An early shoulder repositioning program in birth-related brachial plexus injury: a pilot study of the Sup-ER protocol

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Abstract

Background Birth-related brachial plexus injury (BRBPI) occurs in 1.2/1,000 births in British Columbia. Even in children with “good” recovery, external rotation (ER) and supination (Sup) are often weaker, and permanent skeletal imbalance ensues. A preventive early infant shoulder passive repositioning program was created using primarily a novel custom splint holding the affected arm in full ER and Sup: the Sup-ER splint. The details of the splint and the shoulder repositioning program evolved with experience over several years. This study reviews the first 4 years.

Methods A retrospective review of BCCH patients managed with the Sup-ER protocol from 2008 to 2011 compared their

recovery scores to matched historical controls selected from our database by two independent reviewers.

Results The protocol was initiated in 18 children during the study period. Six were excluded due to the following: insufficient data points, non-compliance, late splint initiation, and loss to follow-up. Of the 12 matches, the Sup-ER group final score at 2 years was better than controls by 1.18 active movement scale (AMS) points ($p=0.036$) in Sup and 0.96 AMS points in ER (but not statistically significant ($p=0.13$)). Unexpectedly, but importantly, during the study period, zero subjects were assessed to have the active functional criteria to indicate brachial plexus reconstruction, where previously we operated on 13 %.

Conclusions Early application of passive shoulder repositioning into Sup and ER may improve outcomes in function of the arm in infants with BRBPI. A North American multi-site randomized control trial has been approved and has started recruitment.

Keywords Birth-related brachial plexus injury · Obstetrical brachial plexus palsy · Splint · Sup-ER · Protocol · Sup-ER splint

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Introduction

Birth-related brachial plexus injury (BRBPI) occurs in 0.9–4.6/1,000 births globally [6, 10, 13, 16, 18, 22] and 1.2/1,000 births in British Columbia [7], similar to other North American published figures [6, 18]. Spontaneous recovery to functional levels is reported historically to occur in anywhere between 50 and 92 % of patients [9, 10, 16, 19, 22]. However, the historical literature is inconsistent in defining what is considered functional and what measurement scales to use. By current standards, a subset of these children, often quoted to be about 25 %, present with nerve injuries severe enough

that they are offered surgical reconstruction with nerve grafts and/or nerve transfers. Distal nerve transfers are also part of the modern approach to management of patients with BRBPI, however, significant variations in protocols and clinical guidelines determining treatment goals and end points exist center-to-center [21].

In children with otherwise “good” BRBPI recovery, there are very commonly impairments in the passive and active range of both supination (Sup) and shoulder external rotation (ER) [12, 13, 16, 24]. Theories of why this occurs include the following: imbalance of strength in muscles with recovering compared to non-injured nerves, relative agnosia affecting development during recovery of joint sensation and movements, direct shoulder capsular injury during birth, and imbalanced functional reinnervation of some muscles. Balanced growth of the shoulder is negatively affected by the dominance of an internally rotated position. This deformity has been noted to be progressive with age and appears early in infancy [26]. Hypoplasia, retroversion, and biconcavity or convexity of the glenoid, and flattening and posterior subluxation of the humeral head can all be consequences. The scapula tends to be elevated and anteriorly rotated. Internal rotation contracture and associated skeletal changes can secondarily prevent full range of even otherwise recovered muscle action leading to significant functional consequences. For example, glenohumeral abduction is limited significantly with the humerus internally rotated, and flexion of the elbow becomes problematic when the abdomen gets in the way of the internally rotated hand [17]. In cases where shoulder pathology exists to a degree that global arm movements are affected, skeletal and tendon transfer surgeries may be recommended to decrease the effective permanent deformity or disability [14, 20, 26], but no surgery recreates close to normal skeletal anatomy.

