Chapter

Derotational Osteotomies for The Late Treatment of Brachial Plexus Injury

Ahmet Emrah Açan and Ertuğrul Şahin

Abstract

Obstetric brachial plexus palsy [OBBP] can affect the function of the upper extremity. Most of the injuries are limited to the upper spinal nerves and heals spontaneously. However, some of them will have incomplete recovery after OBBP often results in weakness of the external rotators [teres minor and infraspinatus] muscles compared to the internal rotators [teres major, pectoralis major, latissimus dorsi] muscles. The predominance of the internal rotators and adductor muscles over external rotators leads to an internal rotation contracture. The development of internal rotational deformity may progress to increased glenoid retroversion and posterior humeral head subluxation. If the surgeon does not repair internal rotation deformity, the humeral head is forced into a posterior position causing a complete posterior dislocation. Many procedures are performed to treat these deformities: In the young child, improving the remodeling of the glenohumeral joint, capsulectomy, and subscapular release are introduced. Tendon transfers of the shoulder have good results for motion but fail to restore the glenohumeral joint. The failure of improving joint alignment may represent the loss in clinical improvement over time. In older children, a humeral osteotomy can be an alternative to realign the limb into external rotation, improve appearance, and enhance eating, washing hair, and scratching the back of the neck. We will discuss all the techniques along with their advantages and disadvantages.

Keywords: brachial plexus, birth palsy, humeral rotation, glenohumeral join, osteotomy, technique

1. Introduction

Obstetric brachial plexus palsy (OBBP) can substantially impact the function of the upper extremity. The widely agreed-upon mechanism of the birth injury for brachial plexus is a combination of traction and lateral pressure on the head through the late stages of a difficult delivery. The shoulders can be stacked in the birth canal. Partial or complete ruptures of the nerves in the plexus area can occur during that traction.

Most of the injuries are limited to the upper spinal nerves, and the possibility of spontaneous healing is higher than the others [1–3]. The definition of 'Erb-Duchenne palsy' or 'Erb's palsy refers to a C5-C6 injury that results in the paralysis of the shoulder and elbow flexion. In addition, paralyzes of wrist and

finger extensors can be accomplished, and it shows that C7 is also injured. Most of these partial plexus injuries have a good prognosis, and 70–80% recover spontaneously [4, 5].

However, incomplete recovery after brachial plexus birth palsy often results in weak external rotators [teres minor and infraspinatus] muscles compared to the internal rotators [teres major, pectoralis major, latissimus dorsi] muscles. The predominance of the internal rotators and adductor muscles over external rotators leads to an internal rotation contracture. The development of internal rotational deformity may progress to early glenohumeral joint deformity by six months of age and advanced deformity by two years, which is characterized by increased glenoid retroversion and posterior humeral head subluxation [6–10]. If this internal rotation deformity is not repaired, the humeral head is forced into a posterior position, causing an initial subluxation that can evolve to complete posterior dislocation. This condition was thought to be rare.

Many studies have shown that the onset of glenoid dysplasia with obstetric brachial plexus palsy occurs at an earlier age than previously recognized. The prevalence of this problem may have been underestimated [11–13]. Zancolli et al. [14] reported that this posterior dislocation occurs in 8% of patients with proximal humeral deformities and muscle contractures.

Several studies have reported glenoid and humeral pathology in cases of Erb's palsy [7, 8, 15, 16]. Waters et al. [8] defined the seven types for the glenohumeral deformity with OBBP (type I: normal articulation; type II: glenoid retroversion <5 degrees with no subluxation; type III: posterior subluxation; type IV: progressive posterior humeral subluxation into a pseudo-glenoid; type V: advance flattening of the humeral head and glenoid, with progressive or complete posterior dislocation of the humeral head; type VI: dislocation of the glenohumeral joint in infancy and type VII: growth arrest of the proximal part of the humerus). Pearl et al. [15] classified the glenoid deformity in patients with Erb's palsy as concentric, concentric-posterior, flat, bi-concave, and pseudoglenoid. Zancolli et al. [17] reported that a posterior epiphysiolysis of the proximal humerus caused the retroversion of the humeral head.

2. History

Surgical treatment of obstetric plexus lesions began with nerve repairs in 1902 [18] by Kennedy. However, long-term treatment results showed that partially healed birth injuries developed deformities, especially in the shoulders and elbows, and thus surgeons began to find an alternative surgical treatment. The aim of these procedures is to improve the function of a deformed extremity after a partially recovered nerve lesion. Release of tendons and muscles were defined to improve the function and range of motion in the early 20th century [2, 19]. Muscle transfers to improve the strength of the joints, not functional enough, were performed in the 1930s [20]. Surgeons preferred osteotomy techniques for improving the function and motion range of limbs. Thus surgeons hoped that patients could receive a functional level that would be able to cope with daily activities by themselves [21].

To this date, the treatment is controversial. Many procedures are performed to prevent or to treat these deformities: In the young child, improving the remodeling of the glenohumeral joint, capsulectomy, and subscapular release are introduced to reduce the pressure over the glenohumeral joint [22–24]. Tendon transfers of the shoulder have good results for motion but fail to restore the glenohumeral joint [25, 26]. The failure of improving joint alignment may represent the loss in clinical

