five essential patient-oriented outcomes. This tool is completed by the patient or his/her parents depending on the patient age. This tool showed in our cohort a mean partial functional improvement in all five headings.

This finding is of great importance despite the lack of standardization and validation of this tool. This is the first cohort to show a maintained functional improvement in patient’s forearm function at last follow-up. Only one previous cohort in the recent medical literature assessed the functional outcome in patients operated of forearm pronation osteotomy using the Brachial Plexus Outcome Measure (BPOM) [9]. The study failed to show any statistically significant better functional results in operated patients compared to the nonoperated cohort except in playing drums [9]. The good results obtained in our study reflect the importance of preoperative patient and family counseling and clear discussion on awaited outcomes, keeping realistic expectations.

The retrospective design and the small number of patients included in this study are major limitations, however, this is the first case series of its kind in Lebanon, dealing with a very rare condition, which goes in line with the relatively sparse data available on this subject in the medical literature and the retrospective design of all available studies with a small number of patients included.

CONCLUSION

Forearm pronating osteotomy is a reliable, effective and reproducible technique for correcting severe and rigid forearm supination deformity in patients with OBPP. It leads to improved forearm resting position, pronation range of motion, together with a maintained passive and active supination. This is also associated with a partial functional improvement. Age at surgery does not seem to be correlated to outcomes nor does it seem to affect the rate of recurrence.

REFERENCES

4. Gilbert WM, Nesbitt TS, Danielsen B. Associated factors