Upon retrospective review of MRI imaging of the early microsurgical operative candidates in our clinic, we observed shoulder deformity occurring very early, often before 2 or 3 months of age. We also noted that once this growth pattern had become established, it was very difficult to improve or maintain passive range of motion through physiotherapy alone. It was observed that a cycle can become established, where muscle and skeletal restriction of range is associated with significant infant discomfort during stretching and subsequent decreased maximum effective range achieved by parents. More infant growing hours are then spent with the shoulder internally rotated. Later, when the arm may be functioning primarily in a “trumpeting position,” gravity may act to pull the hand consistently downward into even more elbow forward shoulder internal rotation. These deficit differences may increase over time [4, 23].

Early in an infant’s life, BRBPI treatment decisions are most often based on information gleaned from examination of clinical function. Clinically, measuring improvements and rate

of improvements in strength of the upper limb is the most commonly used diagnostic and prognostic tool in the first year of life. The active movement scale (AMS) developed by the Hospital for Sick Children is a commonly used, practical, and validated scale and allows a meaningful graded measurement of active movement [4, 8]. Early deficits in measured active range are usually presumed to be primarily neurological in origin, allowing recommendations for early nerve reconstruction surgery to be based on an infant’s measured deficit in active movement.

We wondered though, especially in Erb’s type palsies, how much the known early architectural changes of the shoulder itself and the prolonged overpowered stretch of imbalanced weaker muscles might contribute as *non-neurological* sources of clinically measured active movement deficits. We hypothesized that if the shoulder structure itself could be more “normalized,” residual deficits in active movement could be more confidently attributed to poor nerve recovery alone and thus nerve surgery would have a more certain impact. Also, if it was possible to prevent or minimize permanent skeletal changes, recommended nerve reconstruction or tendon transfer surgeries would be performed within the most advantageous anatomy for recovery of function. Additionally, the need for later complex reconstructive shoulder surgery might be decreased.

Using the model of skeletal growth and joint congruency changes in developmental hip dysplasia (DDH), it was contemplated that we may similarly be able to prevent permanent shoulder skeletal changes by using a splint to hold the glenohumeral joint in a properly engaged position for a larger percentage of the day. In addition, splinting of congenital clasped thumbs taught us that early passive balanced-position splints alone can allow weaker, overstretched extensor musculotendinous units to recover stronger active function. Thus, we hoped that we could effect improvements in both the skeletal architecture and the relative weakness of external rotators and supinators by using a passive positioning device in infants with BRBPI. Both DDH and clasped thumb splinting begin as close to birth as possible when the diagnosis is made. With brachial plexus injury, given the known changes in shoulder anatomy at 2 to 3 months even in patients with good regular range of motion exercises, we determined the need to start as early as we could confirm injury greater than neurapraxia.

In 2008, we began an ad hoc early shoulder passive repositioning program. With parent feedback and clinical experiences, our criteria evolved significantly over time, eventually being recommended for patients presenting with major weakness or tightness of ER beyond the recovery time period for a neurapraxic injury. We now recommend institution of the protocol if at 6 weeks of age, ER scores $\leq$ AMS 2, or there is significant tightness in passive range of ER. Our team, consisting of surgeon, occupational therapist (OT),

and physiotherapist (PT), designed and administered a novel gentle custom splint constructed to hold the affected limb in full forearm supination (Sup) and shoulder external rotation (ER): the Sup-ER splint. We conjectured that if the arm could be practically, comfortably and safely held for the majority of the day in a position of maximal glenohumeral congruity and with the tightest muscles held stretched, then the normal anatomic growth of the shoulder may be better maintained until recovered nerve-generated active movement returned. Supination, also often a long-term BRBPI weakness, could be co-splinted advantageously. The construction/design of the initial infant splint and the repositioning program algorithm evolved incrementally with experience and feedback over several years. We also became more aggressive with early repositioning with Botox and casting in patients who did not achieve full range with the splint alone. The results were anecdotally very positive but required review. The purpose of this study was to review the pilot group of patients using the evolving Sup-ER protocol.