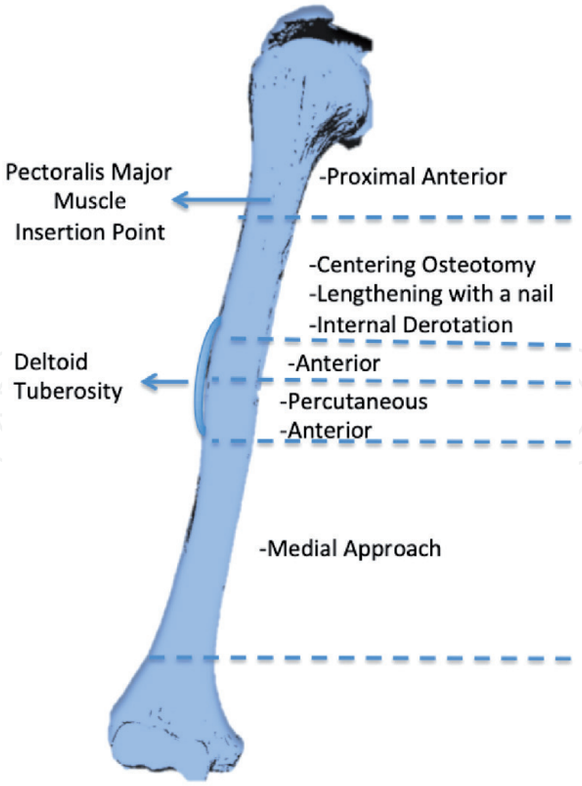

Figure 1.
Demonstration of osteotomy techniques according to the location on the humerus. Dashed lines indicated the border of the defined osteotomy site.

improvement over time [27]. In the older child, it is impossible to reduce the glenohumeral joint. In addition, traumatic brachial plexus injuries in adults can result in the shoulder joint's internal rotational deformity. Humeral osteotomy can be an alternative in both adults and children to realign the limb into external rotation, improve appearance, and enhance activities of daily living, such as eating, washing hair, and scratching the back of the neck [28–30]. Multiple techniques have been described for osteotomy of the humerus. Zancolli et al. [31] performed osteotomy with low axillar incision and at the just distal to the insertion point of the pectoralis major muscle. Glez Cuesta et al. [32] and Goddard et al. [33] performed the osteotomy just above the deltoid insertion via deltopectoral approach. Al Zahrani [34] performed the osteotomy just below the deltoid insertion. Briefly, different osteotomy levels have been described for each technique (**Figure 1**). We will discuss all the techniques along with their advantages and disadvantages in this chapter.

3. Patient evaluation

Preoperatively, the ability of the patients to perform activities of daily living (feeding, washing, and cleaning themselves) with the functionally impaired extremity is evaluated. Muscle strength, the interval for both active and passive movements of the affected size were also assessed. Palpation of the humeral head at the posterior side of the shoulder is performed to evaluate the joint incongruence. In addition, we assess the limited external rotation of the shoulder and the presence of the Putti sign. While the shoulder is passively adducted and externally rotated with the elbow in 90 degrees of flexion, there is an elevation of the upper corner of the scapula termed as the Putti sign [35].

The modified Mallet's classification is used to compare preoperative and postoperative results. This classification includes five criteria: the ability to actively abduct the arm, external rotation of the arm, bring the hand behind the neck and over the mouth. Grade I indicates a firm shoulder or a flailing arm. Grade II indicates active abduction <30 degrees, no active external rotation, and the inability to bring the hand behind the neck and the back. The hand is brought to the mouth with the arm in abduction (the trumpeter sign). Grade III indicates active abduction of 30–90 degrees°, active external rotation <20 degrees, and difficulty placing the hand behind the neck and cephalad to the sacrum. There is still the trumpeter sign. Grade IV indicates active abduction >90 degrees, active external rotation >20 degrees, and no difficulty in bringing the hand behind the neck and over the thoracolumbar region of the back. The hand can be brought to the mouth, and there is no trumpeter sign. Grade V indicates a clinically normal shoulder. If a patient does not meet all five criteria for a grade, he or she is assigned a lower grade [35].

Antero-posterior radiographs of both shoulders must be taken to investigate the size (hypoplastic), location (elevated) of the scapula on the affected side. Moreover, the relationship between acromion and coracoid process, any change in glenoid are also assessed. It is possible to see the hypoplasia of the clavicle and the small proximal humeral epiphysis. The height of space between the acromion and humeral head may be longer than the normal side; the humerus may be more subtle or thicker according to metaphyseal and diaphyseal areas, and the length of the humeral shaft may be shorter [28]. Measurements of humeral retroversion can be done by magnetic resonance imaging or computed tomography (CT) scanning combined with the topographic location of the anterior crease of the elbow pointed upward [36, 37]. These two parameters are helpful techniques to get a more accurate grade of alignment for osteotomies to restore the plane of movement [38].

4. Glenoid anteversion osteotomy combined with tendon transfer

This technique was inspired by the hip's developmental dysplasia; the open reduction and soft tissue procedures are not always sufficient to maintain concentric hip joint reduction and acetabular osteotomies are sometimes necessary [39]. Severe cases of glenohumeral deformity, anteversion of the glenoid would contribute to the stability of an open joint reduction. Glenoidal osteotomy for anteversion

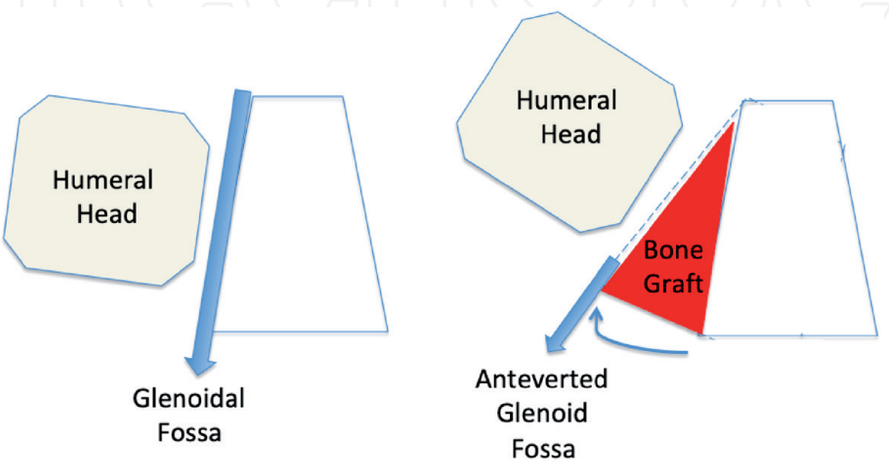

Figure 2.
Osteotomy was performed with the protection of an intact anterior cortex to use as a hinge point, and bone graft was placed with the appropriate size.

is performed to improve the glenoid retroversion whit taking the hinge point as an anterior cortex (**Figure 2**). When combined with a subscapularis slide and transfer of the teres major and latissimus dorsi, anteversion glenoid osteotomy and joint reduction would permit functional recovery of external shoulder rotation. Dodwell et al. [40] reported that they performed on 32 patients with severe glenohumeral dysplasia. Glenoidal osteotomy provided maintenance of the reduction of joint and functional improvement in the short term.

