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LEG EXTENSOR MUSCLE VOLUNTARY ISOMETRIC FORCE PRODUCTION CAPACITY IN CHILDREN WITH SPASTIC DIPLEGIA

M. Pääsuke, K. Kuresson, H. Gapeyeva, J. Ereline, T. Kums, H. Aibast

Institute of Exercise Biology and Physiotherapy, University of Tartu, Tartu, Estonia

ABSTRACT

The aim of this study was to compare the isometric force production capacity of the leg extensor muscles in 9–12-year-old children with spastic diplegia (SD; 11 girls and 10 boys) and age- and gender-matched nondisabled children (11 girls and 10 boys). Isometric maximal voluntary contraction force of the leg extensor muscles was measured during unilateral and bilateral contractions (leg press exercise) using custom-made dynamometric chair. Children with SD had significantly ($p<0.05$) lower isometric maximal force during bilateral and unilateral contractions compared with healthy children. Bilateral strength deficit did not differ significantly in children with and without SD. No significant correlations between isometric force characteristics of the leg extensor muscles and anthropometric parameters were observed in children with SD. These results indicated that in children with SD, isometric voluntary force-generating capacity of the leg extensor muscles during bilateral and unilateral contractions is markedly reduced, whereas bilateral strength deficit is not differ compared with age- and gender-matched healthy children.

***Key words*: muscle force, bilateral strength deficit, cerebral palsy, children**

INTRODUCTION

Cerebral palsy (CP) is an umbrella term for a group of frequent disorders of motor function due to a nonprogressive lesion of the developing brain. The factors related to the impaired motor function in children with CP are spasticity, paresis, lack of motor control in the affected limbs, and dystonia [1]. Spasticity and lack of muscle strength (weakness) are primary impairments associated with CP. It has been shown that low muscle strength, and not spasticity, causes the greatest limitations in motor function in children with CP [22]. Muscle function often becomes progressively more compromised in CP, leading to reduced mobility [3]. Spastic diplegia (SD) is one of the most prevalent type of CP [1]. Muscle force production is an important component of neuromuscular function, which is necessary for the performing of tasks of daily living. Isometric voluntary maximal force (MF) of the muscles of lower extremities has been used for measuring neuromuscular performance in young children with different physical disabilities, including children with SD. It has been suggested that children with spastic SD have significant amounts of lower extremity weakness, i.e., decreased MF compared to their able-bodied peers [7, 25]. This weakness may limit the performance of activities and participation in daily life [26].

A reduction in isometric MF induced by simultaneous bilateral (BL) contraction as compared to the sum of MF of separately performed unilateral (UL) contractions has been reported in adult subjects, and this phenomenon is designated as bilateral strength deficit (BLD) [12, 23, 24]. The neurophysiological mechanisms underlying BLD in human muscles are not well understood. Therefore, one explanation for the BLD is that it could be neural interaction between the two hemispheres connected by comissural nerve fibres [11, 15]. BLD has been associated with reduced movement-related cortical potentials caused by a mechanism of interhemispheric inhibition [15, 16]. It has been suggested that BLD can be caused by a reduced activation of higher threshold (fast) motor units [18]. BLD can also be a consequence of a disproportionate increase in coactivation of antagonist muscles [9]. A marked BLD would suggest a significant limitation of motor control. It has been supposed that despite BL lower extremity involvement, the majority of children with SD have the capability to ambulate, albeit at a later age and less proficiency than normally developing peers [19]. Less information is available in regard to lower extremity BLD in children with and without SD [28]. Most studies of muscle force in children with SD have been performed in UL contraction condition. However, investigation BLD in lower extremity muscles can increase our knowledge concerning muscle weakness and motor control impairment in children with SD.

The purpose of the present study was to compare the isometric force production capacity of the leg extensor muscles during UL and BL contractions, and BLD in 9–12-year-old children with SD and age- and gender-matched nondisabled children. Leg extensor muscles play an important role in motor activities of daily living, e.g. rising from a chair, standing and gait.

