External Rotation Predicts Outcomes After Closed Glenohumeral Joint Reduction With Botulinum Toxin Type A in Brachial Plexus Birth Palsy

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Background: Few studies have investigated outcomes after adjunct botulinum toxin type A (BTX-A) injections into the shoulder internal rotator muscles during shoulder closed reduction and spica cast immobilization in children with brachial plexus birth palsy. The purpose of this study was to report success rates after treatment and identify pretreatment predictors of success.

Methods: Children with brachial plexus birth palsy who underwent closed glenohumeral joint reduction with BTX-A and casting were included. Minimum follow-up was 1 year. Included patients did not receive concomitant shoulder surgery nor undergo microsurgery within 8 months. Records were reviewed for severity of palsy, age, physical examination scores, passive external rotation (PER), and subsequent orthopaedic procedures (repeat injections, repeat reduction, shoulder tendon transfers, and humeral osteotomy). Treatment success was defined in 3 separate ways: no subsequent surgical reduction, no subsequent closed or surgical reduction, and no subsequent procedure plus adequate external rotation.

Results: Forty-nine patients were included. Average age at time of treatment was 11.5 months. Average follow-up was 21.1 months (range, 1 to 9 y). Thirty-two patients (65%) required repeat reduction (closed or surgical). Only 16% of all patients obtained adequate active external rotation without any subsequent procedure. Increased PER (average 41 ± 14 degrees, odds ratio = 1.21, $P = 0.01$) and Active Movement Scale external rotation (average 1.3, odds ratio = 2.36, $P = 0.02$) predicted optimal treatment success. Limited pretreatment PER (average −1 ± 17 degrees) was associated with treatment failure. Using the optimal definition for success, all patients with pretreatment PER > 30 degrees qualified as successes and all patients with PER < 15 degrees were treatment failures.

Conclusions: Pretreatment PER > 30 degrees can help identify which patients are most likely to experience successful outcomes after shoulder closed reduction with BTX-A and cast immobilization. However, a large proportion of these patients will still have mild shoulder subluxation or external rotation deficits warranting subsequent intervention.

Level of Evidence: Level IV—therapeutic.

Key Words: botox, glenohumeral dysplasia, brachial plexus

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Although most children with brachial plexus birth palsy (BPBP) recover spontaneously, those with incomplete neurological recovery may develop shoulder internal rotation contractures and posterior humeral head migration.[1] One theory holds that shoulder internal rotation contractures are the result of muscle imbalance between preferentially denervated external rotators and less affected internal rotators, particularly after an isolated upper-trunk injury. Subsequent abnormal glenohumeral forces during osteocartilagenous development result in glenoid retroversion or biconcavity.[1] Resting muscle lengths also shorten due to lack of passive motion and restricted muscle growth.[2]

Shoulder deformities may persist if capsular or muscle contractures develop before restoration of external rotation.[3] Passive stretching is initiated shortly after birth to mitigate contractures, but is often insufficient to maintain full passive external rotation (PER). OnabotulinumtoxinA (BTX-A) has additionally been recommended as an adjunct during closed reduction and casting to facilitate external rotation.[4]

Few recent studies have investigated outcomes after BTX-A, closed reduction, and spica cast immobilization in children with early posterior shoulder subluxation.[4–6] The purpose of this study was to review our experience with this treatment method to report success rates and determine pretreatment predictors of success.

METHODS

After institutional review board approval, a retrospective database search at an institution that specializes in the treatment of children with BPBP identified all

