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Dear Editor—Muscle strength evaluation is of clinical importance in children with obstetrical brachial plexus paralysis (OBPP), a condition characterized by nerve damage to shoulder rotators at birth. These alterations lead to a typical permanent shoulder attitude in medial rotation (MR) and a loss of active mobility in lateral rotation (LR) [1]. This attitude is attributed to an imbalance between lateral and medial rotator muscle strength because lateral rotators present a larger decrease of innervation than do medial rotators [2]. The shoulder initially remains soft, but a lack of neurological recovery leads to stiffness despite physiotherapy and results in passive LR loss.

A chief objective in children with OBPP is to prevent or treat shoulder muscle imbalance by reducing MR contracture and/or augmenting LR strength to further limit glenohumeral deformities [3]. We lack objective data to determine the surgical indication of muscular transfers. Although hand-held dynamometry is an easy-to-use method to measure muscle strength [4], the isokinetic dynamometer is currently the gold standard for shoulder muscle testing [5], but there are no data available for young children with OBPP in whom a muscle transfer could be indicated.

This study first evaluated the reliability of peak torque (PT) and total work (TW) in LR and MR shoulders measured with an isokinetic dynamometer in young children with OBPP and in healthy children. The second purpose was to compare the PT and TW values for shoulder rotators between children with OBPP and healthy children. Our hypothesis was that children with OBPP would show decreased muscle strength, especially in LR, on the paralyzed side as compared with the healthy contralateral shoulder and with healthy children.

Inclusion criteria were children with OBPP and healthy children between age 3 and 5 years. Age and OBPP type data were collected, and the Mallet score for shoulder motion [6] was assessed. Exclusion criteria were children with other significant neuromuscular, cognitive, or orthopedic disorders or a history of previous muscle transfer or use of botulinum toxin injection in the upper limbs.

The study protocol followed the STROBE guidelines and the recommendations of the Declaration of Helsinki and was approved by the local institutional review board (no. 2018_IRB-MTP_02-14). Written informed consent was obtained from all parents/guardians and

children after an explanation about the nature of the study and the risks related to their participation in the experiments.

Measurements involved use of a CON-TREX MJ isokinetic dynamometer (CMV AG, Dübendorf, Switzerland), in isometric mode with continuous correction of gravitational movement. The children were seated in the Davies position [7] with a support between the backrest and the back of the child and with a wedge at the elbow (see Supplementary Figure for the testing position). The children completed 3 trials for LR and MR in each upper limb. The highest maximal voluntary isometric torque value maintained for 5 s was used as the PT measurement. The area under the torque curve generated by the CON-TREX software for the entire 5 s was calculated to determine the total work (TW) accomplished. A 30-s interval rest between trials was ensured. The order of the torque production (LR, MR) and the resulting TW was randomly assessed by drawing lots.

We analysed the PT (in N.m, highest moment of force) and TW (in J) values obtained during each isometric measurement in each shoulder in each rotational direction because they have the highest levels of reliability [5].

The inter-trial reliability of PT and TW were established according to the intraclass correlation coefficient ($ICC_{2,k}$) as follows: poor (<0.40), acceptable ($0.40-0.75$), good ($0.75-0.90$) and excellent (>0.9) [8]. Absolute reproducibility (degree of variation in repeated measurements for the same individual) was evaluated with the equation for standard error measurement (SEM): $SEM = SD \times \sqrt{(1-ICC)}$, where SD is the standard deviation.

The analyses tested whether children with OBPP and healthy children differed in PT and TW values and any differences in PT and TW measurements between the paralyzed and non-paralyzed limb in children with OBPP or between the non-dominant and dominant side in healthy children, in LR and MR. We used Wilcoxon tests and false discovery rate correction and the Mann–Whitney *U* test. Effect sizes were calculated with Cohen's *d*. $P < 0.05$ was considered statistically significant (R v3.5.3).

We included 16 children with OBPP (7 boys; mean [SD] age 3.7 [0.8] years; Table 1) and 14 healthy children (9 boys; mean age: 3.9 [0.9] years; Table 1). In each group, 2 children aged 3 years were excluded

Table 1
Anthropometric data for children with obstetric brachial plexus palsy (OBPP) and healthy children.