MATERIAL AND METHODS

Subjects

Twenty one prepubertal children aged 9–12 years (11 girls and 10 boys) with SD and 21 age- and gender-matched children without disabilities (11 girls and 10 boys) participated in this study. The anthropometric parameters of the subjects are presented in Table 1. Inclusion criteria for CP children were: 1) diagnosis of spastic diplegia, 2) presence of spasticity with a rating of 2 or 3 on the Modified Ashworth Scale [2], 3) ability to ambulate at least 10 meters without stopping and 4) no fixed contractures or previous surgery on the lower limb. All children were able to follow instructions. None of the children had an impairment of visual, somatosensory, hearing or vestibular function. Pubertal stages were determined according to the criteria of Tanner [27] by a pediatrician of the same gender as the subject. The children were classified as prepubertal if pubic hair and genital development for boys and breast development and pubic hair for girls were both scored as stage 1. Informed parental consent was obtained prior to the children's participation in the experiment. The study carried the approval of the University Ethics Committee.

Table 1. Anthropometric parameters of the subjects groups (mean ± SE).

Variable	Children with SD	Healthy children
Age (years)	10.4 ± 0.2	10.5 ± 0.2
Height (cm)	136.6 ± 2.2	138.1 ± 2.3
Body mass (kg)	32.7 ± 3.3	31.8 ± 2.9
Body mass index ($kg \cdot m^{-2}$)	17.4 ± 1.2	16.8 ± 1.0

SD – spastic diplegia

Apparatus and Experimental Protocol

The subjects were seated on a specially designed dynamometric chair in a horizontal frame with knee and hip angles equal to 110° and 120°, respectively [28]. The body position of the subjects was secured by two Velcro belts placed over the chest and hip. The feet were placed on a footplate mounted on a steel bar held in ball-bearings on the frame. The isometric force production of the leg extensor muscles was recorded by standard strain-gauge transducer (1778 DST-2, Russia) connected with footplate. Signals from the strain-gauge transducer were linear from 0 to 20 000 N. The force signals were sampled at frequency of 1 kHz and stored in a hard disk of a computer using software WsportLab (Urania, Estonia). Acceptable reliability of isometric MF of the leg extensor muscles during BL and UL contractions in children using this dynamometer was demonstrated in our previous study [28]. Test-retest correlations with a 1-week interval between measurements in this study was r = 0.86–0.92 in 6-year-old boys and r = 0.82–0.89 in age-matched girls.

Isometric MF of the leg extensor muscles was measured during UL and BL contractions (leg press exercise). During testing the subjects were instructed to push the footplate as forcefully as possible for approximately 3 s in three cases: 1) UL contraction of the right leg, 2) UL contraction of the left leg and 3) BL contraction. Three maximal attempts were recorded for each case and the best result was taken for further analysis. Strong verbal encouragement and visual online feedback were used to motivate the subjects. A rest period of 2 min was allowed between the attempts. During UL exertions the contralateral leg was allowed to rest. Bilateral index (BI) was calculated by the formula [9]:

$$BI\ (\%) = 100\ [BL / (UL_R + UL_L)] - 100,$$

where BL is isometric MF during bilateral contraction, UL_R and UL_L are isometric MF during right and left leg unilateral contractions, respectively. A negative BI indicated a BLD, while a positive BI indicated a BL facilitation.

Twenty-four to 48 hours before data collection the subjects were given instructions and the strength testing procedures were demonstrated. This was followed by a practice session to familiarize the subjects with the procedures. The same researcher with long-term experience in this kind of testing procedure tested all subjects between 11 am and 3 pm.

Statistical analysis

Data are means and standard errors of mean (± SE). One-way analysis of variance (ANOVA) followed by Tukey post hoc comparisons were used to test for differences between groups of children. Linear correlations were calculated to observe the relationship between the measured characteristics. A level of $p<0.05$ was selected to indicate statistical significance. The main measured characteristics of the leg extensor muscle isometric force production between children with SD and healthy control children were tested for statistical significance (alpha = 0.05). Statistical power analysis demonstrated that 21 children in each group is a sufficient number to detect significant differences ($\beta < 0.80$) in BL (0.92), UL_R (0.94) and UL_L (0.90). However, 25 participants in each group were required to provide sufficient power (0.80) for BI.

