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Hand/Peripheral Nerve

10-year Follow-up of Mod Quad and Triangle Tilt Surgeries in Obstetric Brachial Plexus Injury

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Aim: To evaluate whether obstetric brachial plexus injury (OBPI) children who had mod Quad and triangle tilt surgeries maintained their recovered upper extremity functional movements over 10 years.

Background: The short-term outcomes of surgery in OBPI patients are well documented. However, only a few publications with results over 10-year postoperative follow-up exist. We have previously reported the outcomes of these 2 surgeries in OBPI after 1, 2, and 5 years. Here, we report the successful outcomes in 17 of these patients over 10 years.

Methods: Seventeen OBPI patients, who had mod Quad, a modified muscle release operation and triangle tilt, a bony surgical procedure with us between 2005 and 2008, had postoperative follow-up of 10 years and met the inclusion criteria. Patients who had multiple surgeries and did not have 10-year follow-up are excluded in this study.

Results: Fifteen of 17 children maintain their recovered upper extremity functions for extended long period (mean, 10 years; range, 9–13 years). There was statistically significant improvement in total functional Mallet score after 3 years (mean, 18.8±2.1; $P \leq 0.01$) from the preoperative mean total Mallet score of 14.5±1.2. This improvement was not only maintained for extended period but also improved (mean total Mallet score, 20.35±2.3; $P \leq 0.01$) in some patients.

Conclusions: Overall, all upper extremity functions improved greatly after mod Quad and triangle tilt surgeries in OBPI children, and they were able to maintain their recovered functional movements over extended period of 10 years.

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BACKGROUND

Complications during pregnancy and delivery processes (obstetric) are the most common cause of obstetric brachial plexus injury (OBPI). Risk factors for injury include shoulder dystocia, macrosomia, instrument-assisted delivery, and downward traction of the fetal head.[1–5]

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This was a retrospective study of patient charts, which exempted it from the need for IRB approval in the United States. Patients were treated ethically in compliance with the Helsinki declaration. Documented informed consent was obtained for all patients.

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OBPI occurs at a rate of 0.1–0.6% of live births.[6,7] The upper cervical nerve trunk of brachial plexus (C5-C6) is most commonly injured, affecting shoulder and elbow functions. Wrist function is also affected in more extensive injury involving both the upper and the middle plexus (C5-C7). The entire plexus, including T1 are rarely affected.[8,9] This also compromises the finger movements and function.[10] The severity of injury to the brachial plexus can range from neurapraxia (stretch) to neurotmesis (rupture) or spinal cord avulsion.[8] Many of these injuries are transient; however based on the severity of the initial injury, 50–90% of these infants never recover full function and develop permanent injuries.[10–15]

Poor neurological functional recovery results in muscle weakness and imbalances that cause bony deformities at the shoulder joint, affecting its movements and functions.[12,16–18] Many traditional surgical interventions have been reported to improve the upper extremity functions

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in these patients. Muscle release and tendon transfer procedures have been shown[19–26] to reduce the muscle contractures and improve shoulder movements. Humeral rotational osteotomy corrects the arm at resting position, but does not address the glenohumeral joint incongruity and Scapular Hypoplasia, Elevation and Rotation (SHEAR) deformities. These conventional surgical treatments do not address these 2 osseous deformities. We have published on the effectiveness of triangle tilt surgery in correcting glenohumeral joint incongruity and SHEAR deformities and thereby improving upper extremity functions in OBPI children.[27–29] Here, we show functional improvements significantly 10 years after mod Quad and triangle tilt surgeries in 17 of our OBPI patients.

The short-term outcomes of surgery in OBPI patients are well documented.[19–29] However, only a few publications with results over 10-year postoperative follow-up exist.[30–34] Kirjavainen et al.[34] reported their long-term postoperative follow-up results from a nationwide study with various soft tissue and bone surgeries performed by many surgeons in brachial plexus birth palsy patients (5–13 years follow-up).

There have also been reports in the literature that OBPI children might lose some of their recovered upper extremity functional movements in a few years after surgery. However, more recently, Bains et al.[33] have reported that there was no loss of active range of motion over time in a large series of OPBI patients in their 10-year follow-up study.

We have also previously reported functional and anatomical improvements of mod Quad and triangle tilt surgical procedures in long-term follow-up of 2 years (44 OBPI patients)[35] and 5 years (17 OBPI patients),[36] which we have compared with short-term (1 year) follow-up results of 61 of our OBPI patients.[27] Here, we report the outcomes of mod Quad and triangle tilt surgeries in 17 OBPI children for extended long period (mean, 10 years; range, 9–13 years).