5. Humeral centering osteotomy

The humeral head centering osteotomy increases shoulder stabilization and resolves the anterior contractures with the subscapularis tenotomy. When humeral positioning becomes anatomical, the articular congruency can be adjusted and improve the motion arch of the shoulder. As in developmental hip dysplasia, the idea's origin is to reduce the joint centrally so that its normal growing process occurs. The articular reduction is provided with a medial derotational humeral osteotomy. Unfortunately, there is no standardized degree for angular derotational osteotomy. The ideal one is; first, the shoulder articulation is reduced with the external rotation maneuver. The humeral osteotomy is performed between insertion points of deltoid and pectoralis major muscles. and internally rotated until the patient's hand is brought over his or her abdomen (**Figure 3**). This procedure increases the anteversion of the humerus.

The indications for that procedure are:

- Posterior incongruence of the humeral head that causes dislocation,
- Age < 9 years
- The contraindications are:
- Active infection at the time of the surgery
- No active flexion of the elbow
- Deformity in the extension of the elbow

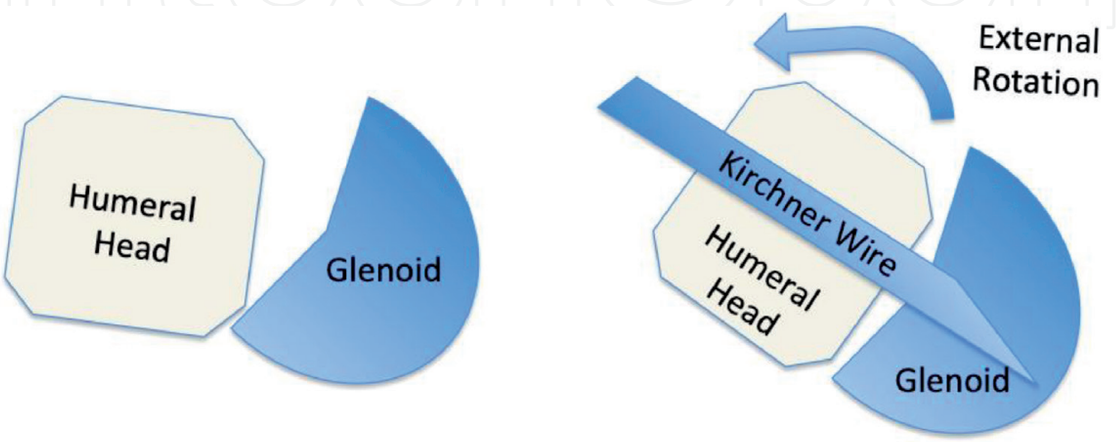

Figure 3.
External rotation of humerus was performed to achieve glenohumeral joint reduction, and a Kirchner wire was placed for the temporary fixation.

- Total brachial plexus lesion
- Trauma or infection sequel that destructs the articular surface
- Age > 9 years

For this procedure, a deltopectoral approach is performed. The subscapularis tenotomy with the anterior capsule is performed at the level of the lesser tuberosity to reach the joint. The reduction of the humeral head is rotated externally to reduce the joint. If there are difficulties or insufficiency for external rotation of the humerus, partial pectoralis major tenotomy can be made. There is no need for any tendon transfer. The humeral head is fixed and centered with a transarticular Kirschner wire. A transverse osteotomy of the humerus between the insertions of the deltoid and the pectoralis major muscles is performed. The humerus is internally rotated until the patient's hand is positioned over his abdomen, and then the osteotomy is fixed with a plate [35]. Vilaça et al. [35] reported 14 patients with centering osteotomy, and in all patients except one, shoulder dislocation to the posterior side could not be corrected.

6. Humeral external rotation osteotomy

Humeral external rotation osteotomy has been described by many surgeons [28, 30, 41–43]. It is mostly suggested for older children with advanced shoulder deformities. The aim of osteotomy is to increase the motion arch of external rotation of the affected shoulder. This osteotomy is accepted as standard treatment for late brachial plexus injury in older children. The results of this osteotomy have satisfactory results with an increase of both external rotation and abduction of the shoulder. Improvement of abduction is dependent on the improvement of the mechanical axis of the deltoid tendons. Moreover, surgeons keep in mind that there is always the possibility of the impairment of internal rotation with this technique. The osteotomy is usually performed proximal to the deltoid tuberosity level to improve the deltoid alignment (**Figure 4**). Some authors have suggested adding a flexion component to osteotomy distally to provide more elevation of the arm [42].

On the other hand, some others also have suggested adding a varus component to osteotomy to restore the abduction contracture [30]. If the plates and screws are used to fix osteotomy, there is no need for immobilization supplied externally by the cast splint. Several different approaches and levels have been described for the external rotational osteotomy of the humerus in literature. We will discuss them below.

6.1 Medial approach for humeral derotational osteotomy

A medial arm incision is performed along the medial intermuscular septum, and The interval between the anterior and posterior arm musculature is used to reach the osteotomy area. The ulnar nerve is just located on the posterior side of the septum and is dissected. The ulnar nerve is a transposition of the ulnar nerve performed to the posterior. In the anterior compartment, the median nerve and brachial artery are palpated and reflected with the biceps and brachialis muscle. The inter-muscular septum is followed through the medial aspect of the humerus and excised.

