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The triangle tilt procedure for treatment of secondary shoulder deformities in obstetric brachial plexus injury

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Abstract
The purpose of this study was to evaluate the shoulder functional and radiographic outcomes of the triangle tilt surgery for treatment of shoulder deformities secondary to obstetric brachial plexus injury (OBPI).
Patients and Methods: A prospective study was executed at our institution, between Dec. 2013 and Jan. 2017, on the triangle tilt procedure for treatment of 22 OBPI patients (who were available for final follow-up), with persistent medial rotation contracture, SHEAR scapular deformity and glenohumeral joint instability. Their mean age at the time of the surgery was 6.1 ± 2.2 years (range: 4 – 12 years). We excluded cases having previous tendon transfers or bony operation.
Results: The mean follow-up period was 17 ± 2.2 months (range: 12 - 24 months).
Clinicaly, significant improvements were noted in the mean overall Mallet score (from 11.3±1.6 to 16.9±1.8 points), also, in (external rotation, hand-to-mouth, hand-to-neck, and hand-to-spine) functions and in the posture of the arm at rest, but with no considerable improvement in global abduction. Radiographically, significant improvements were demonstrated in: posterior subluxation (from a mean of 12±7.2% to 30±3.5%), glenoid version (from a mean of −30±5˚ to −17.5±6˚) and scapular elevation (from a mean of 7.1±2 % to 2.8±0.2 %). No significant postoperative complications were noted.
Conclusions: The triangle tilt procedure is an effective procedure in treating OBPI patients with secondary shoulder deformities; achieving encouraging functional and anatomical results.

Keywords: Brachial plexus, SHEAR, medial rotation contracture (MRC), acromioclavicular triangle (ACT)

Introduction
Obstetric brachial plexus injury (OBPI) has an incidence of 0.4–4.6 injuries every 1000 live births, despite the advances in gynaecology and technology [1]. Although, most injuries are transient and recover function spontaneously within months, some but significant proportion show inadequate recovery of neurological function resulting in permanent significant shoulder deformities and persistent limb dysfunction [2-4]. Because the neurological affection in the OBPI tends to be asymmetric, it will lead to muscle imbalances about the shoulder [with contractures of the internal rotators and adductors versus weakened external rotators and abductors]. Both muscle imbalances and contractures exert asymmetric forces on the infant's growing bones and joints, with resultant twisting and deformities of them with time [5-7].
The major bony and joint problem that occurs is known as the SHEAR (scapular hypoplasia, elevation, and rotation) deformity, which is recognized clinically as twisting of the scapula above the level of the clavicle. The abnormal anterior rotation of the clavicle along with the elevated scapula causes the acromioclavicular triangle (ACT) [its sides defined by the distal clavicular shaft and the acromion process and its base by an imaginary line connecting their medial ends] to tilt anteriorly and causes impingement of the acromion upon the humeral head. This restricts external rotation of the shoulder and contributes to anterior glenohumeral (GH) tightness of the soft tissues. Other significant secondary deformities that follow include medial rotation contracture (MRC) of the shoulder [most probably due to lateral movement of the scapula], elbow flexion contracture and posterior and inferior subluxation of the humeral head in the glenoid fossa. Other deformities include flattening of the glenoid fossa and hooking of

the acromion process which impinges on the humeral head [2, 5, 7-10]. Management of significant shoulder deformities in OBPI includes soft tissue procedures and/or bony procedures [7, 11, 12]. Soft tissue operations include anterior capsule release [open or arthroscopic], tendon transfers, nerve transfers, axillary nerve decompression, glenohumeral posterior capsulorrhaphy and biceps tendon lengthening [13-17]. These surgical procedures may lead to only marginal clinical improvement [with better shoulder abduction and flexion, and improved resting position of the arm], but, no improvement in deformity, because these procedures do not address or attempt to correct the SHEAR deformity [3, 4, 6, 12, 19, 20]. Bony operations include the traditional external rotational humeral osteotomy and the more recent, triangle tilt procedure [11, 12]. Derotational osteotomy of the humerus may improve the cosmesis of the resting position of the arm and shoulder external rotation to some degree [18, 19], but it is associated with a common recurrence of MRC due to uncorrected scapular deformity. Moreover, it does not correct, or attempt to correct GH-dysplasia; therefore, it is at best an incomplete and simplistic solution for a complex pathology. Humeral osteotomy does not stimulate shoulder joint remodeling [5, 6, 8, 20]. The triangle tilt surgery was therefore developed by Nath [3], to directly address the scapular deformity, which is a key pathology in shoulder deformities in OBPI patients. The surgical technique includes osteotomies of the clavicle and the neck of the acromion, allowing the anteriorly-tilted distal ACT to tilt back to a more neutral position, thus relieving the impingement of the ACT on the humeral head and thus, allowing for the passive repositioning of the humeral head into the glenoid and to stimulate favorable joint remodeling. Also, this new position of ACT allows correction of the internal rotation deformity. This improves the chance of satisfactory long-term function [3, 6, 8, 20, 21].