METHODS AND PATIENTS

Between February 2005 and April 2018, over 1,000 OBPI patients had mod Quad and triangle tilt operations at our clinic.

Mod Quad Procedure

OBPI patients underwent latissimus dorsi and teres major muscle transfer; subscapularis, pectoralis major and minor contracture releases and axillary nerve decompression and neurolysis. Transferred muscles were sutured to the teres minor muscle, not to a bony insertion point. For detailed operative procedure, please refer to our previous publication (Nath and Paizi, 2007).

Triangle Tilt Surgical Procedure

The triangle tilt surgery consisted of (1) osteotomy of the clavicle at the junction of the middle and distal thirds; (2) osteotomy of the acromion process at its junction with the spine of the scapula; (3) ostectomy of the superomedial angle of the scapula; (4) splinting of the extremity in adduction, external rotation, and forearm supination. Minor elements of the procedure included bone grafting of the acromion process osteotomy site, and semirigid fixation of the clavicular osteotomy segments to prevent nonunion. We have previously published on the successful outcomes of this procedure in OBPI patients.[27–29,35–38]

Patients who had these 2 surgeries with us between 2005 and 2008 were eligible for this 10-year follow-up study. Majority of these patients previously had 1, 2, or 5-year postsurgical follow-up at our center.[27,35,36] Patients who visited our clinic later for long-term follow-up were mainly to improve their affected arm length. These patients had biceps tendon lengthening (BTL) procedure with us. Seventeen patients met inclusion criteria for this study. All 17 patients had mod Quad and triangle tilt surgeries and had postoperative follow-up of 10 years. Six pa-

Table 1. Total Mallet in OBPI Children, 10-year Follow-up of Mod Quad and Triangle Tilt Surgeries

					Total Mallet Score			
Patient	Sex	MQ Age	TT Age	Nerve Involved	Preoperative	Postoperative Mean 3 y	Postoperative Mean, (TT) 10 y; (MQ) 12 y	Post-TT BTL Surgery
1	F	6.5	7.4	C5-C6	14	18	19	
2	M	2.3	4.2	C5-C7	16	18	20	BTL
3	M	1.0	2.9	C5-C7	15	20	22	BTL
4	F	0.9	3.2	C5-C7	15	19	18	
5	M	1.5	2.3	C5-C7	16	21	22	
6	M	3.9	7.5	C5-C6	15	15	17	
7	F	1.2	4.1	C5-C6	16	19	23	BTL
8	F	1.8	2.8	C5-C7	15	21	22	
9	M	0.7	3.4	C5-C6	13	15	21	
10	F	0.6	1.2	C5-C6	13	20	15	
11	M	1.3	2.2	C5-C6	15	19	23	
12	F	5.5	5.8	C5-C7	15	23	21	
13	F	1.0	3.0	C5-C8	12	19	20	BTL
14	F	0.9	15.1	Total	15	19	19	
15	F	0.5	0.9	C5-C6	13	16	23	
16	M	0.5	1.5	C5-C7	13	17	22	BTL
17	M	2.9	3.4	C5-C7	15	21	19	BTL
Mean					14.5	18.8	20.35	
STD					1.2	2.1	2.3	
P <						0.01	0.01	

F, female; M, male; MQ, mod Quad; TT, triangle tilt.

