ORIGINAL ARTICLE

Kinematic Assessment of the Upper Extremity in Brachial Plexus Birth Palsy

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Abstract: Children with brachial plexus birth palsy (BPBP) may have shoulder external rotation and abduction weakness that can restrict activities of daily living (ADLs). Static range of motion measurements may not measure ADL restrictions. Motion analysis has been used to quantify gait limitations and measure changes associated with treatment. The purpose of this study was to determine whether upper extremity motion analysis (UEMA) can measure the differences in shoulder motion during ADLs between children with BPBP and normal children. Following a previously described UEMA protocol, 55 children with BPBP and 51 normal children (control group) were studied. Kinematic data of selected ADLs were collected before surgery. UEMA was used to measure statistically significant differences between children with BPBP and control subjects for all planes of shoulder motion in all activities tested. The authors conclude that UEMA can discriminate between children with BPBP and control subjects during selected ADLs, and suggest that UEMA can also be used to measure the effects of surgical interventions in children with BPBP.

Key Words: brachial plexus, motion analysis, upper extremity, 3D kinematics

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Brachial plexus birth palsy (BPBP) occurs at a frequency of 1 to 4 per 1,000 live births.[2,4] While many children with BPBP have spontaneous recovery, at least 20%[5] develop significant functional deficits of the affected limb. The upper trunk of the brachial plexus is most commonly affected,[2] leading to weakness of the biceps, deltoid, and external rotators of the shoulder, with eventual development of internal rotation contracture. A significant number of children with BPBP have elbow flexion contractures despite weak elbow flexors[1,11] but associated with triceps weakness in children with significant C7 injury. Active external rotation is essential for normal elevation of the hand to reach the face and head to perform activities of daily living (ADLs) such as feeding and grooming.[2] Development of an internal rotation contracture may lead to bony changes in the glenohumeral joint and eventual posterior shoulder dislocation, which may further restrict motion and function.[2,9,11,14]

Current methods of assessment do not fully evaluate the kinematics of ADL performance. To determine the extent of shoulder weakness and contracture, the child's passive and active shoulder range of motion (ROM) are measured in each plane (forward flexion/extension, abduction/adduction, and internal rotation/external rotation). These static single-plane measurements incompletely evaluate the ability of the child to perform ADLs. Other tests, such as the Mallet scale,[8] rate the child's ability to reach the face and head but do not show which motions the child used to place the hand on the face or head, or whether he or she used compensatory strategies (eg, neck and trunk motion) to achieve the task.

To improve the ability to reach the face, head, and overhead for children with limitations due to BPBP, shoulder external rotation tendon transfer (ERTT) or humerus external rotation osteotomy is performed. Indications for ERTT include good deltoid strength and retained shoulder passive ROM; because passive ROM tends to diminish with age (as the child develops internal rotation contractures), this operation is usually performed for children before 8 years of age.[6,7,13] In the older child with good deltoid strength, humerus external rotation osteotomy has been used to improve arm position.[3] Both of these interventions have been qualitatively associated with improved ability to reach the face and head, but quantification of improved ability to perform ADLs has not been reported.

The development of a reproducible tool for the pre- and postoperative evaluation of patients is a critical step in the assessment of outcomes of current interventions and the design of future prospective studies.[14] The use of motion analysis for evaluating the lower extremity is widely accepted. Motion analysis is a noninvasive and painless technique that allows evaluation of multiplanar motion during functional activity. A biomechanical model for evaluating the upper extremity was recently described by Rab et al.[12] This model allows for reproducible functional evaluation of the upper extremity in three dimensions during the performance of selected activities. The purpose of this study was to determine whether this technique could be used to measure differences between the control group and children with BPBP who were selected for surgical reconstruction.

Study conducted at Shriners Hospitals for Children, Northern California, Sacramento, California.

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MATERIALS AND METHODS

Between December 1998 and July 2003, we studied 55 patients with brachial plexus birth palsy who were scheduled to undergo surgical treatment with ERTT (49 patients) or humerus external rotation osteotomy (6 patients) using the UEMA protocol described below. The children ranged in age from 4 to 18 (mean age 7.5) years. Patients undergoing ERTT had a mean age of 7.1 years, and children undergoing humerus rotation osteotomy had a mean age of 12.8 years. Thirty patients were girls and 25 were boys. During this same period, 51 controls were tested in the same laboratory using the same UEMA protocol. Control subjects ranged in age from 5 to 18 (mean age 11.3) years. This prospective study was approved by the University of California Davis Medical Center Human Subjects Review Committee.