RESULTS

The mean values of measured anthropometric characteristics (height, body mass and body mass index) did not differ significantly ($p>0.05$) in children with SD and age- and gender-matched nondisabled controls (Table 1). As shown in Fig. 1A, isometric MF of the leg extensor muscles during BL contraction was less ($p<0.05$) in children with SD compared to healthy controls. In children with SD, isometric MF during right and left leg UL contraction was also less ($p<0.05$) than in healthy controls (Fig. 1B). No significant differences ($p>0.05$)

in isometric MF between the legs were observed either in children with SD or healthy controls. As shown on Fig. 1C, BI did not differ significantly in children with SD compared to controls.

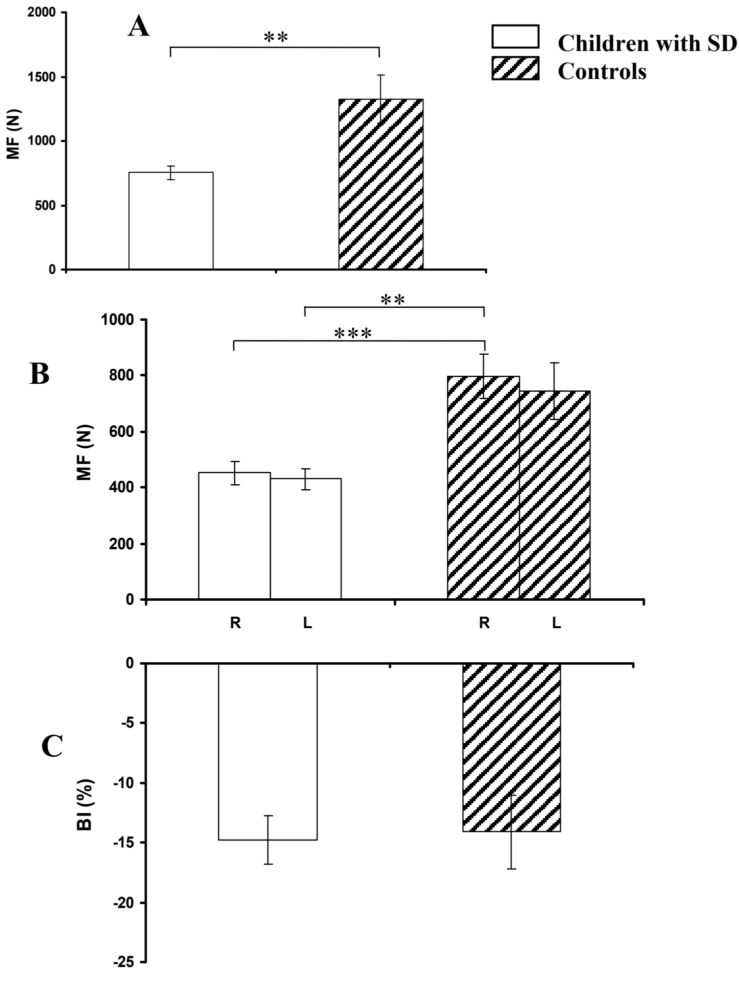

Figure 1. Mean (±SE) isometric maximal force (MF) of the leg extensor muscles during bilateral contraction (A) and during unilateral contraction of the right (R) and left (L) leg (B), and bilateral index (BI) (C) in children with spastic diplegia (SD) and healthy control children. ** $p<0.01$; *** $p<0.001$.

No significant correlations ($p>0.05$) were found between isometric MF of the leg extensor muscles during BL and UL contractions, BI and anthropometric characteristics in children with SD (Table 2). Significant ($p<0.05$) positive correlations were observed between isometric MF during BL contraction, and MF during right and left leg UL contractions ($r=0.77$ and $r=0.88$, respectively) in children with SD. The height, body mass and body mass index of healthy control children correlated significantly ($p<0.05$) positively ($r=0.72$–0.86) with isometric MF of the leg extensor muscles during BL and UL contractions (Table 3). Significant ($p<0.05$) positive correlations were observed between isometric MF of the leg extensor muscles during BL contraction, and MF during right and left leg UL contractions ($r=0.96$ and $r=0.93$, respectively) in control children. No significant ($p>0.05$) correlations were found between BI, anthropometric parameters and isometric MF of the leg extensor muscles during BL and UL contractions in control children.