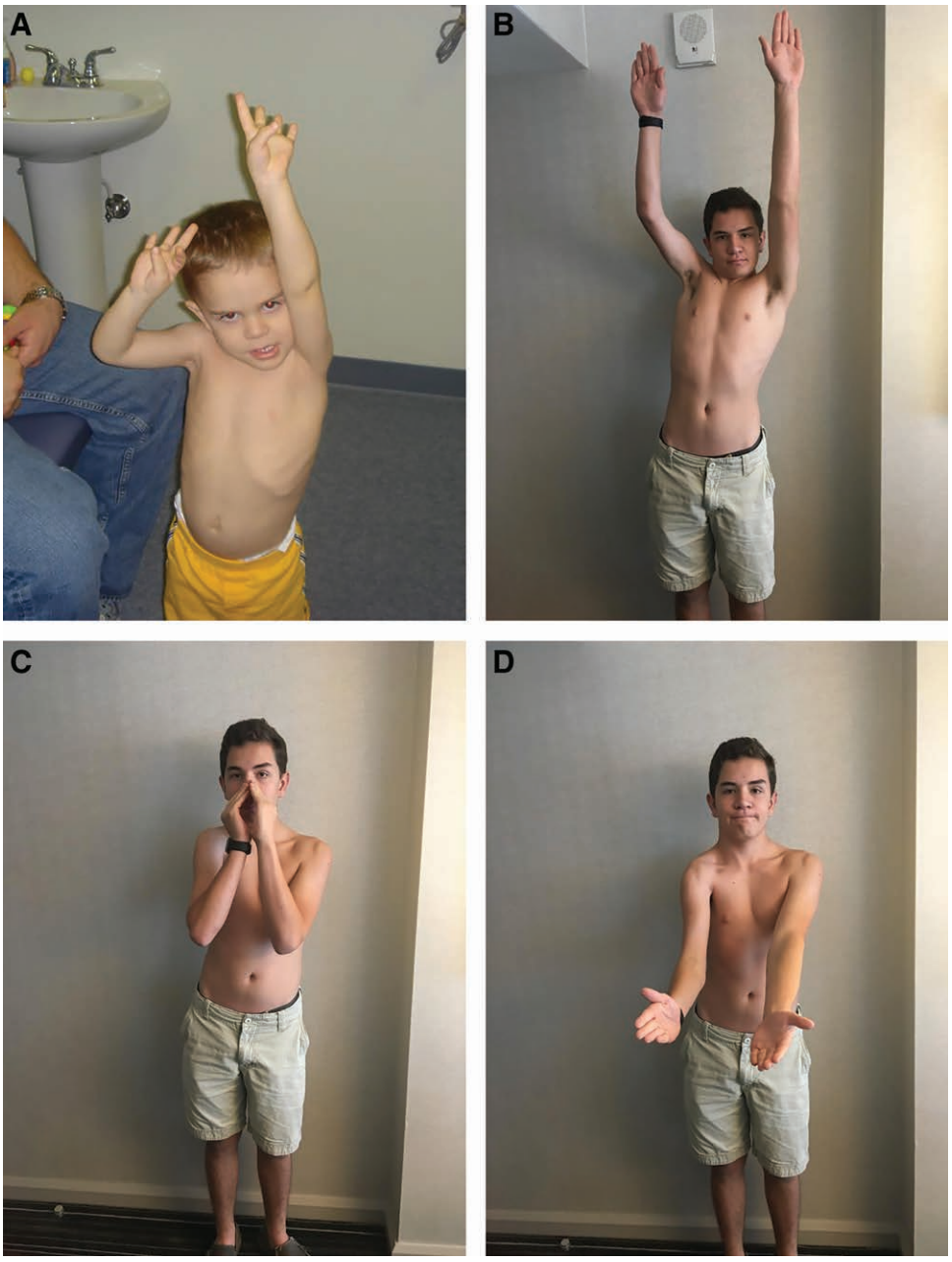

Fig. 1. Clinical photographs of a male OBPI child performing upper extremity movements and showing significant improvement in global abduction, hand to mouth and supination postoperatively. Preoperative picture (A), and 10-year-posttriangle tilt pictures (B, C, D).

tients in this study group also had BTL surgery, who had arm length discrepancy. Patients who had multiple surgeries are excluded in this study. Not all or the same patients who came for 1, 2, or 5-year follow-up came for 10-year follow-up or met the inclusion criteria of this study. Therefore, these patients in this study group are not the same as in our previously published study reports.

- Exclusion criteria: OBPI children, who had multiple surgeries.
- Inclusion criteria: OBPI children, who had mod Quad, triangle tilt and primary nerve surgeries before, and BTL surgery after.

The Mallet functional score is the most widely used and most reliable scoring system for the clinical assessment of shoulder functions.[39] Modified Mallet functional evaluation were performed for 3 years and 10 years postoperative follow-ups, and these data were compared statistically with preoperative Mallet score. In addition to assessing the classical functions of the Mallet system, supination was also evaluated. The paired student's *t* test statistics was applied to compare the pre- and postoperative mean Mallet and supination scores using the Analyze it plug in (Leeds, United Kingdom) for Microsoft Excel 2003. A value of $P < 0.05$ was considered statistically significant.