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children with BPBP who received BTX-A injections to the shoulder internal rotators during closed glenohumeral reduction and casting. Indications for the treatment of interest include no PER past neutral or progressive loss of PER with the shoulder adducted and scapula stabilized and a subluxed glenohumeral joint confirmed by imaging, in patients preferably younger than 2 years old. Subluxation indicates the humeral head center is posterior to the posterior scapular margin axis yet contained within the labrum. Reduction implies relocation of the humeral head center to the anterior half of the glenoid. Patients with incomplete medical records or <1-year follow-up were excluded.[5–7] Patients with concomitant or prior shoulder surgery, or microsurgery within 8 months,[5] were excluded. Two patients underwent repeat closed reductions and only their initial attempts were included. Age, sex, Narakas classification, surgical history, pretreatment, and most recent posttreatment (before further intervention) modified Mallet scores,[8] Active Movement Scale (AMS) scores,[9] and PER measurements were collected. These scoring systems are validated for use in children with BPBP and have acceptable interobserver and intraobserver reliability.[10] At our institution, we use the modified Mallet score described by Abzug et al[8] to adequately document loss of midline. We are currently researching possible risk factors for loss of midline. All examinations were performed without anesthesia by a treating surgeon or experienced occupational therapist within 30 days of treatment. PER was measured in degrees from neutral with the humerus adducted (to minimize scapular motion)[11] and elbow flexed 90 degrees. The status of joint reduction was confirmed before and after treatment using computed tomography, magnetic resonance imaging (MRI), or ultrasound. Resubluxation served as the primary indication for rereduction. If closed reduction or PER > 60 degrees was not achievable after BTX-A treatment, arthroscopic or open surgery was performed and such patients did not meet our inclusion criteria. Patients with persistent shoulder tightness were offered further surgical intervention to include arthroscopic or open treatment with or without tendon transfers and humeral osteotomy in older children.

Surgical Technique

Informed consent was obtained before the off-label use of BTX-A. Under general anesthesia, manipulation was performed by externally rotating the shoulder at least 60 degrees with the scapula stabilized, elbow flexed 90 degrees, and the arm maximally adducted. Of note, we do not fully supinate the forearm because we previously observed 3 cases of posterolateral rotatory instability of the radial head with this position and no cases of radial head dislocation using our current technique. Ultrasound was used during manipulation to confirm a reduced glenohumeral joint. A maximum total dose of 10 U/kg of BTX-A (Botox; Allergan Inc., Irvine, CA) was diluted and injected into the latissimus dorsi/teres major complex, pectoralis major, and subscapularis in equally divided doses. Target muscles were identified by palpation and confirmed through nerve stimulator. A shoulder spica cast was then applied for 6 weeks with the arm in the same position of adduction and maximal external rotation at which ultrasound confirmed glenohumeral joint reduction.

Statistical Analysis

The dependent variable was the outcome after treatment (success vs. failure). We created and separately analyzed 3 different definitions for success and failure (Table 1). Within each predefined group, mean pretreatment values associated with success or failure were compared using unpaired *t* tests. Binary logistic regression was used to assess the ability of preoperative variables to predict a dichotomous outcome. A statistically significant odds ratio (OR) > 1 implies that a variable was predictive of treatment success. Pearson correlation coefficients were computed to analyze relationships between independent variables. Probability values of $P < 0.05$ were considered statistically significant.

RESULTS

Forty-nine patients met inclusion criteria. Average age at time of treatment was 11.5 ± 7.1 months (range, 4 to 35 mo). Average follow-up before subsequent intervention was 21.1 ± 21 months (range, 12 to 113 mo). Average lifelong follow-up (ie, final clinic visit) was 38.1 ± 25.1 months (range, 9 to 108 mo). The study age distribution is represented in Figure 1. Age did not correlate with restricted pretreatment or posttreatment PER ($r = -0.15$ and 0.003, respectively; Fig. 2). There were no complications directly related to BTX-A injections or closed treatment, but 1 patient lost midline function as defined by a modified Mallet internal rotation score <4. This persisted at 4-year follow-up, but was still categorized as a treatment success due to maintenance of shoulder reduction, full active external rotation, and utilization of the affected extremity during sporting activities. One patient who underwent subsequent tendon transfers to augment external rotation did not require a simultaneous rereduction. The parents of 1 patient declined further management for resubluxation and this patient was considered a treatment failure based on intent-to-treat.