The aim of this study was to evaluate the shoulder functional and radiographic outcomes of the triangle tilt surgery for treatment of 22 OBPI patients, with persistent medial rotation contracture, SHEAR scapular deformity and gleno humeral joint instability.

Patients and methods

A prospective study was executed at our institution, between December 2013 and Jan. 2017, on the triangle tilt procedure for treatment of 24 OBPI patients, with persistent MRC, SHEAR scapular deformity and GH-joint instability. Two of them were lost to follow-up. The remaining 22 were followed up for at least 12 months and had sufficient data for analysis. Inclusion criteria are; patients of four to 12 years-old, having at least 12 months of follow-up and had no previous tendon transfers or bony surgery for OBPI. Fourteen of them were girls. Their mean age at the time of the surgery was 6.1 ± 2.2 years (range: 4 – 12 years). The left side was affected in 13 patients and the right one, in 11, with no bilateral cases. The brachial plexus injuries involved C5–C6 nerve in 16 patients, C5–C7 in 5 patients, C5–T1 in 3 patients. None had previous muscle/tendon transfers or bony operation for OBPI. Eight cases (33.3%) had previous soft tissue operations including; primary nerve surgery in infancy in three, open anterior shoulder release in three and arthroscopic anterior shoulder release in two, but all failed to resolve the shoulder deformity. We excluded cases outside the age group of 4-12 years-old, that having previous tendon transfers or bony operation and cases with < one year of follow-up.

The study was authorized by the local Ethical Committee and an informed written consent of the parents of patients to participate in the study [after explanation of risks and benefits] was taken.

Operative technique

We started our operation by performing anterior release of the shoulder. The triangle tilt procedure consisted of osteotomy of the superomedial angle of the scapula, osteotomy of the clavicle at the junction of the middle and outer thirds, osteotomy of the acromion at its junction with the spine of the scapula, and splinting of the limb in adduction, 5˚ of external rotation and full forearm supination. Minor elements of the procedure included bone grafting of the osteotomy sites using the resected superomedial angle and clavicular fixation using absorbable suture through drill holes, to prevent nonunion.

Postoperative care

The patient was splinted for 6 weeks and then splinted only at night for additional 3 months. Physiotherapy was prescribed and continued for 6 months.

Preoperative and postoperative assessment

Clinical assessment

Patients were evaluated preoperatively and postoperatively, using the modified Mallet scale [22, 23], plus the resting position of the arm [4]. The modified Mallet scale consists of five functions: (abduction, external rotation, hand-to-mouth, hand-to-neck and hand-to-spine), and the patients were scored on a scale of 1–5, with 1 being most affected and 5 being normal. The overall Mallet score (5–25) is calculated based on five of these movements (Fig.1).

Hagiographic assessment of GH-deformity

Glenoid version was calculated in axial CT images as described by Friedman *et al*. [24], by measuring the glenoscapular angle (Fig. 2). A scapular line (connecting the medial margin of the scapula and the middle of the glenoid surface) and a glenoid line (tangential to the surface of the glenoid fossa that is articulating with the humeral head) were constructed to define the glenoscapular angle. A total of 90 was subtracted from this angle to define the degree of glenoid version. The normal value = 0, but some variation is possible (mean: 2±5° of anteversion, range; 14° of anteversion to 12° of retroversion) [9].

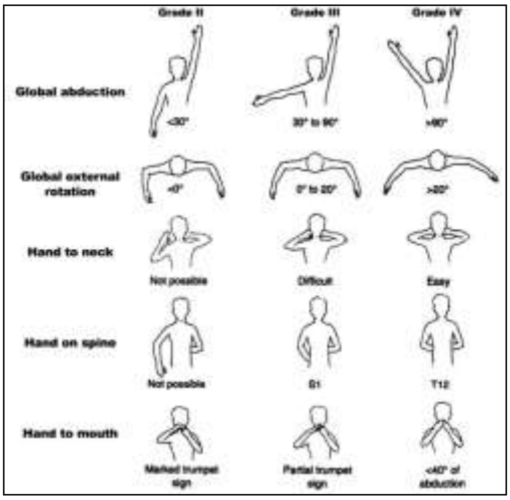

Fig 1: The modified Mallet scale [23].