There are some advantages: Firstly, the scar is more cosmetic because the incision is located at the medial side of the arm and is difficult to see. The incision

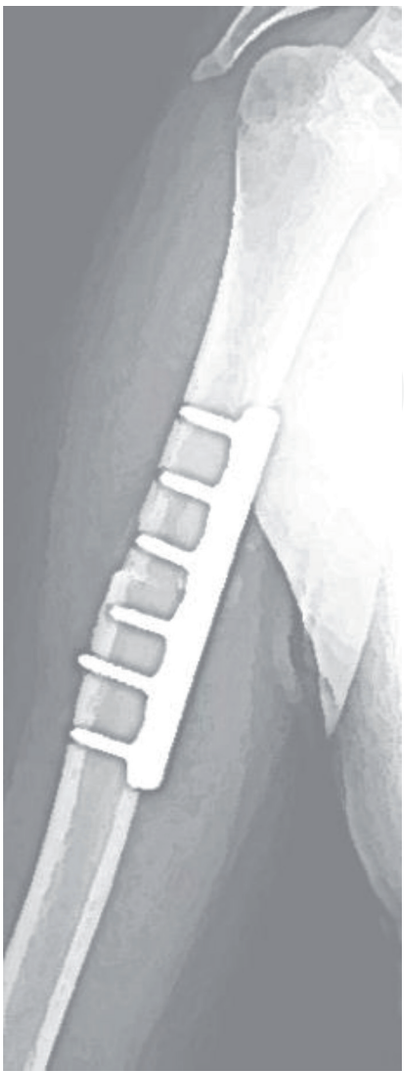

Figure 4.
External rotational osteotomy at the level of deltoid tubercle just distal to the insertion point of the deltoid muscle. Osteotomy was fixed with a plate and screws.

heals better compared to the lateral side. Arm positioning of the arm is easier after external derotational osteotomy places the arm onto the table, making internal fixation easier. In addition, plate application is more suitable at the anteromedial side of the humerus because of its anatomical shape. The disadvantage of the technique is related to its anatomy closer to neurovascular structures. The surgical anatomy is more dangerous because of the close relationship to nerves and is less familiar for the orthopedic surgeon [44].

6.2 Anterior approach for proximal humeral derotational osteotomy

An anterior incision is made through the interval between the biceps brachia and anterior part of the deltoid muscles to reach the proximal part of the humerus. Next, the insertion points of the subscapularis and pectoralis major muscles to humerus are identified. Then using the drill motor, holes through the line of osteotomy planned are opened, but at this phase, the osteotomy is not completed which is not completed. Next, the degree of external rotation of the distal part of the humerus is decided according to the hand position; if the hand can be touched the mouth, rotation of the humerus is enough. After completion of the osteotomy, the proximal and distal sides of the osteotomy are fixated. The use of highly strong sutures in the periosteum can be enough for stabilization

if fragments are well impacted and stabilized. Otherwise, the osteotomy site is stabilized with generally one staple, but if the fixation is not unstable, the surgeon can use two staples [28].

The specific indications for this technique are

- Unimprovable internal rotation of shoulder accompanying to impairment in the function of the teres major and latissimus dorsi muscle in 4–8 years old
- Recrudesce in the dislocation of humerus head or the deformity of the affected side of the arm following a soft-tissue procedure in 4–8 years old
- Internal rotation deformity that can not be restored with procedures other than surgery or decline in the range of active motion through the external side in >8 years old

There are some advantages:

- The osteotomy site consists of a metaphyseal area (cancellous bone). Thus consolidation in there is quicker than other parts of the humerus.
- The staples that are used for fixation of the osteotomized bone are primary, simple devices. Therefore minimal distraction of periosteum and soft tissue is enough
- The osteotomy of the humerus and external rotation of distal part displace the insertion sides of the deltoid (makes tendons more strengthful) and pectoralis major muscle (increase in motion range of internal rotation) more lateral.

6.3 Humeral internal derotational osteotomy

Internal derotation osteotomy of the humerus is performed less often, and there has rarely been reported in the literature [45, 46]. It is described in young children who develop posterior dislocation of the shoulder early in the disease. The internal rotation osteotomy is performed for the reduction of the glenohumeral joint. However, this osteotomy is likely to result in more loss of external rotation. Releasing the internal rotator's muscles and the anterior capsule has to be added to improve the external rotation of the shoulder in these children. In addition, there may be necessary for the transfer of internal rotators to function as external rotators. Skibinski et al. [45] described internal rotation osteotomy (IRO) with a tendon transfer. They first performed soft tissue procedures and then tested the range of motion. Suppose the humeral head was dislocated while internal rotation, the internal humeral rotation was performed to strengthen the joint stability. They reported that the dynamic range of internal rotation difference in children treated with IRO was significantly higher than those treated without osteotomy. The other movements (including external rotation) were similar pre- and postop surgery in both groups. The authors concluded that the addition of IRO to soft tissue procedures improves internal rotation and maintains stable reduction without compromising other movements. Similarly, Kambhampati et al. [46] reported 183 cases of subluxation (101) and dislocation (82) of the shoulder secondary to obstetric brachial plexus palsy. The authors performed anterior release and reduction, and then they measured the degree of retroversion. They performed IRO if the humerus was retroverted more than 40 degrees° or if the head was volatile after reduction.

6.4 Humeral rotational osteotomy with lengthening over a nail

All the techniques that described derotational osteotomy of the humerus in the late treatment of OBPP have neglected upper limb length discrepancy, which is another sequel of OBPP. This technique represents the late treatment of OBPP in patients with upper limb length discrepancy, using derotational osteotomy and lengthening with an elongation nail. A standard deltopectoral approach was applied. Transverse osteotomy between the insertion of the deltoid and pectoralis major muscles was performed. Before the distal locking of the nail, adequate rotation of the humerus was decided intraoperatively by ascertaining that the ipsilateral hand could be placed to the mouth while putting the flexed elbow to the side of the trunk. Once the desired rotation was achieved, the distal locking screws were placed (**Figure 5**) [47].

