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# SHOULDER STRENGTH PROFILES IN CHILDREN WITH AND WITHOUT BRACHIAL PLEXUS PALSY

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## Abstract

**Introduction—**We characterized bilateral shoulder strength and the balance of antagonist/agonist muscle pairs in children with brachial plexus palsy (BPP) and with typical development (TD).

**Methods—**In 15 children with unilateral BPP and 11 with TD, bilateral maximal isometric shoulder strength in flexion/extension, internal/external rotation, and abduction/adduction was recorded using a hand-held dynamometer. Correlation between strength and active range of motion were evaluated using the Mallet score.

**Results—**Children with BPP had strength asymmetry in all muscles, whereas children with TD had significant strength asymmetry for flexors and abductors. In children with BPP, extensors and external rotators were the weakest muscles, leading to sagittal and transverse plane muscle imbalances. Higher strength values were related to better active range of motion.

**Conclusions—**This study highlights the importance of documenting shoulder strength profiles in children with BPP which may help predict deformity development.

### Keywords

children; brachial plexus palsy; shoulder; strength; imbalance

Muscle strength, the maximum voluntary force generated by a muscle group, is related positively to functional activities in children with physical disabilities.[1–3] In children with obstetrical or birth-related brachial plexus palsy (BPP), the nerve root involvement is most commonly C5 to C7. Varying degrees of neurologic injury and recovery lead to strength impairments in the affected upper limb that produce a complex profile of muscle weakness at the shoulder level.[4,5] Because appropriate muscle activation and coordination are important for both shoulder mobility and stability,[6] loss of strength may lead to complex tri-planar biomechanical shoulder dysfunction. In approximately 30% of cases, shoulder muscle weakness and imbalance leads to muscle contracture and glenohumeral migration.[7–10] In

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particular, imbalance between shoulder external and internal rotators is believed to be one of the main causes of glenohumeral migration.[11,12]

Therapeutic interventions in children with BPP focus typically on restoration of a more physiologic balance of muscle length and strength to prevent or treat joint deformity, e.g., muscle stretching or strengthening, botulinum toxin injection, and muscle transfer or lengthening.[4,5,13] Clinical choice of therapies may depend on an individual patient's passive/active range of motion, the degree of joint deformity, and functional or esthetic consequences.[4,5] Although shoulder muscle strength and balance profiles are central to understanding shoulder dysfunction and the pathogenesis of joint deformity, they are rarely reported in this population and thus are not typically part of the clinical examination and decision making process. Because bones remodel based on the stresses placed on them,[14] individual strength profiles may be useful for predicting subsequent bony deformity. A comprehensive assessment of shoulder strength and balance in children with BPP would provide a better understanding of shoulder dysfunction and may help target muscles groups for prevention or corrective interventions.

The aim of this study was two-fold: (1) To report and compare the shoulder strength and strength balance profiles of the nondominant and dominant shoulders of children with BPP and typical development (TD). Our hypothesis was that the impaired shoulders of children with BPP would be weaker than the contralateral shoulders in all directions, with the greatest difference in external rotation. For this comparison to be valid, we also evaluated whether there was a between-side asymmetry of shoulder strength in children with TD and whether strength values in the unaffected shoulder of children with BPP was different from those in the dominant shoulder of children with TD. (2) To test the hypothesis that shoulder strength is related to active shoulder range of motion in children with BPP.

## MATERIALS AND METHODS

### Participants

This study was an observational case-control study. The children with unilateral brachial plexus palsy (mean age=11.2 years, SD=3.7) were recruited according to the following inclusion criteria: age 5–18 years inclusive, unilateral brachial plexus palsy at birth and ability to flex and abduct the impaired arm at least 30° to allow partial performance of the movement tasks. Exclusion criteria were as follows: any other significant neurological or orthopedic impairment or injury, surgery in the past 1 year, botulinum toxin injections to the upper extremities within the 6 previous months, and inability to follow verbal direction. Subject recruitment was performed using the NIH Protocols at Clinicaltrials.gov and by providing a descriptive flyer, approved by the institutional review board, to local physician and physical and occupational therapist practices who were likely to follow patients with obstetrical BPP and typically developing children. Some of the typically developing children were siblings of children with BPP or children of NIH staff not associated with the protocol or identified through the NIH recruitment office. Five children with BPP had undergone prior muscle transfer surgery (teres major transfer) or release (subscapularis), and 1 had undergone acromioplasty. Four female and 7 male controls in the same age range were enrolled (mean age=11.1, SD=2.7). The Narakas classification,[15] which groups the type of nerve involvement into 1 of 4 categories, the Mallet score,[16] which assesses active range of motion (see below), and anthropometric characteristics of the samples are listed in Table 1. No statistically significant differences were found between the 2 samples for age, height, mass, or body mass index.[17] The study was approved by the institutional review board at the Clinical Center, National Institutes of Health, Bethesda, MD. Written consent was obtained from each participant over age 18 years, assent was obtained for children over age 7 years, and parental or legal guardian consent was obtained for children under age 18 years.