Materials and Methods

This retrospective review study was approved by the University of British Columbia/Children's and Women's Health Centre of British Columbia Research Ethics Board (UBC C & W REB) approval number H12-00414. The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Splint Design

The first splint was designed for a child with significant passive tightness and poor active motion of ER (2/7 on the Toronto AMS) at 10 months of age and subsequently used as a model for several other infants in the first year of implementation. A betapile torso suit was created to stabilize shoulder rotation by anchoring the humerus to the bodysuit with a Velcro strap. The elbow was then flexed and the arm rotated out into external rotation with a Velcro strap from the ulnar side of a forearm splint. (see Fig. 1). This produced excellent external rotation and supination, but with summer temperatures, sleep was reported to be difficult to impossible in the full bodysuit, negatively impacting compliance. Also, recognizing that there is a propensity for long-term elbow flexion contractures in this population and finding some early minimal elbow flexion tightness in two patients, we decided to alter the splint design. We include this description and our decision to change from it because many therapists understand the flexed arm

Fig. 1 The initial Sup-ER splint design. The prototype betapile torso suit was created to stabilize shoulder rotation by anchoring the humerus to the bodysuit with a Velcro strap. The elbow was then flexed and the arm rotated out into external rotation and supination with a Velcro strap from the ulnar side of a forearm splint

external rotation position seems a more secure way to achieve shoulder correction and should understand its drawbacks.

The current two-part splint design is simple and reproducible and has been in use for the last 3 years. A custom volar thermoplastic elbow extension splint is anchored on the hand extending proximally to just below the axilla, and a separate neoprene waist belt is positioned like a diaper. The arm splint is secured using Fabrifoam SuperWrap (an elasticized wrap with a semi-adherent undersurface), with the forearm positioned in maximal supination. Two Velcro straps hooked or riveted to the lateral elbow and proximal anterior aspects of the splint are secured to the waist belt with the arm in a position of full external rotation at the shoulder. The volar aspects of the splint and arm face outward when correctly applied, with the straps preventing internal rotation (see Fig. 2). Parents are educated in the application technique and wear schedule of the splint, which is modified monthly according to the child's clinical presentation, age, growth, and development over time.

With ultrasound imaging using the technique studied by Vathana et al. [25], we confirmed that while the Sup-ER splint was on, the glenohumeral joint would reposition/reduce and maintain congruity even in patients who presented with U/S confirmed posterior subluxation in the resting position out of the splint. (see Fig. 3).

Early in the period of our pilot study, we significantly varied the starting age and wear schedule of the Sup-ER splint based on clinical issues and parent feedback, gradually

◀ **Fig. 2** The Sup-ER Splint in its current design. A custom volar thermoplastic elbow extension splint is anchored on the hand extending proximally to just below the axilla, and a separate neoprene waist belt is positioned like a diaper. The arm splint is secured using Fabrifoam SuperWrap (an elasticized wrap with a semi-adherent under-surface), with the forearm positioned in maximal supination. Two Velcro straps hooked or riveted to the lateral elbow and proximal anterior aspects of the splint are secured to the waist belt with the arm in a position of full external rotation at the shoulder. The volar aspect of the splint faces outward with the straps preventing internal rotation

arriving at our current recommended protocol: beginning at about 6 weeks of age, initiate almost full time use (22 h/day) for about 1 month, followed by gradual weaning to nights and naps. A full physiotherapy program is continued throughout the weeks of splint use including passive range of motion exercises and encouragement of age appropriate arm use and developmental skills. Total recommended duration of splint use usually ranges from 8 to 12 months. This seems to balance tolerance, compliance, developmental progression, and practicality and provides the most consistent results.

Although many patients achieve good shoulder and supination results using only the Sup-ER splint, we identified a subgroup of patients who had internal rotation imbalance that was stronger than a Velcro splint could correct. Our repositioning protocol has evolved to recognize these patients as early as 4 months of age and provide them with more aggressive repositioning in the form of Botox injection of the pectoralis major and subscapularis and temporary application of an external rotation spica cast. Although we are still working to determine the best balance, we currently believe that 3 to 4 weeks of casting after Botox is sufficient to achieve stretch and initial correction. Following that, the patient may be returned to Sup-ER splint or a Statue of Liberty/external rotation arm spica splint for Sup-ER positioning for the balance of the protocol. Sup-ER protocol endpoint has varied from about 8 months of age to up to 18 months of night use.