This technique has some advantages: First, the elimination of length discrepancy improves the upper limb function by re-orientation of the shoulder arc into a more functional range. In addition, the appearance of the upper limb can be improved by visible antecubital fossa and diminished forearm pronation. Secondly, lengthening the humerus with the osteotomy above the deltoid insertion can lead to a more lateralized deltoid insertion, thus improving shoulder abduction more than expected. The disadvantages of this procedure are that it is impossible to add varus or flexion to the distal part of the humerus due to the use of the intramedullary elongation nail. Because ERO with added flexion to the distal part of the humerus to create increased flexion of the arm and adding a varus component to repair the abduction contracture is suggested in the literature [30, 42, 48]. We reported one patient with three years of follow-up. First, the proximal side of the osteotomy migrated the upper part at the end of 5 cm lengthening (**Figure 6**).

That problem could lead to restriction of shoulder motion. However, at the three years, Mallet score was four, and the patient was able to reach the occiput without any trumpet sign, and the palm rather than the dorsum was facing the mouth, which he could not do before the operation (**Figure 7**).

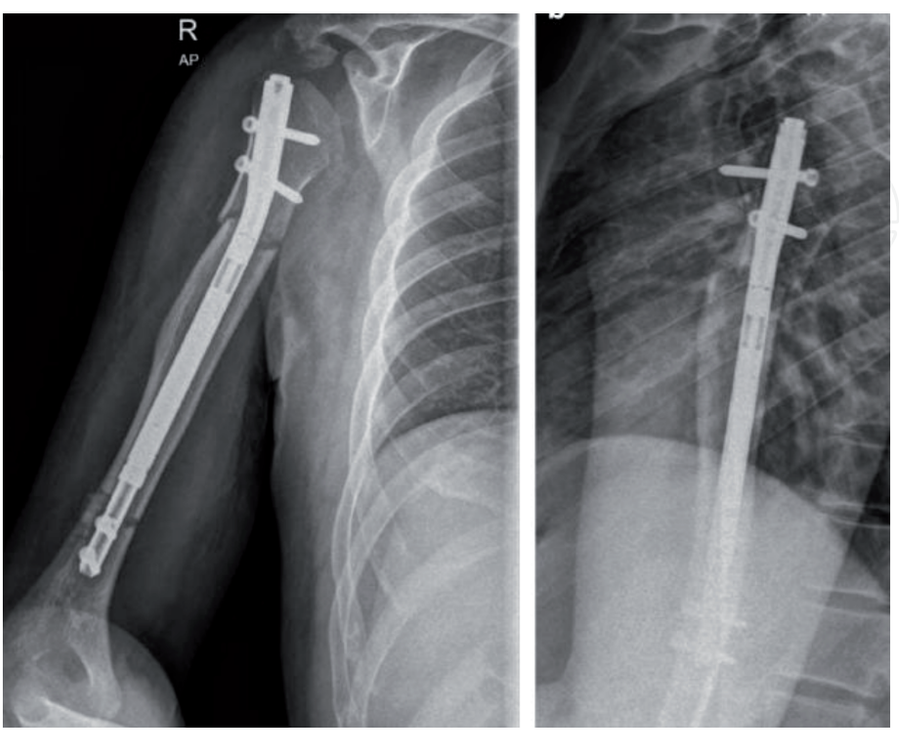

Figure 5.
Postoperative plain AP and Lat. X-rays.

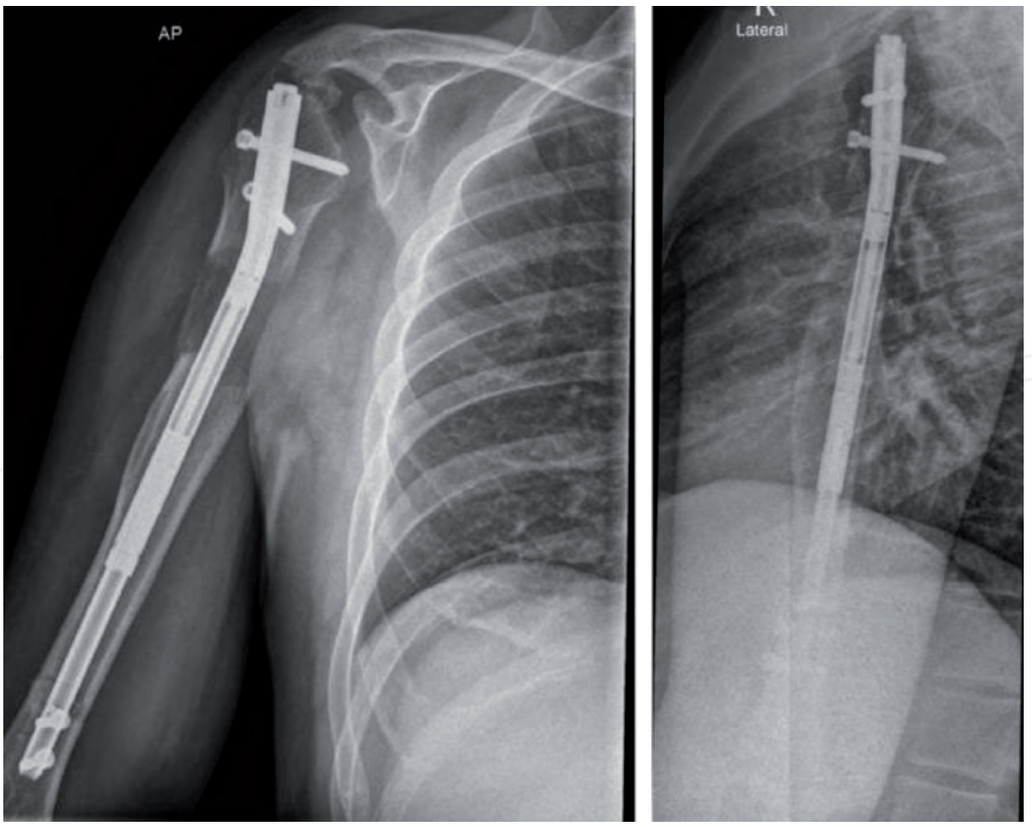

Figure 6.
At the end of 5 cm distraction, AP and Lat. X-rays.