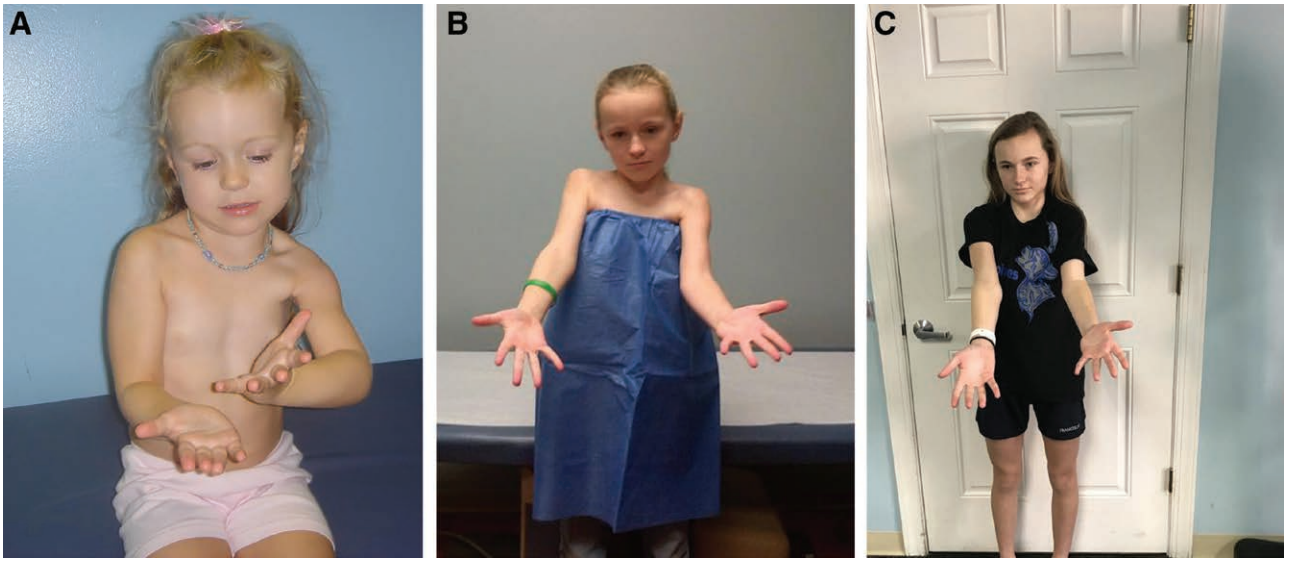

Fig. 2. Clinical photographs of a female OBPI child performing supination. Preoperative (A, right); 3-year (B, middle) and 10-year-post-triangle tilt (C, left) pictures with full recovery (supination angle of 90°).

RESULTS

Functional Improvement over 10-year Post-mod Quad and Triangle Tilt Surgeries

Most of the OBPI children (15 of 17) in this study maintain their recovered upper extremity functions for extended long period (mean, 10 years; range, 9–13 years). There was statistically significant improvement in total functional Mallet score after long-term follow-up of 3 years (mean, 18.8±2.1; $P < 0.01$) from preoperative mean total Mallet score of 14.5±1.2 (Table 1). This improvement was not only maintained for extended period in these patients but also further improved (mean total Mallet score, 20.35±2.3; $P \leq 0.01$) in some patients, mainly who had BTL procedure. Although most of the patients' functional improvement remain the same, 3 patients in this study (patients 9, 15, and 16 in Table 1) showed remarkable improvement over 10 years.

In addition, after BTL surgery, these patients have shown continuing improvements not only in Mallet score (Table 1 and Fig. 1) but also in their supination posture from 10.27±48.9° to 71.8±19 ($P < 0.01$; Table 2 and Fig. 2). Global abduction declined in 1 patient (patient 10 in Table 1) from the previous examination (3.1 year follow-up). However, no significant differences were found between 3-year and 10-year follow-up in total Mallet score.

Table 2. Improvement in Supination after 10-year of Mod Quad and Triangle Tilt Surgeries in OBPI Children

	Supination					
	Preoperative		Postoperative Mean 3 y		Postoperative Mean; (TT) 10 y, (MQ) 12 y	
Patient	Angle°	Score	Angle°	Score	Angle°	Score
1	0	3	45	4	45	4
2	30	3	60	4	50	4
3	80	4	90	5	90	5
4	60	4	90	5	90	5
5	0	3	70	4	40	4
6	60	4	70	4	75	4
7	60	4	45	4	85	5
8	20	3	70	4	70	4
9	0	3	30	3	40	4
10	-90	1	90	5	85	5
11	-90	1	60	4	90	5
12	20	3	80	4	70	4
13	15	3	70	4	90	5
14	30	3	45	4	60	4
15	-70	1	30	3	90	5
16	30	3	70	4	60	4
17	20	3	90	5	90	5
Mean	10.27°	2.9	65°	4.11	71.8°	4.5
STD	48.9	1.0	20	0.6	19.1	0.5
$P <$			0.01	0.01	0.01	0.01

MQ, mod Quad; TT, triangle tilt.