(2) The percentage of humeral head posterior subluxation, (Fig. 2), expressed as percentage of humeral head anterior to the scapular line (PHHA). It was calculated in axial CT

images by taking the ratio of the greatest diameter of the humeral head divided by the perpendicular distance between the anterior portion of humeral head and scapular line and then multiplied by 100. The normal value = 50% [9].

(3) In order to assess the scapular elevation of SHEAR deformity, the anterior view of the 3D-CT was used to measure the area of the scapula visible above the clavicle and then divided by the total area of the scapula in the affected shoulder. The scapular elevation in the contralateral shoulder was then subtracted from that in the affected shoulder, and this value was multiplied with 100 to express SHEAR as a percentage. Scapular elevation (100%) = [C/(C+D) – A/(A+B)] x 100 in (Fig.3). A value of (0%) is considered normal [9].

Statistical analysis

Results were expressed as means ±SD (standard deviation). The differences between pre- and post-operative data were analyzed by Paired T test. A statistical significance was set at $p<0.05$

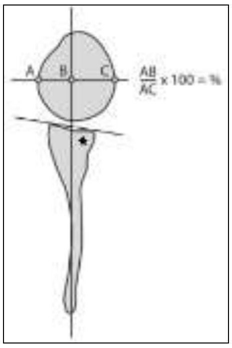

Fig.2: Schematic drawing showing the method of measuring humeral head subluxation.

The percentage of the humeral head anterior to the scapular line (PHHA) indicates subluxation. The glenoid version angle (glenoscapular angle) =(*) - 90º [9, 10].

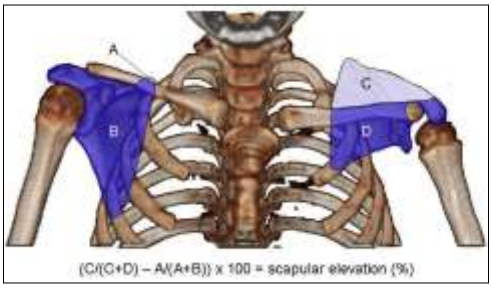

Fig 3: Measuring scapular elevation to quantitate the extent of the SHEAR deformity [9].

Results

The intra-operative findings

Intra-operatively, immediately after the osteotomies, we noted that the clavicular fragments unwind rapidly, the acromial fragments rapidly separate, with the distal segment moving inferiorly and posteriorly, and the humeral head moves into a more normal position with the distal ACT.

The final outcome

The mean follow-up period was 17 ± 2.2 months (range: 12 - 24 months).

Clinical results

a. The mean overall Mallet score increased significantly from 11.3±1.6 points (range: 7-14) preoperatively to 16.9±1.8 points (range: 13-20) post-operatively.
b. Significant improvements were also noted in external rotation, hand-to-mouth, hand-to-neck, and hand-to-spine) functions and also in the posture of the arm at rest.
c. However, no noticeable improvement in global abduction was detected.
d. No patient had deterioration in shoulder function.

Table 1: Comparison of the mean values of modified Mallet score parameters before and after triangle tilt surgery

	preoperative	postoperative	P value
Abduction	2.5±0.4	2.6±0.3	0.37
External rotation	2.3±0.1	3.9±0.3	0.0001**
Hand-to-mouth	2.2±0.5	3.7±0.4	0.00**
Hand-to-neck	2.3±0.4	3.6±0.7	0.01*
Hand-to-spine	2.1±0.1	3±0.1	0.00**
Total Mallet score	11.3±1.6	16.9±1.8	0.00**

(* significant, ** highly significant)

Radiographic results

Measurements taken from axial and 3D-CT demonstrated significant improvements of: posterior subluxation from a mean of 12±7.2% (range: -5 to 19%) preoperatively to 30±3.5% (range:20 to 42%) postoperatively, glenoid version from a mean of −30±5 º (range: -45 to -20 º) pre-operatively to −17.5±6 º (range: -21 to - 14 º) postoperatively and scapular elevation from a mean of 7.1±2 % (range:5 to 12%) to 2.8±0.2 % (range: 0 to 3.2%).