Pilot Study Design

The Sup-ER splint was fabricated for 18 children at the BC Children's Hospital from 2008 through 2011. This time period includes the splint in its original design, various modifications, the evolution of timing and wear schedule, and the current Sup-ER protocol. Two of these 18 children were lost to follow-up, two had insufficient data at comparable points to be analyzed, one was excluded because of complete lack of compliance with splint wear, and one initiated splint use after 1 year of age.

Data of the remaining 12 children who underwent early repositioning with the Sup-ER protocol were compared with prospectively documented AMS score data from a historical group of 12 control subjects from our database. Due to the extreme variability of presentation and recovery of this

Fig. 3 Ultrasound image of affected shoulder with arm in and out of Sup-ER splint. Image on left demonstrates the slight posterior positioning of the humeral head relative to the scapular spine and glenoid. Image on the right shows a corrected anterior positioning and decrease in the alpha angle with the arm in splint

population, and the different ages and frequency of retrospective follow-up, this was a challenging task. Control subjects were selected by two independent reviewers and matched by age and AMS scores for Sup and ER at presentation. Fifty percent of the historical controls were chosen identically by both of the reviewers. To create one uniform control group to pair with subjects, we took the remaining 50 % of chosen controls and the Sup-ER subjects who had identical scores for Sup and ER and set the final criterion to include the control subject whose age at initial presentation was closer to the matched Sup-ER subject. Our data collection for the pilot study concluded at the end of 2011 calendar year, with any patients having less than 12 months of data at that date excluded due to insufficient data at comparable points. Therefore, some of the most recent Sup-ER patient data (which benefit from the improvements and consistency in timing and algorithm) are not included in this pilot study, potentially eliminating the strongest results.

Results are summarized and reported using descriptive statistics. Differences in results of ER and Sup at 24 months of age were analyzed using the Mann–Whitney *U* test in IBM SPSS Statistics version 18.0.

Metrics which were not previously collected routinely and therefore incomparable to our historical database were also documented in our Sup-ER protocol patients. The anatomic position of the shoulder in its glenohumeral joint, sonographic confirmation of joint congruency, visible position of the scapula, shape of the glenoid fossa, the carrying position of the arm, passive range of motion, and functional hand position were subjectively assessed in most patients.

Results

The two groups were identically matched at baseline with age mean of 2.15 months in both groups, mean supination of 0.33 AMS score in both groups, and mean external rotation of 0.83 AMS score in both groups.

Supination measured by AMS at age 24 months was 6.00 (SD=1.05) in the Sup-ER group and 4.82 (SD=1.17) in the control group. ER measured by AMS at the same age was 5.60 (SD=1.43) in the Sup-ER group and 4.64 (SD=1.43) in the control group. The comparison of Sup at 24 months between the groups using Mann–Whitney *U* test showed a clinically meaningful and statistically significant AMS improvement of 1.18 ($p=0.036$) in the Sup-ER group. The same comparison performed for ER did not show a statistically significant difference between the two groups ($p=0.132$), although the mean AMS score difference was 0.96, which would be of clinical importance (see Fig. 4).

The change over time graph suggests that the Sup-ER group has an early rapid AMS improvement, followed by a stable linear rise, whereas the control group only shows the linear steady rise in score from the initial time point (see Fig. 4).