Figure 7.
Range of motions at 36 months.

6.5 Percutaneous humeral derotational osteotomy

The traditional humeral external derotation osteotomy method is open surgery and fixation with implants such as plates and nails. Open surgery often leaves a flagrant incision scar, but it can be hidden via a medial approach. Sometimes, other complications are resourced from implants, such as irritative effects, non-union, failure of implants, or peri-implant fracture [29, 30, 42]. When the implant has to be removed, it can be difficult, especially in the medial approach due to closer location to neurovascular structures. Therefore to avoid these complications,

percutaneous osteot¬omy of the humerus and external fixation is designed. In the first step, two pins are placed at the level of the distal half of the deltoid muscle and below the proximal humeral physis through the lateral side of the humerus. Then, another two pins are placed at the distal insertion point of the deltoid muscle but more anteriorly than before two pins to provide interval while external rotating of the distal fragment of the humerus. The position of these two pins on the anterior plane is decided according to how much rotation is required. The second phase is performing the percutaneous transverse osteotomy of the humerus. The third phase is that the distal fragment is rotated externally till all pins are arranged in the same plane. One or two rods are used to connect the proximal and distal pins and stabilize the osteotomized bone [49]. Advantages of these techniques are

- Incision is minimal. Thus the development of scars does not cause cosmetic problems.

- The placement of the proximal side pins is distal to the deltoid, where there is no risk for physical bone and axillary nerve injuries [50]. In addition, the distal pins are located anteriorly away from the lateral side, where the radial nerve passes through the bone.

- Rotational control of the distal humerus is difficult during open reduction and plate fixation. However, in this technique, distal pins supply stability and controlling the distal fragment efficiently.

Aly et al. [49] reported that six cases that healing processes were completed at an average of 1–2 months without complication. In addition that they showed improvement in the shoulder motion.

7. Osteotomy of the radius and ulna or one-bone forearm

Mild rigid supination deformities can be treated with osteotomy of the radius or ulna [51]. However, osteotomy of both bones requires correcting severe supination deformities completely. Nowadays, the creation of one-bone forearm procedures is preferred to combined osteotomies for severe fixed supination deformities due to the recurrence overtime after combined osteotomies caused by persistent muscle imbalance and the ability to correct substantial deformities. A curvilinear incision is made along the distal radius and proximal ulna. The osteotomies are planned with the radius osteotomy 1 to 2 cm distal to the ulnar osteotomy. The interosseous membrane is incised to allow the radius to be positioned on top of the proximal ulna. The radius is manually mobilized toward the proximal ulna. The bones are coapted, the radius is rotated into the desired position, the plate is placed to the distal radius to connect to the proximal ulna [52].

8. Outcomes

Activities that require external rotation can be done quickly with humeral derotational osteotomy. Before surgery, many patients cannot perform self-care activities, such as eating, dressing, and washing. After surgery, most patients can dress, wash, perform self-cleaning, and eat themselves better and no longer need help. The Mallet score for shoulder function increases after osteotomy. The level of osteotomy is still controversial. Theoretically, rotational osteotomy between the insertions of the subscapularis and pectoralis major muscles improves the deltoid

function. There are no standard methods of fixation. Osteotomy stabilization has varied from flimsy catgut sutures to rigid plates and screws. The fixation technique will affect postoperative rehabilitation. The improved outcome has been represented regardless of fixation [28–30].

9. Conclusion

The arm's fixed adduction and internal rotation are the most common deformities of the extremity in patients with a. In addition, the limited flexion-extension motion of the elbow because of fixed pronation of the forearm can be seen in brachial plexus birth injury. The surgical procedures performed to correct the shoulder deformity provide the range of motion to more acceptable mobility and position and are highly possible to affect the useability of all parts of the upper extremity. This is mostly seen in the patients with the latissimus dorsi and teres major muscles problems and abnormal radiographic findings of the glenohumeral joint. Difficulties in bringing the hand to the mouth without leaning the head forward and toward the involved side and incompetent abduction-flexion of the shoulder if the fixed internal rotation deformity of the shoulder is more than 20 degrees [53]. Suppose external rotation of the shoulder is less than 65 degrees and limited abduction at 80 degrees. In that case, it is impossible to reach the mouth by hand, significantly if the motion range of the hand wrist and elbow is impaired [54]. The soft-tissue contracture is released to improve the cosmetic appearance. Besides, the function of the joint improves slightly. However, there is an increase in only external rotation, not an increase in abduction is observed, and there is a high possibility for anterior dislocation of the shoulder. In addition, recurrence of the fixed internal rotation deformity reduces the range of rotational movement with time passing [53]. Sever described a technique that involves the release and replacement of the teres major and latissimus dorsi muscles to the posterior and lateral parts of the humerus to function as external rotators of the shoulder if muscle strength is enough. The glenohumeral joint has any abnormalities [20]. The osteotomy of the proximal humerus for the late treatment of brachial plexus birth injuries' suggested first time by Roger [21].

Since then, several techniques have been described, including either the proximal or the distal humeral derotational osteotomy in case of structural abnormality (irreducible internal rotation) and anatomical pathology (flattened humeral head or posterior subluxation) of the shoulder [14, 21, 32, 33, 53]. There is a gradual increase in the arc of active motion at the expense of passive motion. Therefore, rotation of the extremity can be increased during the growth of the extremity in a neutral position and alignment. This can result in changing the relationship between the joint congruency and the soft tissues that cover the joint. Therefore, surgeons must consider the alteration of the congruency due to the growth of the bones and soft tissues and not overcorrect the abnormality.