A standardized three-dimensional (3D) video camera-based technique was used to record upper extremity motion based on a 10-segment biomechanical model (head, neck, trunk, pelvis, left upper arm, right upper arm, left lower arm, right lower arm, left hand, right hand).[12] Eighteen retroreflective skin markers were placed over easily palpable and reproducible bony landmarks of the upper extremity. The landmarks were located over areas with thin subcutaneous tissue that is relatively fixed to the underlying skeleton, thus minimizing marker movement artifact. Data were recorded using an eight-camera Motion Analysis ExpertVision system and the associated software (Santa Rosa, CA). Subjects were asked to attempt to perform three selected movements representing ADLs to demonstrate upper extremity function. These simulated ADLs were based on self-care requirements and environmental interaction and were as follows: attempting to place the hand on top of the head (to groom hair), high overhead or reach (to throw or climb), and to the back pocket (to perform perineal hygiene) (Figs. 1–3). Start position was defined as relaxed resting position. Subjects were asked to attempt to perform each ADL from the start position, complete the ADL, and return their arm to their side. For children with BPBP, each ADL was performed with the unaffected limb followed by the affected limb. For control subjects, each ADL was performed with the dominant limb followed by the nondominant limb. It was acknowledged that children with BPBP might be unable to achieve the desired position, so their best effort was recorded. Kinematic representation of the movement pattern about each axis of motion (flexion/extension, abduction/adduction, external rotation/internal rotation) during each activity was obtained. Sequential angular displacement for each joint was calculated using the sequence of flexion/abduction/external rotation. The magnitude of individual angular displacements is highly dependent on this arbitrary sequence (see Appendix). The techniques and its use and limitations are discussed in detail in the referenced article.[12]

The results were recorded as degrees of angular excursion, with positive values representing joint motions of shoulder flexion, abduction, external rotation, and forearm pronation and negative values representing joint motions of shoulder extension, adduction, internal rotation, and forearm supination. Values were recorded during the entire movement and statistically analyzed at the point at which the activity was achieved. Two-tailed Student *t* tests were used for analysis. Type I error was set at 0.05.

FIGURE 1. Child with brachial plexus birth palsy, left side affected, performing hand-to-head task. A, Unaffected limb. B, Affected limb.

RESULTS

The UEMA technique described above measured statistically significant differences in motion between children with BPBP and control subjects (Table 1). For the high reach activity and hand-to-head activities, children with BPBP exhibited statistically significant decreases in shoulder abduction and external rotation compared with control subjects. Significant differences were also seen in shoulder and elbow flexion, but patterns differed between the two movements. For high reach, children with BPBP had less shoulder flexion and more elbow flexion. For the hand-to-head movement, children with BPBP had more shoulder flexion and

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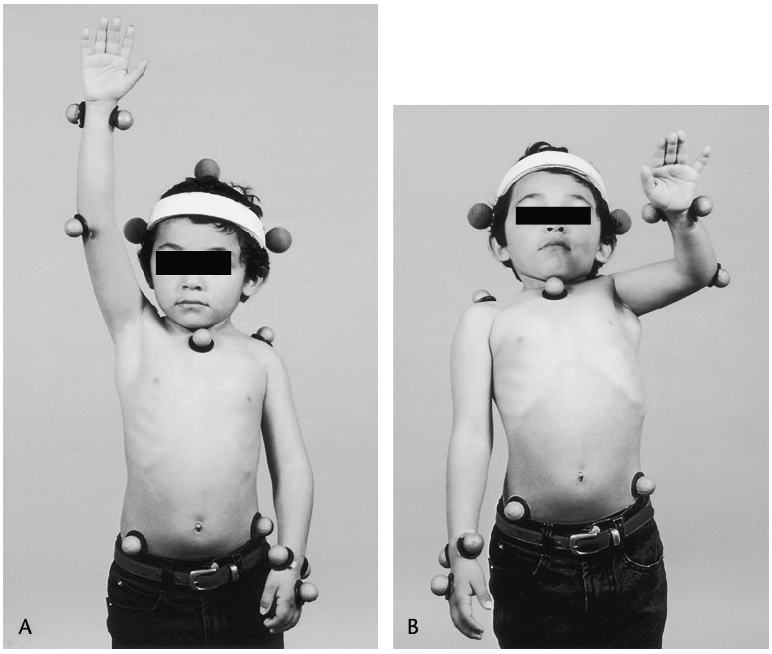

FIGURE 2. Child with brachial plexus birth palsy, left side affected, performing high-reach task. A, Unaffected limb. B, Affected limb.

less elbow flexion. Neck flexion was significantly increased in the BPBP cohort for the hand-to-head movement (see Fig. 1). During hand to back pocket, children with BPBP demonstrated statistically significant reduction in shoulder extension, external rotation, elbow flexion, and forearm supination.