The additional metrics which were not collected routinely prior to our Sup-ER protocol and therefore incomparable to our historical database were also anecdotally affected. The anatomic position of the shoulder in its glenohumeral joint, sonographic confirmation of joint congruency, visible position

Fig. 4 Linear change over time from baseline to 24 months for ER and Sup in the Sup-ER and the control group. The graph shows the linear change over time in Sup and ER measured on the Toronto AMS from baseline to 24 months. Note the more rapid improvement in the Sup-ER group over the first 6 months

of the scapula, shape of the glenoid fossa, the carrying position of the arm, passive range of motion, and functional hand position were all positively affected, some to the point of being close to normalized. We did not collect these data in a sufficiently standardized or proactive fashion to report in this pilot; however, we plan for more comprehensive comparable measurements in a larger prospective randomized control study.

We did also note some unexpected results. During the 4-year-study period, ZERO clinic patients were assessed to demonstrate the active functional indications for brachial plexus reconstruction at 3 or 6–9 months of age. We use the Hospital for Sick Children algorithm for clinical active range of motion limitations at 3 and 8–9 months of age to determine recommendations for nerve reconstruction. Our institution has a relatively small clinic population, and historically, we have averaged three reconstructions per year, or about 13 % of new cases presenting to the clinic. In almost 5 years between March 2008 and January 2013, we performed none. A surgical reconstruction done in March 2008 was completed on a 9-month-old patient who had not been treated with the protocol (which started in January 2008). In January 2013, we did our first brachial plexus nerve reconstruction on a Sup-ER protocol patient who had sustained avulsions of C6 and C7 (see Fig. 5).

Adverse Events in Pilot Study

1. Skin sensitivity. Two children were noted to develop skin sensitivity to the thermoplastic splint. This was resolved with the use of stockinette and/or lining the splint with moleskin.
2. Elbow flexion contractures. Two children were noted to develop very mild ($<10^\circ$) early elbow flexion end range tightness with the original flexed arm splint design. Elbow contracture in BRBPI is historically documented as a common recovery pattern [3, 11] and thus may have occurred without Sup-ER splint use. However, this was

one of the considerations leading to the change in splint design. We have not found elbow flexion contractures with the new design.

3. Differential forearm and humeral rotation with elbow valgus position in a patient in the subgroup with more severe tightness of the shoulder. An early elbow extension splint design was used that did not anchor to the hand and had more distal insertion of Velcro strapping. This rotated the forearm and humerus unequally, and the child developed a valgus elbow positioning in the 1-month follow-up. This resolved completely with soft casting in extension, and our current long-arm hand-anchored splint design protects against differential pull.
4. Tightness of the posterior glenohumeral joint. In three patients with prolonged (12 weeks) cast application following Botox injection, almost full internal rotation range of motion was functionally achievable, but with the scapula visibly rotated forward with the arm due to what we presume is shortening of the posterior shoulder girdle or capsule. We have subsequently reduced the amount of casting time post-Botox injection and increased our vigilance of range of motion stretching into stabilized scapula full internal rotation in our more recent patients. Almost all patients in the Sup-ER protocol still show some minor degree of this asymmetry of scapular position when in full internal rotation but usually demonstrate no associated dysfunction and an otherwise excellent resting and functional position (see Figs. 6 and 7).

Discussion

While awaiting maximal nerve recovery, physical therapy (PT) is an important component of BRBPI management. Goals include prevention of joint contractures, strengthening

Fig. 5 Comparison of new BRBPI cases and primary nerve reconstruction surgeries performed at the BC Children's Hospital in the period 1997 to 2012. Our retrospective review showed lack of patients with indications for nerve surgery over the 4 years since the start of the Sup-ER protocol

Fig. 6 Scapular position. Mild posterior capsule tightness may cause the scapula to rotate forward during full internal rotation as demonstrated in this 14-month-old child

Fig. 7 A child with BRBPI at 1 year. This subject who had external rotation of AMS 0 at 2 months and 2 at 4 months was treated with the Sup-ER splint, Botox, and casting. The subject now demonstrates minimal associated dysfunction and an excellent functional position

of recovering muscles, development of sensory stimulation, and improving developmental milestones in the presence of incomplete neuromuscular function. PT strategies for the shoulder may include stretching to maintain full passive glenohumeral range of motion, encouragement of active motion (including functional voluntary use), adjunctive Botox weakening of overpowering muscles, constraint induced movement therapy, splinting, shoulder spica casts, electrical stimulation, and intensified therapy. However, there is presently no consistent data to guide clinicians in the indications and expected outcomes of these various treatment approaches [15, 26].