## Hand-Held Dynamometer Assessment

Strength was recorded using a hand-held dynamometer (HHD) (JTECH COMMANDER POWERTRACK II), which allows for a relatively quick quantification of isometric strength in various positions. HHD-based assessment has shown good to excellent criterion validity with motorized dynamometer (ICC=0.78–0.93) and good to excellent intra- and inter-rater reliability (ICC=0.93–0.97) for assessing strength in children with TD[17–22] and children with Duchenne muscular dystrophy.[23]

To improve consistency between trials, sides, and children, the following items were standardized[22]: (1) position of the child, observer, and HHD, (2) order of muscle tests, and (3) verbal encouragement. The same observer performed all assessments in the 2 groups, which has been shown to improve the reliability of HHD assessment. After a time of familiarization with the set-up and a warm-up, children were placed on the examination table in a position that minimized trunk compensation. The warm-up included a series of slow active shoulder stretches in both arms and in all 3 planes for approximately 5 min. Table 2 describes the standardized positions according to the direction tested. For all tasks, children were asked to push “as hard as you can” without moving the elbow and using the shoulder as much as possible. To prevent any upper-arm compensatory movement, a strap held the elbow close to the body during the internal/external rotation assessment.

Each child underwent 3 trials of a maximal voluntary isometric contraction lasting at least 3 s in flexion/extension, internal/external rotation, and abduction/adduction of both shoulders. Before each series of 3 trials, children were asked to perform a submaximal contraction as a warm up and to ensure that the task was well understood and joint stabilization was adequate. To minimize fatigue, children rested at least 10 s between trials and at least 1 min between directions. The tester held the HHD in a stationary position with the subject pushing against the HHD, previously described as a “make test,” which has been shown to be more reliable and less uncomfortable than a “break test.”[19,22] The dominant side was assessed first, and the order of testing was set as flexion, abduction, external rotation, internal rotation, and adduction/extension. A standardized rather than random order of testing was preferred for several reasons; it minimized the number of position changes (prone or supine) as well as placement/removal of a stabilizing strap used for assessment of internal/external rotation, thereby decreasing the time required for strength assessment. We also thought this would lead to more consistent results within a muscle group, because we were comparing between limbs and subject groups, not muscles (i.e., any fatigue or attention effects would likely be more similar within a muscle with a fixed rather than random order). No children complained about discomfort during testing.

Three trials in each direction were recorded in Newtons (N). This force was multiplied by the distance between the posterior acromion and the lateral epicondyle for flexion, abduction, adduction, and extension to obtain a moment in Newtonmeters (Nm). For external and internal rotation, the force was multiplied by the distance between the lateral epicondyle and the radial styloid. The rationale was to control for potential between-side size asymmetry in children with BBP.[24] Moment values were divided by the mass of the child (Kg) for normalization. The maximum value of the 3 trials was used in the analysis.

### Mallet Score

Active ranges of motion in flexion and abduction and for hand to head, hand to mouth, and hand to spine tasks were evaluated using the Mallet score. This classification is widely used and has shown good reliability in children with BPP.[16,25] For each of the 5 motions, performance was assigned a score from 1 (no motion) to 5 (symmetric range). The smallest total score possible (5) reflects a very limited range of motion, and the greatest total score possible (25) reflects a typical range of motion.

### Statistical Analysis

The data were analyzed using SPSS v20. A signed rank Wilcoxon paired test was used for between side comparisons, and a Mann Whitney U test was used to compare groups (BPP vs. TD). The level of significance was set at $P<0.05$. Correlation between strength and the Mallet scores was performed using a Spearman rho coefficient ($r_s$).