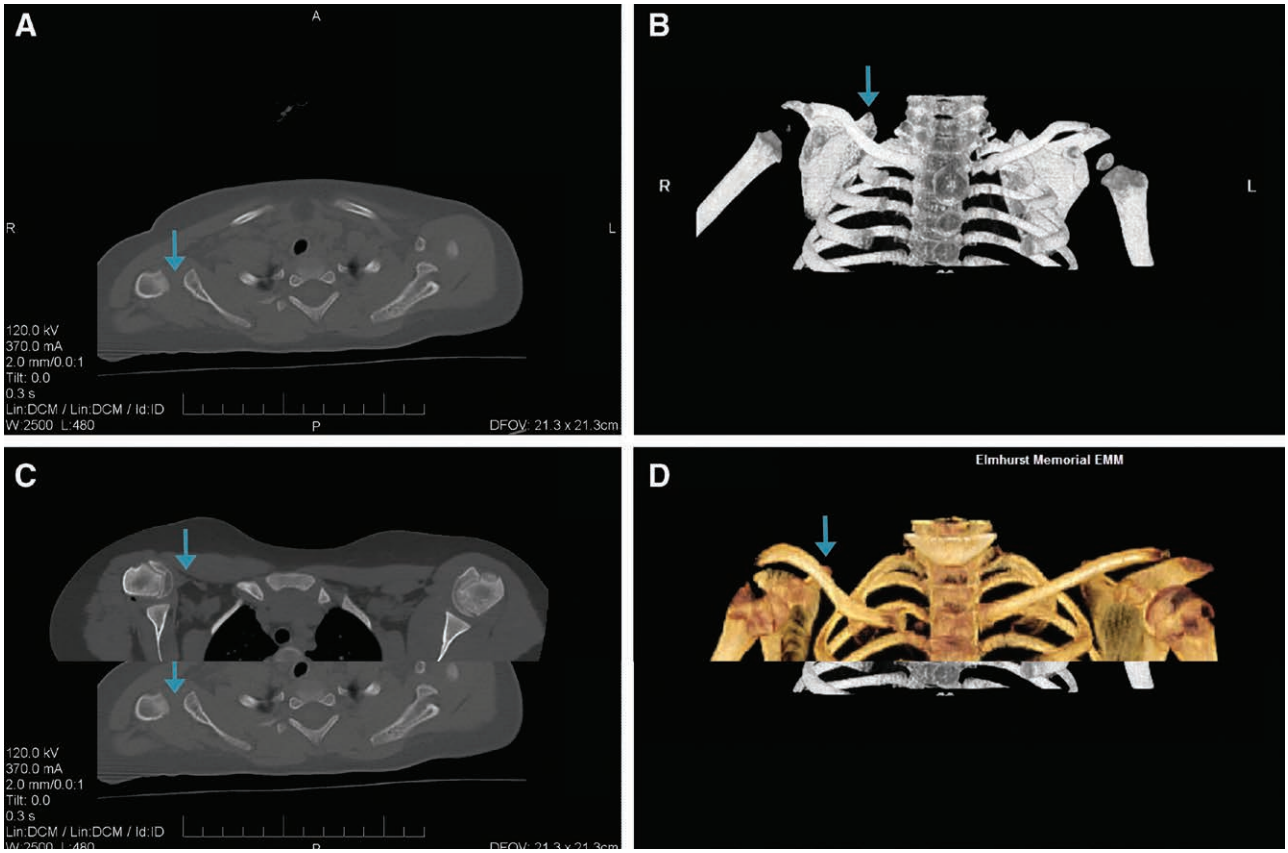

Fig. 3. Axial CT scans of the affected shoulder of an OBPI patient before and 10 years after triangle tilt surgery. A, 2D- CT image before triangle tilt surgery. The arrow head pointing posterior subluxation of the humeral head and incongruity of the glenohumeral joint (left). C, CT image after triangle tilt surgery showing improvement. B, 3D- CT image of the same patient before triangle tilt surgery, the arrow head pointing the scapular hypoplasia, elevation and rotation (SHEAR) deformity of the affected (left) side. D, No SHEAR deformity after triangle tilt surgery.