Elbow flexion contractures were noted clinically in 18 of the 55 patients. Mean elbow flexion contracture in these patients was 19 degrees (range 5–45 degrees). Passive elbow ROM data were not available for four additional children in the BPBP cohort.

DISCUSSION

Our findings are consistent with those of previous studies and show loss of active shoulder motion during simulated ADLs in children with BPBP.[2,5,11] The UEMA protocol used in this study documented significant differences in all three planes of shoulder motion in each of the ADLs tested.

Despite their shoulder weakness, children with BPBP used more shoulder flexion or abduction in some ADLs than control subjects (see Table 1). However, for all ADLs studied, children with BPBP used less shoulder external rotation than controls.

FIGURE 3. Child with brachial plexus birth palsy, left side affected, performing hand-to-back-pocket task. A, Unaffected limb. B, Affected limb.

TABLE 1. Amount of Joint Motion Required to Perform Selected ADLs

	High Reach		Hand to Head		Hand to Back Pocket	
	BPBP	**Normal**	**BPBP**	**Normal**	**BPBP**	**Normal**
Shoulder flexion	104* (28)	139 (11)	96* (28)	83 (14)	−14* (16)	−49 (8)
Shoulder abduction	27* (9)	32 (11)	29* (10)	39 (13)	21* (12)	4 (8)
Shoulder external rotation	76* (29)	−20 (20)	−88* (30)	−28 (15)	−63* (33)	−30 (12)
Elbow flexion	35* (23)	22 (8)	88* (18)	110 (9)	43* (25)	66 (17)
Forearm pronation	3* (32)	67 (28)	−33 (30)	−41 (16)	−36* (54)	−64 (16)
Trunk flexion	−26* (7)	−21 (8)	−29* (7)	−20 (6)	13 (8)	15 (5)
Neck flexion			21* (12)	−10 (10)		

Data are given in degrees. Mean values are reported with standard deviations in parentheses.
*Significantly different from normal ($P < 0.05$).

In addition to changes in arm position at the time of task achievement, the pattern of movement during each activity was qualitatively different from the normal pattern for children with BPBP. For example, during high reach, controls display a "double-bump" pattern of elbow flexion, with increased flexion at the beginning of the motion followed by near full extension at the moment the task is achieved and flexion of the elbow as the arm is brought back to start position (Fig. 4). In contrast, children with BPBP begin the motion with a greater degree of elbow flexion and slightly increase the elbow flexion at the moment the task is achieved. This increase in elbow flexion may represent the patient's attempt to increase the hand "height" in compensation for limited shoulder flexion (see Fig. 2). The etiology of elbow flexion contractures in BPBP is unclear. Thirty-three percent of children with BPBP in this study had elbow flexion contractures, a lower proportion than noted by Ballinger and Hoffer.[1] In their cohort of 38 children with BPBP, 34 had elbow flexion contractures, with an average of 19 degrees.

Another movement pattern difference was seen in shoulder abduction during the hand to back pocket task. Control subjects display a "double-bump" pattern representing increasing shoulder abduction at the start of the motion as they clear their hip, followed by adduction to a nearly neutral position as they reach their back pocket, followed by abduction once more as they return to the starting position (Fig. 5). Children with BPBP perform the motion with a greater degree of shoulder abduction but are limited in their dynamic range. Most children with BPBP were unable to reach their back pocket. They tried to "swing" their arm around their back, thus accounting for the initial increased shoulder abduction, but typically reached only their side (see Fig. 3).

The absolute values of angular displacement about the three axes of motion are highly dependent on the sequence in which those motions occur. We arbitrarily selected a sequence that began with flexion to maintain compatibility with previous studies in our laboratory. Had we begun the sequence with abduction, values would be different, although they all reflect the same 3D position of the joints of the upper extremity. A further discussion of this issue is available in the Appendix.

This study shows that the UEMA protocol used can quantify statistically significant differences in arm position during movements representing ADLs between control subjects and children with BPBP. It also identifies and quantifies the compensatory patterns used by children with BPBP in performing these movements.