## RESULTS

### Strength Values: Between-side Differences within Groups

In children with BPP, muscles in the impaired shoulder showed significantly less strength than muscles in the unaffected shoulder in all directions (Table 3). Extension and external rotation were the weakest directions, showing a mean between-side difference [(impaired shoulder − unaffected shoulder) over unaffected shoulder] of −76.5% (*P*=0.001) and −72.2% (*P*=0.001), respectively. Flexion and abduction were the strongest directions, showing differences of −30.8% (*P*=0.009) and −34.5% (*P*=0.001), respectively. In children with TD, significant differences were also found between shoulders in flexion and abduction with mean percentage of difference [(nondominant − dominant) over the dominant shoulder)] of −10.2% (*P*=0.041) and −8.2 (*P*=0.017), respectively; however other directions showed no differences between sides.

### Strength Values: Between-group Differences within Sides

The impaired shoulder in children with BPP showed significantly lower values in extension (−65.7%, *P*=0.002), external rotation (−65.2%, *P*=0.0001), and internal rotation (−21.9%, *P*=0.02) than the nondominant shoulder of children with TD. Of interest, there were no significant group differences in flexion, abduction, or adduction, in contrast to the comparison between sides in children with BPP. The greater strength differences seen between sides in children with BPP were also explained in part by the larger mean strength values of the unaffected side in BPP in comparison to the dominant side of children with

TD. However, only strength in adduction was significantly higher on the unaffected shoulder in BPP compared with children with TD (Table 4).

### Tri-planar Shoulder Balance

Strength ratios for antagonist muscle pairs in each of the 3 planes (arbitrarily calculated here as extensors over flexors, abductors over adductors, and external rotators over internal rotators) were computed for each arm to assess whether the balance of muscle forces across the shoulder joint were similar between sides and groups (Table 5). In the impaired shoulder of children with BPP, strength in extension was 29.3% of strength in flexion, as compared to a ratio of 78.2% on the dominant side ($P = 0.002$) and 85.4% on the nondominant side in children with TD ($P = 0.001$). Also, the strength in external rotation was 45.5% of the strength in internal rotation, whereas this ratio was 76.8% in children with TD ($P = 0.001$).

### Strength and Active Range of Motion

Overall mean strength for all 6 directions correlated significantly with the total of the Mallet score ($r_s = 0.66$, $P < 0.01$). The strength measured in external rotation correlated significantly with active range of motion in external rotation ($r_s = 0.59$, $P < 0.05$), and strength measured in extension ($r_s = 0.62$, $P < 0.05$), adduction ($r_s = 0.62$, $P < 0.05$), and internal rotation ($r_s = 0.81$, $P < 0.001$) correlated significantly with the hand to spine range of motion.

## DISCUSSION

This study characterized shoulder strength and agonist/antagonist muscle balance profiles of the nondominant and dominant upper-limbs of children with BPP and TD. We found that the impaired shoulder has significantly less strength than the unaffected shoulder in all directions, especially in extension and external rotation. Children with TD also have evidence of between-side strength asymmetry, but less than that observed in children with BPP and only involving flexion and abduction. The greater asymmetry observed in children with BPP is due in part to weakness of the impaired shoulder as well as to greater strength in the unaffected shoulder, revealing some compensatory mechanisms. Regarding the impaired shoulder of children with BPP compared with children with TD, significant strength imbalances occurred in flexion–extension and internal rotation–external rotation strength ratios. Finally, impaired shoulder strength in the group with BPP correlated with active range of motion.

### Long-Term Consequences of Birth Injury

This study confirms the complex pattern of muscle involvement following obstetrical injury of the brachial plexus in terms of strength. While a general pattern emerged in the entire group, the larger standard deviations in children with BPP indicate, as anticipated, that individual results may differ depending on the severity of involvement, the degree of recovery, and whether surgery had been done or not. However, analysis of strength data revealed no significant differences between the children with BPP who had prior orthopedic surgery and those who had not. Extensors and external rotators were the weakest muscles in this sample of children with BPP. Extension, external rotation, and internal rotation involve muscles innervated by the posterior cord of the brachial plexus (triceps, deltoid, teres minor, subscapularis, and teres major). In contrast, the innervation of muscles involved in flexion, the less impaired direction, are from the medial or lateral cords, with the exception of the deltoid (coracobrachialis, pectoralis major, and biceps brachii).[26] It is generally thought that birth-related or obstetrical brachial plexus palsies involve the uppertrunk of the brachial plexus preferentially in contrast to BPP injuries in adults, which more often involve the lower trunk due to different injury mechanisms.[4,27] Our results provide more detailed information related to the site of injury, emphasizing the key role of posterior cord injury leading to long-term shoulder dysfunction following birth injury. Information from EMG testing in infancy is usually limited to a description of the involvement of the roots and trunks without describing the involvement of the divisions and cords. Additional studies would be useful to detail the results of early electrodiagnostic testing, including the extent and pattern of brachial plexus involvement at the level of the cords, patterns of neurologic/clinical recovery, and long-term functional consequences.