Author details

Ahmet Emrah Açan[1*] and Ertuğrul Şahin[2]

1 Department of Orthopaedics and Traumatology, Faculty of Medicine, Balikesir University, Balıkesir, Turkey

2 Department of Orthopaedics and Traumatology, İzmir Kemalpaşa State Hospital, Izmir, Turkey

*Address all correspondence to: dremrahacan@hotmail.com

References

[1] Sjoberg I, Erichs K, Bjerre I. Cause and effect of obstetric (neonatal) brachial plexus palsy. Acta Paediatr Scand. 1988;77(3):357-364.

[2] Sever JW. Obstetric Paralysis-Its Cause and Treatment. Can Med Assoc J. 1920;10(2):141-161.

[3] Strömbeck C, Krumlinde-Sundholm L, Forssberg H. Functional outcome at 5 years in children with obstetrical brachial plexus palsy with and without microsurgical reconstruction. Dev Med Child Neurol. 2000;

[4] Badger B. Perinatally acquired brachial plexus palsy - A persisting challenge. Acta Paediatr Int J Paediatr. 1997;86(11):1214-1219.

[5] Pondaag W, Malessy MJA, Van Dijk JG, Thomeer RTWM. Natural history of obstetric brachial plexus palsy: A systematic review. Dev Med Child Neurol. 2004;46(2):138-144.

[6] Kozin SH. Correlation between External Rotation of the Glenohumeral Joint and Deformity after Brachial Plexus Birth Palsy. J Pediatr Orthop. 2004;24:189-193.

[7] Pearl ML, Edgerton BW. Glenoid deformity secondary to brachial plexus birth palsy. J Bone Jt Surg - Ser A. 1998;80:659-667.

[8] Waters PM, Smith GR, Jaramillo D. Glenohumeral deformity secondary to brachial plexus birth palsy. J Bone Jt Surg - Ser A. 1998;80:668-677.

[9] Gudinchet F, Maeder P, Oberson JC, Schnyder P. Magnetic resonance imaging of the shoulder in children with brachial plexus birth palsy. Pediatr Radiol. 1995;25:125-128.

[10] van der Sluijs JA, van Ouwerkerk WJR, de Gast A, Wuisman PIJM, Nollet F, Manoliu RA. Deformities of the shoulder in infants younger than 12 months with an obstetric lesion of the brachial plexus. J Bone Jt Surg - Ser B. 2001;83:551-555.

[11] Moukoko D, Ezaki M, Wilkes D, Carter P. Posterior Shoulder Dislocation in Infants with Neonatal Brachial Plexus Palsy. J Bone Jt Surg - Ser A. 2004;86B:787-793.

[12] Troum S, Floyd WE, Waters PM. Posterior dislocation of the humeral head in infancy associated with obstetrical paralysis. A case report. J Bone Jt Surg - Ser A. 1993;75A: 1370-1375.

[13] Torode I, Donnan L. Posterior dislocation of the humeral head in association with obstetric paralysis. J Pediatr Orthop. 1998;18:611-615.

[14] Zancolli EA. Classification and management of the shoulder in birth palsy. Orthop Clin North Am. 1981;12:433-457.

[15] Pearl ML, Edgerton BW, Kon DS, Darakjian AB, Kosco AE, Kazimiroff PB, et al. Comparison of arthroscopic findings with magnetic resonance imaging and arthrography in children with glenohumeral deformities secondary to brachial plexus birth palsy. J Bone Jt Surg - Ser A. 2003;85A:890-898.

[16] Saifuddin A, Heffernan G, Birch R. Ultrasound diagnosis of shoulder congruity in chronic obstetric brachial plexus palsy. J Bone Joint Surg Br. 2002;84B:100-103.

[17] Zancolli EA ZE. Congenital brachial plexus exploration. In: Gupta A KS, LR S, editors. The Growing hand. London: Mosby; 2000. p. 805-823.

[18] Kennedy R. Suture of the brachial plexus in birth paralysis of the upper

extremity. Br Med J. 1903;1(2197): 298-301.

[19] HAT F. BIRTH PALSY : SUBLUXATION OF THE SHOULDER-JOINT IN INFANTS AND YOUNG CHILDREN. Lancet. 1913;3(1): 1217-1223.

[20] L'Episcopo J. Restoration of muscle balance in the treatment of obstetrical paralysis. New York Med J. 1939;39:357-363.

[21] Rogers MH. An Operation for the Correction of the Deformity Due to Obstetrical Paralysis. Bost Med Surg J. 1916;174:163-164.

[22] Pearl ML. Arthroscopic release of shoulder contracture secondary to birth palsy: An early report on findings and surgical technique. Arthrosc - J Arthrosc Relat Surg. 2003;19:577-582.

[23] Hui JHP, Torode IP. Changing glenoid version after open reduction of shoulders in children with obstetric brachial plexus palsy. J Pediatr Orthop. 2003;23:109-113.

[24] Pedowitz DI, Gibson B, Williams GR, Kozin SH. Arthroscopic treatment of posterior glenohumeral joint subluxation secondary to brachial plexus birth palsy. J Shoulder Elb Surg. 2007;16:6-13.

[25] Kozin SH, Chafetz RS, Barus D, Filippone L. Magnetic resonance imaging and clinical findings before and after tendon transfers about the shoulder in children with residual brachial plexus birth palsy. J Shoulder Elb Surg. 2006;15:554-561.

[26] Waters PM, Bae DS. Effect of tendon transfers and extra-articular soft-tissue balancing on glenohumeral development in brachial plexus birth palsy. J Bone Jt Surg - Ser A. 2005;87: 320-325.

[27] Pagnotta A, Haerle M, Gilbert A. Long-term results on abduction and external rotation of the shoulder after latissimus dorsi transfer for sequelae of obstetric palsy. Clin Orthop Relat Res. 2004;426:199-205.