Table 2. Correlations between anthropometric parameters and leg extensor muscle isometric force production characteristics in children with SD (n=21)

Variable	Height	Body mass	BMI	UL_R	UL_L	BL	BI
Height	**X**	**0.95***	**0.70***	**–0.14**	**0.05**	**–0.08**	**0.09**
Body mass		**X**	**–0.04**	**–0.08**	**0.24**	**0.11**	**–0.10**
BMI			**X**	**–0.04**	**0.36**	**0.22**	**–0.23**
UL_R				**X**	**0.45**	**0.77***	**0.32**
UL_L					**X**	**0.88***	**–0.25**
BL						**X**	**–0.25**
BI							**X**

SD – spastic diplegia; BMI – body mass index (body mass/height^2); UL_R – isometric maximal force (MF) during unilateral contraction of the right leg; UL_L – isometric MF during unilateral contraction of the left leg; BL – isometric MF during bilateral contraction; BI – bilateral index.
* $p<0.05$.

Table 3. Correlations between anthropometric parameters and leg extensor muscle isometric force production characteristics in healthy children (n=21)

Variable	Height	Body mass	BMI	UL_R	UL_L	BL	BI
Height	**X**	**0.88***	**0.73***	**0.75***	**0.86***	**0.74***	**0.27**
Body mass		**X**	**0.96**	**0.79***	**0.85***	**0.80***	**0.06**
BMI			**X**	**0.72***	**0.76***	**0.74***	**–0.02**
UL_R				**X**	**0.91***	**0.96***	**–0.01**
UL_L					**X**	**0.93***	**0.09**
BL						**X**	**–0.21**
BI							**X**

BMI – body mass index (body mass/height^2); UL_R – isometric maximal force (MF) during unilateral contraction of the right leg; UL_L – isometric MF during unilateral contraction of the left leg; BL – isometric MF during bilateral contraction; BI – bilateral index.
* $p<0.05$.

DISCUSSION

A markedly reduced isometric voluntary force-generation capacity of the leg extensor muscles during BL and UL contractions (leg press exercise) in 9–12-year-old children with SD compared to age- and gender-matched nondisabled children was observed in this study. In children with SD, isometric MF of the leg extensor muscles during BL contraction was on an average of 43% lower than in healthy controls. Children with SD produced on the average by by 43% and 42% lower isometric MF of the leg extensor muscles during right and left leg UL contractions, respectively, than the healthy children. This is in agreement with the results of several previous studies [7, 25], indicating a significant reduction of isometric voluntary force production capacity of the muscles of lower extremities in children with SD. For example, Stackhouse et al. [25] demonstrated 73% less isometric MF of the plantarflexor muscles in boys with CP (with mean age of 10.5 years) compared to the control group. Damiano and Abel [5], who measured isometric voluntary force production capacity of eight muscle groups in both lower extremities with a hand-held dynamometer in children with SD, observed a significantly reduced isometric MF in diplegic children in all measured muscle groups compared to age-matched children.

Impaired central motor drive and coactivation of the antagonist muscles across the joints, and disuse atrophy can hinder the isometric force production in the lower extremities in children with SD. Voluntary force-generation capacity of muscles is highly dependent upon the degree of motor unit activation, which is influenced by the development of the central nervous system. Low voluntary force production in CP has been attributed to either incomplete motor unit recruitment or decreased motor unit firing rate during maximal voluntary contraction [5, 20]. The reduced isometric MF of the skeletal muscles in children with CP could be partly attributable to a reduced ability to recruit higher threshold (fast) motor units or to drive lower threshold (slow) motor units to higher firing rates [4, 20]. Increased antagonist coactivation could also contribute to measured deficit in voluntary muscle force production in CP [6, 7]. It has been suggested that children with CP often demonstrate excessive amount of cocontraction of antagonist muscles in the lower extremities during muscle force testing [6]. Spasticity, defined as hypertonicity and hyperreflexia [14], may be one of the major factors responsible for the increased amount of cocontraction of antagonist muscles in diplegic subjects. Therefore, increased levels of cocontraction of antagonist muscles may restrain the action of the agonist muscles and reduce force output in children with SD.