Table 2: Comparison of the mean values of radiographic parameters before and after triangle tilt surgery

	preoperative	postoperative	P value
Glenoid version	−30±5º	−17.5±6º	0.00**
Posterior subluxation	12±7.2%	30±3.5%	0.003*
Scapular elevation	7.1±2 %	2.8±0.2 %	0.005*

(* significant, ** highly significant)

Postoperative complications: included**;** superficial infection in two cases that recovered on antibiotics and local wound care, and ugly keloid of the wound scar in two cases, but no cases of nonunion or deep infection.

Discussion

A significant proportion of OBPI patients suffer from permanent significant shoulder deformities and persistent limb dysfunction, secondary to inadequate recovery of neurological function [7, 21]. Shoulder pathologies include soft tissue contractures, GH dysplasia, subluxation or dislocation and scapular deformities [2, 3, 8, 19, 20]. A major treatment goal in OBPI children is to obtain optimal shoulder range of motion through improved GH-alignment [5, 11]. The so-called SHEAR deformity as a residual of OBPI is a common and key pathology leading to other shoulder deformities including MRC of shoulder, GH dysplasia, posteroinferior subluxation or dislocation. Therefore, the successful and direct management of these pathologies should be through correction of the underlying SHEAR deformity, using the so-called triangle tilt surgery, rather than the traditional surgical procedures [3, 4, 6, 8]. The principle of the triangle tilt procedure is to solve the impingement of the anteriorly tilted distal ACT against the humeral head by releasing it from the medial spine of the scapula and the medial clavicle through osteotomies. This allows the distal ACT to tilt back to its neutral position, reducing the abnormal elevation and rotation of the scapula, therefore, realigning the glenohumeral joint properly [3, 6, 25].

Our intraoperative findings are consistant with that of Nath *et al* [3, 5]. Intra-operatively, immediately after the osteotomies, we noted that the clavicular fragments unwind rapidly, the acromial fragments rapidly separate, with the distal segment moving inferiorly and posteriorly, and the humeral head moves into a more normal position with the distal ACT. Nath *et al* [3], suggested that these findings reflect the highly abnormal bony framework around the shoulder, associated with considerable intraosseous torque, which is released when the distal ACT is separated from the abnormal medial structures. The humeral head is related to the lateral structures and therefore moves into a more normal position with the distal ACT.

Fig 4: A four and half years old girl with RT. OBPI; (A-E) defective preoperative resting position of arm and Mallet functions ; (F-J) 18 months-postoperative clinical result; with improved all Mallet movements except abduction. ... (Continued)

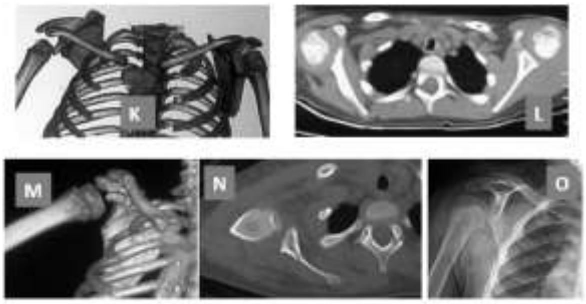

Fig 4 (Continued): (K) preop. SHEAR ; (L) preop. axial CT showing GH dysplasia& subluxation ; (M-O) postop. 3 D, axial CT and X-ray showing remarkable improvements of scapular and GH deformities.

Fig 5: An eight years old boy with LT. OBPI; (A-E) defective preoperative resting position of arm and Mallet functions ; (F-J) two years-postoperative clinical result; with improved all Mallet movements except abduction. ... (Continued)

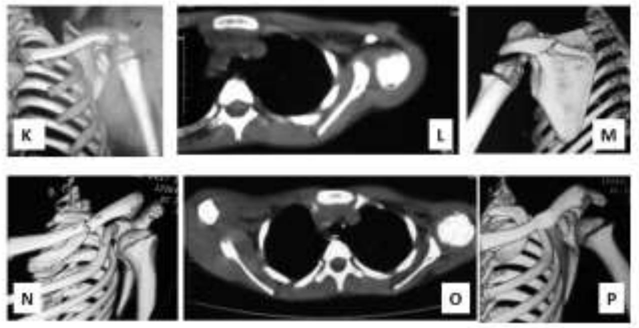

Fig 5 (continued): (K) preop. SHEAR ; (L) preop. axial CT showing GH dysplasia&dislocation; (M,N) immediate postop.; (O,P) Two years-postop. axial and 3D-CT showing remarkable improvements of scapular and GH deformities.