[28] Kirkos JM, Papadopoulos IA. Late treatment of brachial plexus palsy secondary to birth injuries: Rotational osteotomy of the proximal part of the humerus. J Bone Jt Surg - Ser A. 1998;80:1477-1483.

[29] Al-Qattan MM. Rotation osteotomy of the humerus for Erb's palsy in children with humeral head deformity. J Hand Surg Am. 2002;27:479-483.

[30] Waters PM, Bae DS. The effect of derotational humeral osteotomy on global shoulder function in brachial plexus birth palsy. J Bone Jt Surg - Ser A. 2006;88:1035-1042.

[31] Zancolli EA, Zancolli ER. Palliative surgical procedures in sequelae of obstetric palsy. Hand Clin. 1988;4: 643-669.

[32] Glez Cuesta FJ, Lopez Prats F, Glez Lopez FJ, Bergada Sitja J. The role of bone operations as palliative surgical treatment for the sequelae of obstetrical brachial paralysis in the shoulder. Acta Orthop Belg. 1982;48:757-761.

[33] Goddard NJ, Fixsen JA. Rotation osteotomy of the humerus for birth injuries of the brachial plexus. J Bone Jt Surg - Ser B. 1984;66:257-259.

[34] Al Zahrani S. Modified rotational osteotomy of the humerus for Erb's palsy. Int Orthop. 1993;17:202-204.

[35] Vilaça PR, Uezumi MK, Zoppi Filho A. Centering osteotomy for treatment of posterior shoulder dislocation in obstetrical palsy. Orthop Traumatol Surg Res. 2012;98:199-205.

[36] Ivalde FC, Miguens GN, Socolovsky M. Using the main elbow

flexion skin crease as an intraoperative parameter to determine the degree of exorotation needed for humeral derotational osteotomies in upper-type brachial plexus patients. J Orthop Surg. 2018;26(3):230949901879271.

[37] Pearl ML, Batch M, Van De Bunt F. Humeral retroversion in children with shoulder internal rotation contractures secondary to upper-trunk neonatal brachial plexus palsy. J Bone Jt Surg - Am Vol. 2016;98(23):1988-1995.

[38] Itamura JM, Papadakis SA, Vaishnav S, Gourmet R. The relationship between main elbow flexion skin crease and osseous anatomy of the elbow joint. Surg Radiol Anat. 2009;31(1):55-58.

[39] Vitale MG, Skaggs DL. Developmental dysplasia of the hip from six months to four years of age. J Am Acad Orthop Surg. 2001;9(6):401-411.

[40] Dodwell E, O'Callaghan J, Anthony A, Jellicoe P, Shah M, Curtis C, et al. Combined glenoid anteversion osteotomy and tendon transfers for brachial plexus birth palsy: Early outcomes. J Bone Jt Surg - Ser A. 2012;94:2145-2152.

[41] Abzug JM, Chafetz S, Gaughan JP, Ashworth S, Kozin SH. Shoulder function after medial approach and derotational humeral osteotomy in patients with brachial plexus birth palsy. J Pediatr Orthop. 2010;30(5):469-474.

[42] Al-Zahrani S. Combined sever's release of the shoulder and osteotomy of the humerus for ERB's palsy. J Hand Surg Eur Vol. 1997;22:591-593.

[43] Al-Qattan MM, Al-Husainan H, Al-Otaibi A, El-Sharkawy MS. Long-term results of low rotation humeral osteotomy in children with erb's obstetric brachial plexus palsy. J Hand Surg Eur Vol. 2009;34(4):486-492.

[44] Kozin SH. Medial Approach for Humeral Rotational Osteotomy in Children with Residual Brachial Plexus Birth Palsy. Oper Tech Orthop. 2007;17(2):88-93.

[45] Sibiński M, Synder M. Soft tissue rebalancing procedures with and without internal rotation osteotomy for shoulder deformity in children with persistent obstetric brachial plexus palsy. Arch Orthop Trauma Surg. 2010;130(12):1499-1504.

[46] Kambhampati SBS, Birch R, Cobiella C, Chen L. Posterior subluxation and dislocation of the shoulder in obstetric brachial plexus palsy. J Bone Jt Surg - Ser B. 2006;88:213-219.

[47] Acan AE, Gursan O, Demirkiran ND, Havitcioglu H. Late treatment of obstetrical brachial plexus palsy by humeral rotational osteotomy and lengthening with an intramedullary elongation nail. Acta Orthop Traumatol Turc. 2018;52:75-80.

[48] Bae DS, Waters PM. External rotation humeral osteotomy for brachial plexus birth palsy. Tech Hand Up Extrem Surg. 2007;11(1):8-14.

[49] Aly A, Bahm J, Schuind F. Percutaneous humeral derotational osteotomy in obstetrical brachial plexus palsy: A new technique. J Hand Surg Eur Vol. 2014;39(5):549-552.

[50] Klepps S, Auerbach J, Calhon O, Lin J, Cleeman E, Flatow E. A cadaveric study on the anatomy of the deltoid insertion and its relationship to the deltopectoral approach to the proximal humerus. J Shoulder Elb Surg. 2004;13(322-7).

[51] Kozin SH. Treatment of the supination deformity in the pediatric brachial plexus patient. Tech Hand Up Extrem Surg. 2006;10:87-95.

[52] Sarah Ashworth SHK. Brachial Plexus Birth Palsy: Secondary Procedures to Enhance Function. In: Abzug, Joshua M., Scott H., Kozin, Zlotolow DA, editor. The Pediatric Upper Extremity. Springer; 2015. p. 1830-1831.

[53] WICKSTROM J, HASLAM ET, HUTCHINSON RH. The surgical management of residual deformities of the shoulder following birth injuries of the brachial plexus. J Bone Joint Surg Am. 1955;37:27-36.

[54] WICKSTROM J. Birth injuries of the brachial plexus. Treatment of defects in the shoulder. Clin Orthop. 1962;23: 187-196.