PER improved throughout the study population (from an average of 6 to 27 degrees, $P < 0.001$) and improvement arcs did not differ based on outcome (Table 2). Success rates, computed separately for all 3 outcomes definitions, are summarized in Table 3. Preoperative means associated with success that were significantly different than those associated with failure are highlighted in Tables 4 and 5. Increased pretreatment PER was associated with maintenance of joint reduction. Increased pretreatment AMS external rotation score and PER predicted the combination of joint reduction maintenance and adequate active external rotation. Average preoperative PER associated with positive outcomes ranged from 11 to 41 degrees (depending on the definition used for success). Conversely, average preoperative PER associated with negative outcomes ranged between −6 and

TABLE 1. Outcomes Criterion

	Success	Failure
A	No subsequent surgical reduction required	Required subsequent surgical reduction (AR, OR)
B	No subsequent reduction required	Required any repeat reduction (CR, AR, OR)
C	No subsequent procedure and adequate external rotation*	Required subsequent procedure (CR, AR, OR, TT, HO) and/or Inadequate external rotation†

*Adequate external rotation defined as modified Mallet external rotation ≥ 4 and/or AMS external rotation ≥ 6.

†Inadequate external rotation defined as modified Mallet external rotation < 4 and/or AMS external rotation < 6.

AMS indicates Active Movement Scale; AR, arthroscopic reduction; CR, closed reduction; HO, humeral osteotomy; OR, open reduction; TT, tendon transfers.

−1 degrees. ORs are summarized in Table 6. Age did not predict outcomes using simple or multiple logistic regression analysis. Table 7 groups overall success and failure rates (according to Criteria C in Table 1) based on preoperative PER ranges chosen to represent values within approximately 1 SD of their predictive means.

DISCUSSION

Posterior shoulder subluxation occurs in 8% to 20% of patients with BPBP as early as 3 months of age.[12–15] Internal rotation posturing of the shoulder gradually forces the humeral head posteriorly due to weak active shoulder external rotation, loss of passive stretch, capsular contractures, and subsequent glenoid biconcavity or retroversion.[1,2,16–19] If uncorrected, progressive glenohumeral dysplasia can lead to permanent shoulder deformity and limited motion.[20] Generally accepted treatment techniques to minimize dysplasia include therapy, closed reduction and casting (with or without BTX-A injections), tendon transfers, and arthroscopic or open reduction.[21–24] All treatment options aim to restore external rotation and create a concentric glenohumeral joint. Regardless of treatment method, several studies confirm the remodeling potential of the glenohumeral joint after reduction in young children.[25–27] Therefore, experts recommend addressing the deformity as early as possible.[26,27]

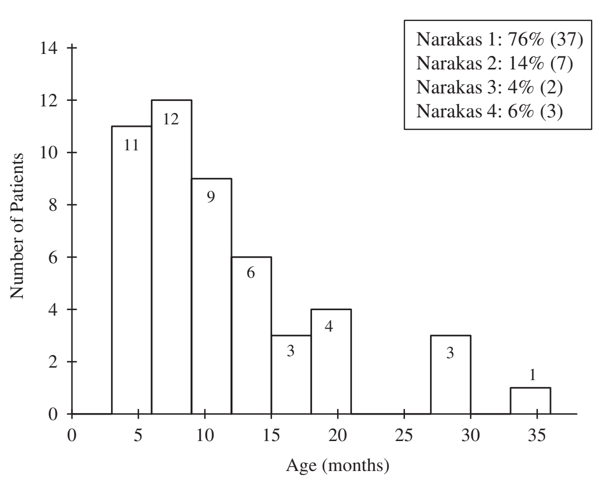

FIGURE 1. Distributions of age at time of treatment and severity of palsy for the study population.