Chan (2002) describes splinting as one of the most useful modalities to minimize deformities, prevent joint contractures, and substitute loss of motor control following a peripheral nerve injury [5]. Ter Steeg et al. (2003) reported that shoulder bracing for BRBPI was recommended in the first half of the twentieth century, but then advised against it, and subsequently is seldom mentioned in the modern literature [24]. Existing literature does not clarify why there was a reversal of recommendations, but these papers retrospectively comment that splinting may have led to difficult contractures in the externally rotated and abducted position. The authors discussed the differing styles of bracing reported over time with the most currently documented position recommended in 1962 by Wickstrom as complete external rotation, 45° forward flexion and 70° abduction [27]. No reports on bracing techniques are noted in the literature since their

rejection by Adler in 1967 [1], with the exception of Aston and Hardy in 1979 [2] and 1981 [10], who reported that brace use could lead to external rotation and abduction contractures, especially in children who had no additional physiotherapy during the bracing period. While not specifically documented, one can also hypothesize that a large hard splint or cast repositioning the shoulder of an infant full time into external rotation, flexion and abduction, may not have been well accepted by patients or families. Ter Steeg, et al. (2003) concluded that the use of arm braces “during the period of flaccid palsy of the shoulder muscles be reconsidered but could only be justified after a randomized clinical trial” [24].

The idea of developing a soft wrap removable system to favorably position an infant’s shoulder in external rotation and supination early enough in their recovery to prevent permanent joint changes, but also allow ongoing PT, was appealing to our team. In our clinic, we observed that in children with BRBPI, it was effective and relatively easier to position the arm into external rotation only rather than into the shoulder abduction and flexion positions of historical splints. Supporting this was the sonographic confirmation that external rotation corrected the posterior subluxation of the glenohumeral joint. We also theorized that a soft wrap system would be safer and more readily accepted by families of infants than a rigid device.

We found that family compliance, acceptance, and efficacy of splint use were improved if the splinting process was initiated well prior to 3 months of age and first introduced for almost full time use (22 h/day). While it is not impossible to start at a later age, babies older than 6 months can often overpower the Velcro strapping, or have already developed imbalances, tightness, or attitudes that make the soft wrapping system difficult to introduce as effectively. In addition, babies closer to the newborn age are less developmentally active with extended periods of sleep time, and thus opportunities for passive splinting are less likely to interfere with normal development. While our goal for recommended repositioning is arbitrarily to the age of 10–12 months, some children do not tolerate it beyond 8 months, while others have successfully used a splint during sleep until 16 to 18 months of age. It is very important to note that although we recommend the patient initially be splinted for about 22 h/day in the first month, the remaining hours of the day are always at least partially apportioned to physiotherapy for full range of motion and sensory stimulation of all the joints of the upper limb. This especially includes hand to hand and hand to face interactions, and internal rotation and pronation in an effort to reduced posterior capsule and pronation tightening. Lack of stretching into these positions may contribute to stiffness and the potential for contractures as seen historically. As the patient’s active and passive range of motions improve, splint use is gradually decreased during waking hours, until it is worn only during nights and naps. For patients who show continued passive

tightness or shoulder joint positioning not corrected by Sup-ER splint application, we recommend Botox injection on the pectoralis major and subscapularis muscles and a shoulder spica cast as early as 4 months of age.