Overall, all upper extremity functions improved greatly after mod Quad and triangle tilt in OBPI children in our present study, and they were able to maintain their recovered functional movements over extended period of 10 years.

DISCUSSION

The short-term outcomes of surgery in OBPI patients are well documented.[19–29] However, only a few publications with results over 10-year postoperative follow-up exist.[30–34] Kirjavainen et al.[34] reported their long-term postoperative follow-up results from a nationwide study with various soft tissue and bone surgeries performed by many surgeons in brachial plexus birth palsy patients (5–13 years follow-up). These authors (Kirjavainen et al.[32]) also reported later, their 12 years follow-up study results in 102 OBPI patients. They have measured and reported patients' ROM and strength of the shoulders, elbows, wrists, and thumbs after different surgical procedures. However, the authors have stated that their study weakness was 27-year-long inclusion period (between 1971 and 1998). In addition, they mentioned there have been changes in primary nerve reconstruction and secondary (muscle and bony) surgical procedures in such a long period.

Hulleberg et al.[31] reported their reexamination data of 69 OBPI adolescents after 10–20 years of their birth/infant examination and reported the outcomes. Majority (52 of 69) of their study subjects were transient OBPI. Seventeen patients only had permanent OBPI.

There have been also reports in the literature that OBPI children might lose some of their recovered upper extremity functional movements in a few years after surgery. However, more recently, Bains et al.[33] have reported that there was no loss of active range of motion over time in a large series of OPBI patients in their 10-year follow-up study.

In our previously published study of 61 OBPI patients,[27] we observed no significant differences between 1-year and 2-year follow-ups for the functions of external rotation, hand-to-mouth and apparent supination, demonstrating the stabilization of certain improved functions postsurgically.[27,35] Further, we have also reported that the overall improvement in these upper extremity functions were also maintained over extended long-term (5 years) in OBPI children, who had mod Quad and triangle tilt surgeries.[36]

In addition, we have previously reported on glenohumeral remodeling of glenoid congruence after these 2

surgeries in our OBPI patients.[27,35] Most of these patients had radiological examinations [computed tomography (CT)/magnetic resonance imaging) before and 1–2 year after triangle tile surgery. However, they do not have third or long-term follow-up radiological examination, except for some patients, for example, one patient (patient 10 in Table 1 and Fig. 3) in this study as this patient's all upper extremity functional movements were not significantly improved. This patient was recommended for further treatment. Preoperative and 10-year follow-up CT images of this patient is given in Figure 3. There were no additional CT images and therefore no radiological data for 10-year follow-up period for other patients.

In this study report of 17 OBPI children, 6 had BTL surgery to improve their limb length 3 years after triangle tilt surgery. Gosk et al.[30] reported the discrepancy of affected limb length and circumference and functional efficiency in 44 OBPI children in comparison with their unaffected limb. We recently demonstrated that elbow flexion and arm length were greatly improved in OBPI patients, who undergone BTL surgery.[10] These improvements might be the reasons for further overall functional improvement over 10 years in these patients.

Kirjavainen et al.[34] concluded their long-term follow-up study stating that following surgical treatment of several brachial plexus birth palsy, substantial number of their patients continued to need help performing activities of daily living and had pain in the affected limb. The pain was due to a clavicular nonunion in one-fourth of their patients.[34] One female patient in our present study had clavicle repair (patient 8 in Table 1), and she was also able to maintain the Mallet score of 22 and supination angle of 60°.

Though the strongest prognostic factor predicting outcome appears to be the extent of the brachial plexus injury, one female patient in our present report (patient 14 in Table 1), who had total plexus injury (C5-T1) was even able to maintain her recovered posttriangle tilt functional movements (total Mallet score, 19) in 3-year as well as in 10-year follow-ups. Preoperative total Mallet score for this patient was 15.

CONCLUSIONS

Overall, all upper extremity functional movements improved greatly after mod Quad and triangle tilt in OBPI children, and they were able to maintain their recovered functions over extended period of 10 years.

INFORMED CONSENT/ETHICAL APPROVAL STATEMENT

Written informed consent was obtained from all patients for publication and accompanying images. A copy of the written consent is available for review on request.

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