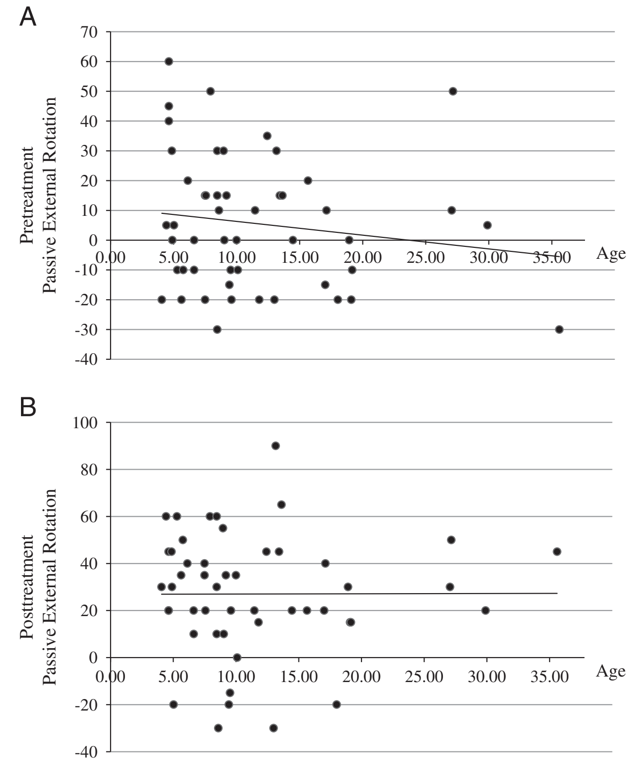

FIGURE 2. Age at time of treatment (horizontal axis) versus pretreatment passive external rotation (A, vertical axis) and posttreatment passive external rotation (B, vertical axis).

BTX-A has been used to treat spasticity and joint contractures in children with neuromuscular disorders for decades.[28,29] The toxin, produced by *Clostridium botulinum*, contains proteins that block transmission of acetylcholine across the neuromuscular junction by interfering with presynaptic neurotransmitter unloading mechanisms. With regards to children with BPBP and nonspastic contractures, BTX-A has been shown to enhance the ability of muscle to passively stretch[30] and magnify active motion through inhibition of imbalanced antagonistic muscles.[31,32] Some authors believe BTX-A has the additional ability to alter cortical patterning.[33,34] This may explain why some series demonstrate functional

TABLE 2. Comparison of Changes in Passive External Rotation Arcs Associated With Success Versus Failure

Criteria	△PER (Success)	△PER (Failure)	*P*
A	28	14	0.08
B	29	21	0.23
C	18	25	0.38

△PER = change in passive external rotation (deg.).

TABLE 3. Final Outcomes (n = 49)

Criteria	Success (%)	Failure (%)	Definition of Success (per Table 1)
A	69	31	No arthroscopic or open reduction
B	35	65	No repeat reduction performed
C	16	84	No subsequent procedure and adequate external rotation

improvements beyond the established 3 to 4 months of therapeutic efficacy of BTX-A.[7]

Ezaki et al[4] endorsed the use of BTX-A as an adjunct to closed reduction of subluxed glenohumeral joints in children with BPBP. In a series of 35 patients followed for a minimum of 1 year, 69% maintained reduction after receiving BTX-A to the shoulder internal rotators during closed reduction and casting. The number of open reductions performed at the authors' institution during the study period decreased despite a simultaneous increase in patient volume. Hence, they concluded that the addition of BTX-A to their treatment algorithm was responsible for the decreased frequency of resubluxations. Of note, treatment failures were comprised of patients who either refused further treatment or subsequently underwent open reduction. In our study, 69% of treatments were considered successful when subsequent surgical reduction (open or arthroscopic) implied treatment failure (Table 3, Criteria A). This result is identical to the success rate reported by Ezaki et al.[4]

However, our perceived rate of success dropped from 69% to 35% after we updated our outcomes criteria to identify 17 additional resubluxations that did not require open or arthroscopic reduction, but did require a closed rereduction in the operating room either alone or as an adjunct to tendon transfers (Table 3, Criteria B). Moreover, maintenance of reduction is only part of the solution to gain a more functional glenohumeral joint. Persistent lack of external rotation reexposes the immature glenohumeral joint to soft-tissue imbalance, resubluxation, and dysplasia.[35] We therefore again modified our definition of success to consider treatment failure of any patient who either lost reduction or exhibited resistant internal rotation contractures (defined as modified Mallet external rotation <4 and/or AMS external rotation <6) at final follow-up. According to this modified outcomes criteria, the fraction of injections considered successful declined to only 16% (Table 3, Criteria C).