## Muscle Weakness and Imbalance

We aimed to explore absolute and relative shoulder strength values in all 3 planes to better understand shoulder dysfunction.[12] Shoulder weakness, contracture, and joint deformity in children with BPP are frequent even in children with the mildest chronic plexopathy.[11] External rotation weakness and the resultant imbalance are believed to lead to internal rotation contracture and perhaps even to glenohumeral joint deformity.[11] Our results confirm a prominent imbalance between internal and external rotators in the impaired shoulder[12] by showing that internal rotators were approximately twice as strong as external rotators. Paradoxically, MRI studies which can evaluate individual muscle sizes, rather than the groups of muscles assessed with strength testing, have shown that subscapularis (internal rotator) is more atrophied than infraspinatus (external rotator).[9,28] It is thus likely that other internal rotators than subscapularis (e.g., pectoralis major, anterior deltoid) play a major role in compensating for subscapularis weakness and that the other external rotators (e.g., posterior deltoid) cannot compensate as much for infraspinatus weakness.

We also found an even greater imbalance between shoulder flexors and extensors. This sagittal plane imbalance, coupled with the transverse imbalance, may play a role in the general posture of the shoulder and may induce additional scapulothoracic compensations[29] and glenohumeral deformities. Preserving the passive and active external rotation range is often reported as a main goal in this population,[11] and extension might be considered to be a secondary target. Targeting this direction as well by stretching and strengthening in children with residual strength may improve global shoulder muscle balance, posture, motion, and joint integrity. Future studies are needed to elucidate the relationship among sagittal and transverse strength imbalance, underlying muscle atrophy, and glenohumeral deformities.

## Measuring Strength Profiles: What Is the Potential Impact on Care Strategy?

Manual muscle testing provides a rough estimation of anti-gravity strength of a group of muscles, and its ability to provide motion, stability, and support around a joint. HHD provides a more objective, reliable, and sensitive strength assessment that requires minimal additional assessment time. In children with BPP, preventing or treating shoulder muscle imbalance by reducing internal rotation contracture and/or augmenting external rotation strength to prevent glenohumeral deformities is a main goal.[4,5,11,13] It is likely that performing an evaluation of individual shoulder strength profiles may help with the decision making process and evaluation of such procedures. Furthermore, this study revealed a good correlation between isometric strength and active shoulder range of motion, i.e., shoulder function. This reinforces the importance and clinical relevance of a multidirectional strength assessment in children with BPP for predicting both deformity and movement restrictions.

### Children with TD and Unaffected Shoulders

In adults, demonstration of greater strength in the more-versus less-preferred shoulder has been inconsistent, depending on the population and muscle tested.[30–32] For instance, in a population of adults who did not play asymmetrical sports, shoulder adduction, extension, and internal rotation strength values were shown to be greater on the dominant side, but abduction and external rotation were greater on the nondominant side.[32] In our study in children with TD, a significant asymmetry of approximately 10% in flexion and abduction was found, but no asymmetries were detected for external and internal rotation. This typical “physiologic” asymmetry should be taken into account when interpreting strength asymmetry in children with unilateral upper limb impairment. A limitation of our study was the lack of control for the practice of symmetrical or asymmetrical sports in both populations, which may have had a confounding influence on these comparisons.

In this study, the adductors of the unaffected shoulder of children with BPP were significantly stronger than adductors of the dominant shoulder of children with TD. This was associated with greater mean strength in all directions, but especially in internal rotation. We hypothesize that the upper limb on the healthy side of the children with BPP may cross the midline more frequently than normal to compensate for limitations in movement on the impaired side, thus increasing strength in this direction.