There is inherent variability in upper extremity motion, even among normal children, and this may account for the wide standard deviations seen in the data. In addition, it may be difficult to evaluate an uncooperative or young child's level of function in a reproducible manner[14]—and the BPBP cohort had a younger average age than the control cohort. However, this study has shown that the UEMA protocol can reliably differentiate children with BPBP selected for surgical reconstruction from normal children. This study lays the

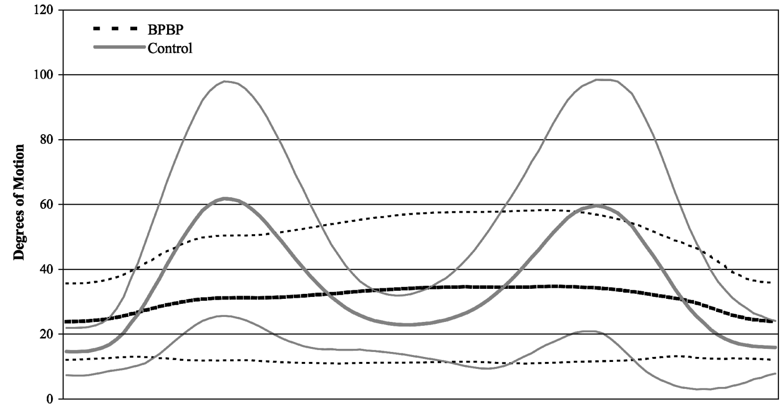

FIGURE 4. Graph of elbow flexion in normal subjects (solid) versus BPBP (dashed) during high-reach activity. *x* axis represents time to complete activity; *y* axis represents degrees of motion. Thick lines represent mean values; thin lines represent ±1 SD.

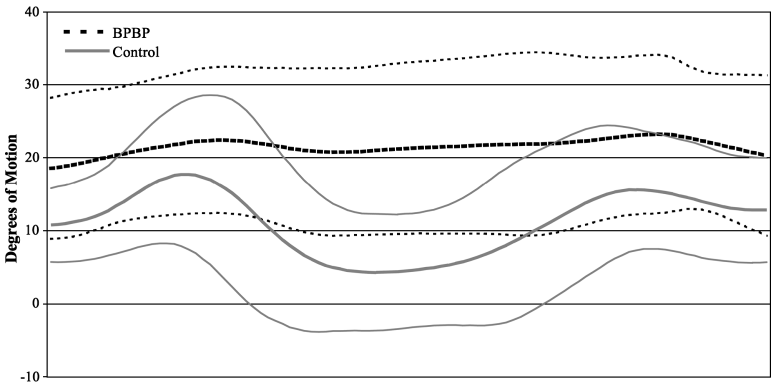

FIGURE 5. Graph of shoulder abduction in normal subjects (solid) versus BPBP (dashed) during hand-to-back-pocket task. *x* axis represents time to complete activity; *y* axis represents degrees of motion. Thick lines represent mean values; thin lines represent ±1 SD.

groundwork for the use of the UEMA protocol to evaluate the effects of surgical reconstruction in children with BPBP, including changes in arm position and compensatory strategies used during ADLs. The compensatory neck and trunk movements noted in certain ADL tasks appear to be quite variable and are the subject of further investigation in our laboratory.

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APPENDIX

Measurement of 3D angular movement can appear confusing because the values of the angular displacements are highly dependent on the sequence of movements required to move from a resting base position to the new position of interest. Surgeons have intuitively recognized this phenomenon in their descriptions of shoulder motion. Ninety degrees of shoulder flexion followed by 90 degrees of abduction, does not result in the same position as 90 degrees of shoulder abduction followed by 90 degrees of flexion. This has been termed "Codman's paradox," but it is not really paradoxical mathematically.[10]

The rotation sequence chosen for this study was flexion, followed by abduction, followed by external rotation. We chose this sequence to remain consistent with human gait studies of the lower extremity and to mirror the methods of data analysis that have been used in our laboratory for normal subjects performing ADLs. This sequence appears logical and realistic for activities where the major motion is sagittal, such as forward high reaching or reaching to the back pocket.

However, when the subject abducts and externally rotates the arm (eg, in a side wave), this rotation sequence produces numbers that are mathematically accurate but intuitively confusing. In such instances of activities that are performed in the frontal (coronal) plane, using a sequence of abduction/flexion/external rotation produces numbers that appear more understandable to clinicians.

Since both methods are mathematically equivalent, we have chosen to maintain uniformity of our data by using only the former rotation sequence. A more extensive discussion of this topic and a survey of the various analytic techniques used for upper extremity kinematic analysis can be found in reference 12.