TABLE 4. Comparison of Preoperative Means (Success vs. Failure)

	P		
	Outcomes Criteria		
Preoperative Variables	A	B	C
Active Movement Scale			
Shoulder abduction	0.271	0.195	0.340
Shoulder adduction	0.268	0.606	0.296
Shoulder flexion	0.976	0.497	0.651
Shoulder internal rotation	0.578	0.103	0.251
Shoulder external rotation	0.260	0.066	**0.005**
Elbow flexion	0.721	0.857	0.690
Elbow extension	0.465	0.349	0.541
Forearm supination	0.109	0.718	0.063
Forearm pronation	0.568	0.751	0.818
Wrist flexion	0.742	0.860	0.305
Wrist extension	0.348	0.627	0.571
Finger flexion	0.288	0.320	0.427
Finger extension	0.824	0.170	0.453
Thumb flexion	0.481	0.288	0.598
Thumb extension	0.812	0.429	0.386
Total	0.607	0.759	0.158
Passive external rotation	**0.015**	**0.002**	**< 0.001**

P-values <0.05 (in bold) indicates preoperative group means were significantly different.

Increased preoperative AMS external rotation (OR = 2.36, $P = 0.02$) and PER (OR = 1.21, $P = 0.01$) were the only predictors of reduction maintenance with adequate active external rotation. The duration of increased range of motion after BTX-A in children with BPBP is controversial. Price et al[7] reported significantly better functional shoulder scores at long-term follow-up in a small cohort of patients who received BTX-A injections during standard tendon transfers. Michaud et al[6] reported a series of 51 injections in which several shoulders maintained their original degree of improvement beyond 7 months. In contrast, Arad et al[5] reported that a clinically relevant improvement in shoulder external rotation is not sustained at 1 year. Our results agree with the latter and suggest that adequate external rotation is not maintained over time in the majority of patients receiving BTX-A injections.

On the basis of the current literature, it is difficult to predict which patients with BPBP and shoulder abnormalities benefit from closed treatment. We recommend the use of BTX-A and casting in patients with >30 degrees of PER who are amenable to closed reduction (Table 7). However, clinicians should be aware that closed treatment in children with <15 degrees of PER is unlikely to work as a stand-alone treatment. These patients are more likely to require tendon transfers and/or surgical reduction even after BTX-A and casting. In a patient population whereby surgical indications rely heavily on physical examination, the ability to forecast likelihood of treatment success based on preoperative PER is useful.[36]

There are a few important details with regards to interpretation of our study. First, improved PER (because of the chemical effects of BTX-A and/or mechanical effects of casting) was uniformly present in both the success and failure groups (Table 2). Therefore, failures did not occur simply because treatment was ineffective. Second, it is possible that capsular contractures also contribute to limited PER, but improved PER throughout the entire study population after closed treatment indicates that the etiology of limited pretreatment external rotation was extracapsular. Third, average AMS external rotation scores associated with treatment success (1.3) versus failure (0.3) suggest that patients are more

TABLE 5. Descriptive Statistics for Preoperative Variables With Significantly Different Means Associated With Treatment Success Versus Failure

		n		Mean		SD		Minimum		Maximum	
Criteria	Preoperative Variables	Success	Failure	Success	Failure	Success	Failure	Success	Failure	Success	Failure
C	AMS external rotation	8	41	1.3	0.3	1.3	0.8	0	0	3	3
A	PER	34	15	11	−6	23	17	−30	−30	60	30
B	PER	17	32	19	−1	27	16	−20	−30	60	30
C	PER	8	41	41	−1	14	17	15	−30	60	30