Participant number																
OBPP children	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sex	F	M	M	F	M	M	M	F	F	F	F	F	M	F	F	M
Age	5	3	4	3	5	5	3	4	3	5	3	4	3	3	4	3
Paralyzed side	R	R	R	R	R	L	R	R	L	R	L	L	R	R	R	R
Body mass (kg)	19	20	21	15	21	25	N/A ^a	18	13	19	14	16	14	N/A ^b	17	14
Mallet score	9	14	17	18	19	16		17	14	18	15	20	16		21	19
OBPP type	complete	complete	complete	C5C6	complete	C5C6C7		C5C6	C5C6C7		C5C6	complete	complete	complete	C5C6	C5C6

Participant number														
Healthy children	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sex	M	F	M	M	F	M	F	F	F	M	M	M	M	M
Age	5	3	3	5	3	4	5	3	3	5	4	5	3	3
Dominant side	L	L	L	R	R	R	R	R	R	R	R	R	R	R
Body mass (kg)	17	14	N/A ^b	16	N/A ^b	17	14	13	13	17	21	18	15	15

^a did not manage; ^b refused; N/A, not available; M, male; F, female; R, right; L, left

(3 refused to participate and one could not perform the protocol), which reduced the number of participants available for analyses to 14 children with OBPP and 12 healthy children. The 2 groups were homogeneous, with no differences in age or body mass (Table 1).

Relative (ICC) and absolute (SEM) reliability were excellent (ICC 0.95–0.99, SEM < 0.71 N.m, Table 2) for both PT and TW in healthy children. In children with OBPP, the ICC values also ranged from acceptable to excellent (ICC 0.51–0.99) for both PT and TW. Although the SEM values for TW were high (indicating greater variability) in children with OBPP in both paralyzed and non-paralyzed sides, these values were still acceptable (SEM < 3.94 N.m).

In healthy children, the mean isometric PT values were similar between the dominant and non-dominant sides in LR and MR (Fig. 1). PT values were lower in LR than MR in non-dominant ($p = 0.002$,

Cohen's $d = 1.09$) and dominant sides ($p = 0.011$, Cohen's $d = 0.69$). Children with OBPP had lower PT values in the paralyzed than non-paralyzed side in both MR ($p < 0.001$, Cohen's $d = 0.48$) and LR ($p = 0.032$, Cohen's $d = 0.72$); PT values were lower in LR than MR on the paralyzed ($p = 0.011$, Cohen's $d = 0.56$) and non-paralyzed sides ($p = 0.003$, Cohen's $d = 0.46$). PT values were lower on the paralyzed side of children with OBPP than the non-dominant side of healthy children in both LR ($p = 0.002$, $d = 1.09$) and MR ($p = 0.003$, Cohen's $d = 1.15$). The non-paralyzed side did not differ from the dominant side in healthy children ($p = 0.4$). Altogether, children with OBPP presented a significant decrease in rotator muscle strength in the paralyzed shoulder in both LR and MR.

In healthy children, the TW was lower in LR than MR ($p = 0.017$, Cohen's $d = 0.74$), with no differences in dominant/non-dominant

Table 2
Reliability of isometric peak torque (PT) and total work (TW) measurements during lateral rotation (LR) and medial rotation (MR) of the shoulder in children with OBPP and healthy children.

		OBPP children		Non-paralyzed limb		Healthy children		Dominant limb	
		Paralyzed limb		LR	MR	Non-dominant limb		LR	MR
Peak torque (N.m)	ICC(2,k)	0.94	0.99	0.51	0.85	0.97	0.96	0.98	0.97
	SEM	0.29	0.24	1.19	0.94	0.34	0.48	0.31	0.71
Total work (J)	ICC(2,k)	0.75	0.91	0.7	0.93	0.97	0.96	0.95	0.95
	SEM	2.19	2.47	3.94	2.49	0.14	0.24	0.18	0.21

ICC, intraclass correlation coefficient; OBPP, obstetrical brachial plexus palsy; SEM, standard error measurement.