Our goal is to demonstrate both skeletal and muscular functional improvements. We, like others, have observed that there is an intrinsic imbalance of the strength of pronators and internal rotators over the typically weaker external rotators and supinators.⁸ By protecting against overstretching by intrinsically stronger muscles, we hope that supinator and external rotator muscles may regain strength in a splinted position similar to what may happen in congenital clasped thumb. In our Sup-ER patients, we have noted a large improvement in shoulder external rotation between 6 and 8 months of age. Skeletally, the anatomic development of the glenohumeral joint may be optimized by the Sup-ER protocol similar to the way the Pavlik harness encourages modeling and growth of the hip joint.⁴ We have also used this splint successfully in a few cases of unilateral upper extremity arthrogryposis where internal rotation imbalance has been a primary problem.

As the Sup-ER protocol does not affect factors that should change the rate of nerve recovery nor are we specifically treating movements used to determine primary surgical reconstruction candidacy (i.e., elbow flexion, distal arm function), we did not anticipate the change to zero candidates for primary nerve surgery in our study group. This is not likely to be entirely attributable to the Sup-ER protocol. Examination of our clinic database shows that patients with the more extensive or lower trunk injuries that would almost automatically become surgical candidates were underrepresented in our patient census for those years. However, the more common moderately severe Erb's palsy patients were typically well represented in the Sup-ER group study period. Based on historical rates for these patients, we would have expected two or three per year to have achieved AMS scores and "cookie test" results that would support surgical recommendations; we saw none. We will continue to explore the effect that optimizing musculoskeletal anatomy of the shoulder has on determining brachial plexus nerve reconstruction guidelines and eventual outcomes. It seems possible that perhaps even in infancy, more of the measureable arm function depends on shoulder balance and shape than we previously credited. Inability to fully abduct the shoulder or even fully flex the elbow may be attributable to not only the degree of nerve injury but also to the shoulder anatomy. We are also now exploring the concept of limiting required nerve surgery to more distal nerve transfers in those patients whose active shoulder motion is more normal than would warrant full brachial plexus exploration and grafting. Since the study period ended, two of our Sup-ER patients have had good shoulder outcomes and successful brachial plexus rehabilitation with only distal nerve transfers (i.e., Oberlin's), avoiding opening the plexus itself.

This pilot study is limited by the size of our clinic and its catchment of about 40,000 births per year, variability of the treatment protocol especially in the early years and by potential confounders not eliminated in the historical database matching process. Our potentially most demonstrative later results are excluded by the dates of study period. We are still learning what the ideal length of time of repositioning might be, whether the nerve surgical indicators recommended by previous authors should be modified in Sup-ER patients and what the long-term expectations may be. Our oldest Sup-ER patients are not close to fully grown. We recognize the need for a formal comparison of this protocol with "standard" therapy and for a process that will minimize single center developer bias. We have recently been approved by our institutional ethics review board to collect data in a multi-center randomized control trial of the Sup-ER protocol, with several centers in North America currently reviewing the protocol in anticipation of participation.

Conclusion

In BRBPI, consistent shoulder and forearm passive repositioning into external rotation and supination during infancy using primarily splints and active physiotherapy may have a positive effect on balanced shoulder growth, muscular function, and prognosis for a long-term outcome. It may optimize the active functional expression of nerve recovery and has the potential to limit the need for complete nerve reconstruction of the brachial plexus. More formalized prospective study is required and is currently in progress.

Centers interested in participating in the randomized control trial or in acquiring the full protocol details may contact the authors for additional information.

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Conflict of Interest Cynthia Verchere declares that she has no conflict of interest.

Kim Durlacher declares that she has no conflict of interest.

Doria Bellows declares that she has no conflict of interest.

Jeffrey Pike declares that he has no conflict of interest.

Marija Bucevska declares that she is working full time as a clinical research coordinator for the University of British Columbia (UBC). As part of her employment, she worked on this study and received pay from UBC but does not declare conflict of interest.

Statement of Human and Animal Rights CV, KD, DB, JP, and MB state that the procedures followed were in accordance with the ethical standards of the University of British Columbia/Children's and Women's Health Centre of British Columbia Research Ethics Board (UBC C & W REB) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Statement of Informed Consent Deemed as not essential, subjects' identifying details were not included in this manuscript.

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