AMS indicates Active Movement Scale; PER, passive external rotation.

likely to achieve adequate active external rotation and maintain reduction as long as external rotators have enough neurological input to contract (thus earning an AMS value >1). Fourth, increased preoperative PER predicted maintenance of reduction regardless of how we defined success. However, our data included a small number of patients with unexpected outcomes. For example, preoperative PER as high as 30 degrees in 1 case did not satisfy our criteria for success and preoperative PER closer to neutral did not always guarantee treatment failure. This implies clinicians may still offer the treatment of interest to patients with limited options. It is unclear why this occurred, but perhaps these patients are in earlier stages of internal rotation posture development which is believed to be multifactorial (ie, muscle imbalance, musculotendinous adaptations, muscular hypoplasia, soft-tissue contractures, and then bony changes). Finally, it is possible that patients classified as treatment failures experienced enough improvement after closed treatment to improve overall outcomes, allow deferment of surgery, and minimize the effects of glenohumeral dysplasia. This is a subject for further study. It is also possible that longer follow-up would identify additional failures, although at the time of final follow-up our patients did not have findings to suggest future disease progression.

Our study was limited by the inherent bias of retrospective data collection. Also, our series lacked a comparison group to separately analyze the effects of BTX-A. The goal of our study was primarily to report success rates and pretreatment predictors of success after closed treatment with BTX-A. Casting alone may be responsible for our findings but the prior conclusions of Ezaki et al[4] suggest that BTX-A may be an effective adjunct in appropriate patients. In addition, this study does not address the utility of repeat injections, but in our experience these patients ultimately require further surgery possibly secondary to increased glenohumeral dysplasia or capsular contracture development over time. Furthermore, our study does not determine the ideal age at which glenoid remodeling occurs because either MRI or ultrasound was used, but often not both. These imaging modalities use slightly different methods to track glenohumeral dysplasia. Thus, analyzing statistical parameters for the entire sample population using 2 different modalities would be unsound. Finally, age was not predictive of outcomes. However, younger age likely permits more glenohumeral remodeling potential. Future studies should prospectively use MRI and serial examinations to clarify which shoulders optimally remodel after closed treatment.

SUMMARY

BTX-A injections with shoulder closed reduction and casting may avoid subsequent reduction procedures and optimize glenohumeral joint development. However, a large proportion of patients still have functional deficits warranting subsequent surgery. Physicians should assess PER before closed treatment as a predictor of success. However, because no definitive thresholds of the preoperative examination can predict outcomes with certainty,

TABLE 6. Binary Logistic Regression of Select Predictive Preoperative Variables

Variables	Criteria	Odds Ratio	*P*	95% Confidence Interval
AMS external rotation	A	1.63	0.27	0.68, 3.91
	B	1.85	0.07	0.96, 3.56
	C	2.36	0.02	1.18, 4.73
Passive external rotation	A	1.04	0.02	1.01, 1.08
	B	1.05	0.01	1.01, 1.08
	C	1.21	0.01	1.05, 1.39
Age	A	0.94	0.24	0.86, 1.04
	B	0.98	0.71	0.89, 1.08
	C	1.00	0.98	0.89, 1.13

AMS indicates Active Movement Scale.

TABLE 7. Probability of Success or Failure Grouped by Preoperative Passive External Rotation

		PER (deg.)*		
Criteria	Outcome	≤15	15 < PER ≤ 30	> 30
A	Success	18 (58)	10 (83)	6 (100)
	Failure	13 (42)	2 (17)	0
B	Success	6 (19)	5 (42)	6 (100)
	Failure	25 (81)	7 (58)	0
C	Success	0	2 (17)	6 (100)
	Failure	31 (100)	10 (83)	0

*Ranges represent values within 1 SD of the mean corresponding to outcomes Criteria C.

Values represent [n (%)].

PER indicates passive external rotation.

close follow-up to allow time for additional interventions is required to optimize function and minimize glenohumeral dysplasia.

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