In conclusion, this study describes bilateral shoulder strength profiles in children with BPP and TD. Where children with TD show significant strength asymmetry for flexors and abductors, children with BPP have greater asymmetry in all muscle groups due to overall weakness of the impaired shoulder and also to greater strength in the unaffected shoulder. Extensors and external rotators are the weakest muscles, which lead to an abnormal sagittal and transverse imbalance at the shoulder joints and to active range of motion restrictions. Intervention strategies that preserve or increase strength or create more physiologically balanced forces at the shoulder joint may help preserve motion and minimize deformity.

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## Abbreviations

| | |
|---|---|
| **BPP** | brachial plexus palsy |
| **HHD** | hand-held dynamometer |
| **Newtons (N)** | Newton-meter (Nm) |
| **SD** | standard deviation |
| **TD** | typical development |

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**Table 1**

Characteristics of the children with brachial plexus palsy (BPP) and with typical development (TD).

| Characteristics | BPP | TD | *P* |
|---|---|---|---|
| Gender | 4F/11M | 4F/7M | – |
| Mean age (SD) (years) | 11.5 (3.5) | 10.9 (2.5) | 0.959 |
| Mean height (SD) (m) | 1.5 (0.2) | 1.5 (0.2) | 0.483 |
| Mean mass (SD) (kg) | 51.2 (18.3) | 49.3 (17.3) | 0.856 |
| Mean BMI (SD) (kg/m$^2$) | 21.5 (3.7) | 22.2 (4.7) | 0.551 |
| Dominant side | 9 R | 11 R | – |
| Median Narakas (range) | 3 (1–4) | – | – |
| Median Mallet score (range) | 15 (9–20) | – | – |

BMI, body mass index; M, male; F, female; R, right; SD, standard deviation.

**Table 2**

Hand-held dynamometer (HHD) testing.

| | | | Initial posture | | | |
|---|---|---|---|---|---|---|
| **Directions** | **HHD location** | **Task** | **Trunk** | **Shoulder** | **Elbow** | **Hand** |
| Flexion | Above elbow, anterior | Push up | Supine | 0° flexion<br>0° abduction<br>Neutral rotation | Extension | Facing down |
| Extension | Above elbow, posterior | Push up | Prone | 0° flexion<br>0° abduction<br>Neutral rotation | Extension | Facing down |
| Abduction | Above lateral epicondyle, elbow | Push laterally | Supine | 0° flexion<br>0° abduction<br>Neutral rotation | Extension | Facing down |
| Adduction | Above medial epicondyle, epicondyle | Push medially | Prone | 90° flexion<br>0° abduction<br>Neutral rotation | Extension | Facing medially |
| External rotation | Above wrist | Push laterally | Supine | 0° flexion<br>0° abduction<br>Neutral rotation | 90° flexion | Facing medially |
| Internal rotation | Above wrist | Push medially | Supine | 0° flexion<br>0° abduction<br>Neutral rotation | 90° flexion | Facing medially |

## Table 3

Within-group comparisons.*

| Group | Direction | Dominant Mean (Nm/kg) | Dominant SD | Nondominant Mean (Nm/kg) | Nondominant SD | Mean percentage of difference (%) | *P* |
|---|---|---|---|---|---|---|---|
| BPP | Flexion | 0.64 | 0.33 | 0.45 | 0.37 | −30.8 | **0.009** |
| | Extension | 0.48 | 0.21 | 0.12 | 0.17 | −76.5 | **0.001** |
| | Abduction | 0.59 | 0.27 | 0.36 | 0.17 | −34.5 | **0.001** |
| | Adduction | 0.62 | 0.29 | 0.35 | 0.21 | −41.4 | **0.001** |
| | Int Rotation | 0.45 | 0.25 | 0.25 | 0.27 | −48.5 | **0.001** |
| | Ext Rotation | 0.31 | 0.12 | 0.08 | 0.06 | −72.8 | **0.001** |
| TD | Flexion | 0.49 | 0.17 | 0.42 | 0.12 | −10.2 | **0.041** |
| | Extension | 0.39 | 0.09 | 0.35 | 0.12 | −10.9 | 0.062 |
| | Abduction | 0.49 | 0.09 | 0.44 | 0.14 | −8.2 | **0.017** |
| | Adduction | 0.42 | 0.09 | 0.39 | 0.09 | −6.4 | 0.286 |
| | Int Rotation | 0.33 | 0.13 | 0.32 | 0.11 | 0.2 | 0.790 |
| | Ext Rotation | 0.24 | 0.06 | 0.23 | 0.04 | −2.2 | 0.374 |

*Mean strength and standard deviation (SD) of both shoulders of children with brachial plexus palsy (BPP) and typical development (TD). The mean percentage of difference was calculated using the percentage (strength of the non-dominant arm- strength of the dominant arm) over (strength of the dominant arm)*100 of each child.