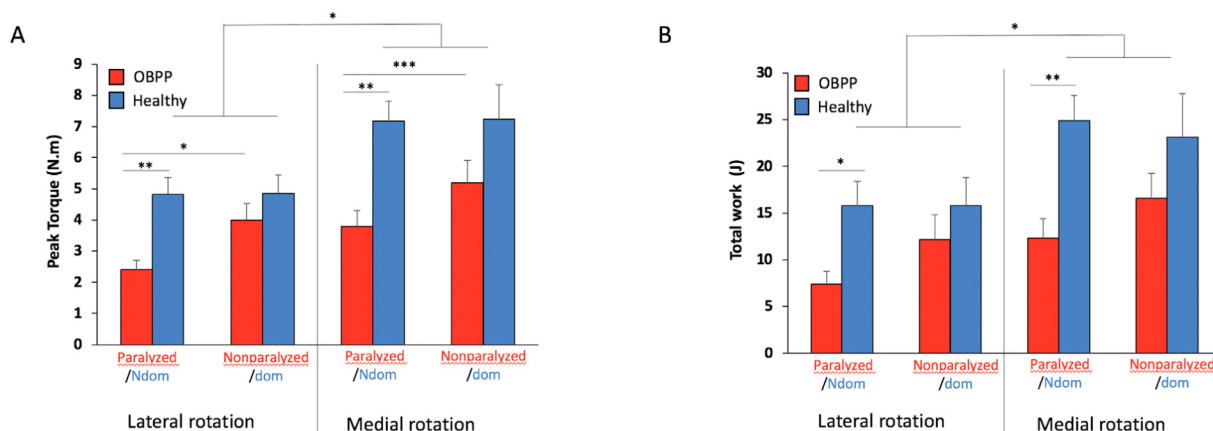


Fig. 1. Results of peak torque (A) and total work (B) during lateral and medial rotation in isometric mode in the paralyzed and non-paralyzed (Nparalyzed) side of children with obstetrical brachial plexus paralysis (OBPP) and in the dominant (dom) and nondominant (Ndom) side of healthy children. Data are mean (SD). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

side ($p = 0.8$). TW was also lower in LR than MR in children with OBPP ($p = 0.042$, Cohen's $d = 0.59$), with an effect of paralyzed/non-paralyzed side ($p = 0.05$). TW was lower in the paralyzed side of children with OBPP than the non-dominant side of healthy children in both LR ($p = 0.010$, Cohen's $d = 1.14$) and MR ($p = 0.009$, Cohen's $d = 1.23$). Finally, the non-paralyzed side of children with OBPP did not differ from the dominant side of healthy children in LR ($p = 0.112$) or MR ($p = 0.166$).

The present results demonstrate that isometric muscle strength measurements can be performed with acceptable reliability by using an isokinetic dynamometer, even in children 3 to 5 years old. This information is of crucial importance for a follow-up of shoulder disability and to improve therapeutic indications such as rehabilitation adaptation or surgical indications for muscle transfer in children with OBPP. We found lower PT in MR in addition to the anticipated impairments in LR in children with OBPP as compared with healthy children.

The successful and reliable use of the gold-standard isokinetic dynamometer to evaluate shoulder muscle strength in this study opens the door for evaluating children with movement deficits such as those with OBPP. Indeed, this device will allow for evaluating the muscle strength throughout the range of motion, when children will be able to perform isokinetic tests, allowing for assessing treatment progression and effectiveness and quantifying the amount of change in movement quality and force development over time.

Our data confirm that medial rotator muscles of the shoulder are stronger than the lateral rotators, with no dominant/non-dominant side effect in healthy children.

Our data highlight muscle strength impairments in MR in children with OBPP as compared with healthy children and not limited to LR as often purported. The subscapularis muscle is the largest of the 4 rotator cuff muscles and has been implicated as a primary deforming force leading to the development of shoulder MR contracture [9]. To date, the mechanisms leading to subscapularis muscle growth impairment have been explained by muscle imbalance. The imbalance theory infers that the subscapularis changes are secondary to the lack of passive stretching in the absence of active shoulder LR, which further leads to progressive shortening and stiffness of subscapularis muscle due to abnormal muscle growth or muscle hypoplasia. However, this finding does not explain the recurrence of contracture in MR after arthrolysis and intensive rehabilitation, especially with performance of a muscle transfer of reinforcement of lateral rotator muscles. Another hypothesis [10], although not as well accepted, is that denervation of the subscapularis muscle causes progressive muscle fibrosis, shortening, and contracture [11, 12]. Our results suggest a potentially considerable role of subscapularis muscle alterations in the etiology of OBPP and requires further analyses.

The present study has some limitations. The number of participants was low, albeit sufficient to provide satisfactorily reproducible results. We targeted very young children to provide objective data to indicate muscle transfer in a population in which they are lacking.

In conclusion, the isometric protocol was successfully performed by young children with acceptable reliability. Muscle strength impairments are observed in LR and MR in the paralyzed side of children with OBPP and are not limited to LR, as previously believed. This protocol is promising to better understand the shoulder disorders in OBPP and could help in muscle transfer indications.

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