Clinical results: of our series showed significant improvements of the resting position of the arm, the mean overall Mallet score and its components except abduction (Table 1). These results are comparable to that of Nath *et al* [3-7, 21], except in abduction which was improved significantly in their studies, by their performance of tendon transfers for abduction before TTS in a separate session. On the contrary, we chose not to do tendon transfer, to separately and accurately assess the effect of TTS. Our results and that of Nath *et al* [3-7], suggest that TTS do not improve abduction and therefore, tendon transfers for abduction are needed, in a second session either before or after TTS. The abnormal preoperative resting position of the arm resulted from the pre-operative MRC that caused the arm to flare laterally in the resting position with the elbow in flexion. After TTS, the correction of MRC significantly improved the resting arm position and movement [3].

Radiographic results of this series: showed significant improvements of: posterior subluxation, glenoid version and scapular elevation. These findings demonstrate improved GH-congruence and significant GH-remodeling and are consistant with that of Nath *et al* [3, 5-8, 25]. Nath *et al*., 2007 [3], reported nonunion of the clavicular osteotomy in two patients early in their series, that was treated by wire fixation connected by an absorbable suture, suggesting its routine use. On the contrary, we found no cases of clavicular nonunion in our series, despite we did not use wire fixation, but only suture fixation passed through two drill holes, plus the already-used postoperative splint. Age of the patients at time of TTS is an important affecting factor. Nath *et al* [25], stated that TTS can be performed as early as nine months and can be performed up until late adolescence (16-17 years). This upper age is limited by the declining ability of the glenohumeral joint to remodel. They demonstrated and thus recommended that the optimal time to perform the TT surgery is before the age of 2 years. However, our results also indicate that improvement in clinical functioning can still be achieved in older children.

Other alternative traditional secondary procedures exist [12, 18]. Open or arthroscopic anterior shoulder release may improve certain shoulder functions and/or glenoid remodeling [13, 15, 16, 17] but results in significantly reduced internal rotation, a deformity equal to that being addressed [3, 4, 12]. Muscle/tendon transfer with or without open reduction works only on younger patients with a normal to mildly deformed GH-joint, while leaving patients with severe GH-deformity (including complete dislocation) untreatable [12, 14, 17]. External rotational humeral osteotomy seems to be the main option available to a number of surgeons treating OBPI patients (≥ 6years-old) with severe GH-deformity and persistent MRC [12, 15, 18, 19, 20], however, it may be associated with a relatively high recurrence of MRC [3, 7, 12, 20]. Moreover, all these traditional surgeries do not address or attempt to correct the key pathology, which is the SHEAR deformity and have minimal or adverse effects on the GH-anatomic derangements [12, 20, 25].

TTS is indicated for: OBPI children of nine months to 16-17 years-old, with secondary shoulder deformities associated with SHEAR deformity. It can be used as a primary surgery and also, as a salvage of failed other soft tissue surgeries or failed humeral osteotomy [3, 4, 7, 12, 20].

The advantages of the triangle tilt surgery include: (a) It can be effective as a primary procedure or as a salvage of failed previous other reconstructive surgeries including humeral osteotomy, (b) It can be effective in treating of mild, moderate and severe neurological defects, including severely deformed GH-joints, even with complete GH dislocations, (c) It can be applied in a wide age range (8-9 months up to 16-17 years old),(d) It directly addresses the pathophysiology of the MRC., (e) It can achieve remarkable anatomical and functional improvements and encourage GH- joint remodeling by repositioning of the GH-joint [3-8, 12, 25].

An important disadvantage of TTS is: inability to improve abduction, if done alone. Therefore, it should be preceded by Mod Quad surgery in cases with weak abduction or complete OBPI [4].

Conclusions
The tringle tilt surgery is indicated for OBPI children, having SHEAR deformity associated with other shoulder deformities such as medial rotational contracture, glenohumeral dysplasia and instability. It can be applied in a wide age range, and can be beneficial in older children. It can be used as a primary surgery and also, as a salvage of failed other reconstructive surgeries. Despite, it cannot improve abduction if done alone, it can achieve significant anatomical and functional improvements and encourage GH- joint remodeling by repositioning of the GH-joint.

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