### Table 4

Between-group comparisons.*

| Direction | BPP Mean | BPP SD | TD Mean | TD SD | Percentage BPP/TD (%) |
|---|---|---|---|---|---|
| Nondominant side strength (Nm/kg) | | | | | |
| Flexion | 0.45 | 0.37 | 0.42 | 0.12 | 7.1 |
| Extension | 0.12 | 0.17 | 0.35 | 0.12 | **−65.7**† |
| Abduction | 0.36 | 0.17 | 0.44 | 0.14 | −18.2 |
| Adduction | 0.35 | 0.21 | 0.39 | 0.09 | −10.3 |
| Int rotation | 0.25 | 0.27 | 0.32 | 0.11 | **−21.9*** |
| Ext rotation | 0.08 | 0.06 | 0.23 | 0.04 | **−65.2**‡ |
| Dominant side strength (Nm/kg) | | | | | |
| Flexion | 0.64 | 0.33 | 0.49 | 0.17 | 30.6. |
| Extension | 0.48 | 0.21 | 0.39 | 0.09 | 23.1 |
| Abduction | 0.59 | 0.27 | 0.49 | 0.17 | 20.4 |
| Adduction | 0.62 | 0.29 | 0.42 | 0.09 | **47.6*** |
| Int rotation | 0.45 | 0.25 | 0.33 | 0.13 | 36.4 |
| Ext rotation | 0.31 | 0.08 | 0.24 | 0.06 | 29.2 |
| Between side difference comparison (%) | | | | | |
| Flexion | −30.77 | 20.61 | −10.19 | 18.60 | † |
| Extension | −76.49 | 26.59 | −10.93 | 15.06 | ‡ |
| Abduction | −34.49 | 24.62 | −8.20 | 10.78 | † |
| Adduction | −41.43 | 19.86 | −6.36 | 13.60 | ‡ |
| Int rotation | −48.54 | 29.05 | −0.23 | 17.12 | ‡ |
| Ext rotation | −72.77 | 23.06 | −2.24 | 16.06 | ‡ |

Values are expressed in Newton meters by kilogram (Nm/kg).

*Mean strength and standard deviation (SD) of the nondominant and dominant shoulders of children with brachial plexus palsy (BPP) and typical development (TD). The percentage BPP over TD (right column) was calculated using (mean BPP value – mean TD value) over (mean TD value)*100.

*=P<0.05

†P<0.01;

‡P<0.001.

## Table 5

Shoulder strength balance in extension/flexion, abduction/adduction, and external/internal rotation in children with brachial plexus palsy (BPP) and typical development (TD).*

| Side/children | | Extension/flexion ratio | | | Abduction/adduction ratio | | | External/internal rotation ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean (%)** | **SD** | ***P*** | **Mean (%)** | **SD** | ***P*** | **Mean (%)** | **SD** | ***P*** |
| BPP | Dominant | 78.2 | 16.3 | **0.002** | 107.1 | 26.8 | 0.363 | 71.9 | 15.0 | 0.112 |
| | Non dominant | 29.4 | 41.7 | | 110.4 | 79.8 | | 45.5 | 54.8 | |
| TD | Dominant | 86.0 | 23.1 | 1 | 92.6 | 21.3 | 0.959 | 76.7 | 16.6 | 0.657 |
| | Non dominant | 85.4 | 21.0 | | 94.8 | 25.6 | | 76.8 | 26.0 | |
| Dominant | BPP | 78.2 | 16.3 | 0.337 | 107.1 | 26.8 | 0.243 | 71.9 | 15.0 | 0.622 |
| | TD | 86.0 | 23.1 | | 92.6 | 21.3 | | 76.7 | 16.6 | |
| Nondominant | BPP | 29.4 | 41.7 | **0.001** | 110.4 | 79.8 | 0.697 | 45.5 | 54.8 | **0.031** |
| | TD | 85.4 | 21.0 | | 94.8 | 25.6 | | 76.8 | 26.0 | |

SD, standard deviation.

*The mean ratios were calculated using the strength ratios of extension over flexion, abduction over adduction, and external over internal rotation of each child.