Another source of CP-related muscle weakness may be the occurrence of significant structural and mechanical changes in skeletal muscles. The most common findings in CP are an increased incidence of muscle fibre atrophy, increased intramuscular fat and connective tissue in the most involved muscle groups [3, 21], and increased percentage of slow-twitch (type I) muscle fibres [10, 21]. Histological and histochemical studies have also showed mild myopathic changes in muscles and atrophy of type I and type II muscle fibres in children with CP [21]. Ito et al. [10] reported a selective atrophy of type II muscle fibres during development in CP. Moreover, during growth there occurs progressive fibrosis and the number of sarcomeres does not increase as rapidly as in children without CP. An abnormal variation in the size of muscle fibres and myosin heavy chain expression has been found in children with spastic CP [21]. It has been suggested that muscle cells in patients with spasticity are shorter and stiffer than normal muscle cells [8]. Elder et al. [7] demonstrated that muscle weakness in plantarflexor muscles in subjects with CP is based partly on reduced muscle cross-sectional area and an inability to produce torque levels commensurate with cross-sectional area. One of our previous studies [29] indicated that prepubertal children with SD in comparison with normal children are characterized by markedly reduced isometric voluntary and electrically evoked twitch contraction maximal force, capacity for twitch postactivation potentiation, and rates of twitch force production and relaxation of the plantarflexor muscles. These peripheral factors can reduce muscle force-generation capacity in children with SD.

A negative BI, i.e. BLD in the leg extensor muscles in all measured 9–12-year-old children was observed in the present study. The mean values of BI in children with SD and their age- and gender-matched controls were –15% and –14%, respectively, whereas difference between these groups was not significant ($p>0.05$). Our previous study [28] indicated that BI of the leg extensor muscles during isometric maximal contractions in 6-year-old children with SD and age- and gender-matched healthy controls was on an average –25% and –22%, respectively ($p>0.05$). Taniguchi [30] indicated that BLD is reduced with bilateral training and increases with unilateral training. However, it has been suggested that bilateral training reduces the BLD, whereas unilateral training has minimal effect on the BLD [13]. The nature of the neural mechanism of BLD must ultimately involve altered motor unit discharge frequency and/or recruitment during maximal voluntary BL contraction. The BLD can be caused by a reduced activation of higher threshold (fast) motor units [18]. The UL muscle contraction is controlled mainly by the contralateral cerebral hemisphere. The BL contraction is considered to be generated by the simultaneous activation of both hemispheres. The mechanisms of BLD have been widely discussed, however, remaining still unclear. Therefore, one explanation for the BLD is that it could be neural interaction between the two hemispheres connected by comissural nerve fibres [11, 15]. BLD was associated with reduced movement-related cortical potentials caused by a mechanism of interhemispheric inhibition [15]. It has been suggested that the BLD may be related to inhibitory spinal reflexes [17]. BLD can be consequence of disproportionate increase in the coactivation of antagonist muscles [16].

In this study, correlation analysis indicated no significant relations between anthropometric characteristics and leg extensor muscle isometric force production parameters in children with SD. Thus, the leg extensor muscle isometric force production capacity is not related with body size in these children. However, in healthy control children, the height, body mass and body mass index correlated significantly positively with isometric MF of the leg extensor muscles during BL and UL contractions. The results demonstrated that the indicator of BLD, i.e. BI did not correlate significantly with anthropometric characteristics and isometric maximal force production parameters of the leg extensor muscles in children with and without SD. Our previous study [28] indicated that in 6-year-old children, BLD was most obvious in children with SD with considerably decreased maximal and body mass-related isometric MF of the leg extensor muscles during BL contraction. However, similarly to the present results, no significant correlations were observed between BI and isometric MF of the leg extensor muscles during BL and UL contractions in healthy children.

In conclusion, the present study indicated that in 9–12-year-old children with SD, isometric voluntary force-generating capacity of the leg extensor muscles during BL and UL contractions is markedly lowered compared to age- and gender-matched healthy controls. The observed BLD in the leg extensor muscles did not differ significantly in children with and without SD. In children with SD, leg extensor muscle isometric force production capacity characteristics are not significantly correlated with body size characteristics.

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Correspondence to:
Mati Pääsuke, PhD, professor
Institute of Exercise Biology and Physiotherapy,
University of Tartu
5 Jakobi Street, 51014 Tartu
Estonia
Phone/fax: +3727 376 286
E-mail: mati.paasuke@ut.ee