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Abdominal and lower extremity muscles activity and thickness in typically developing children and children with developmental delay

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We investigated abdominal and lower extremity muscle activity and thickness in typically developing children and children with developmental delays. A total of 35 children participated: typically developing peers (n=13), children with hypotonia (n=10), and children with spasticity (n=12). Muscle activity and thickness were measured at rest and during activity. Electromyography was used to measure abdominal and lower extremity muscle activities, and abdominal muscle thickness was measured using ultrasonography. There was a significant difference between the groups in the activity of the rectus abdominis and quadriceps muscles at rest and during activity ($P<0.05$). There was a significant difference between the groups in the thickness of the external oblique and transversus abdominis muscles during activity ($P<0.05$). There was a significant difference between the groups in the thickness of the external oblique and internal oblique muscles in the sitting position ($P<0.05$). Therefore, the characteristics of muscle tone should be considered when applying interventions to children with developmental delay.

Keywords: Developmental delay, Hypotonia, Spasticity, Muscle tone

INTRODUCTION

Developmental delay (DD) is generally determined when a child does not attain developmental milestones relative to their peers (Choo et al., 2019). This includes a wide range of diseases such as cerebral palsy (CP), intellectual disability, congenital myopathy, chromosomal abnormalities, and congenital malformations (Hong et al., 2017). Children with DD have problems with muscle tone for various reasons, such as brain damage or chromosomal abnormalities that cause motor dysfunction (Harris, 2008; Rosenbaum et al., 2007).

Muscle tone is required to maintain a standing posture with continuous activity of the antigravity muscles and is one of the factors affecting motor development in children (Kaminishi et al., 2021). Problems with muscle tone can cause hypotonia or spasticity (Ganguly et al., 2021). Hypotonia refers to an impaired ability to maintain postural control and movement against gravity (Peredo and Hannibal, 2009). Spasticity is a motor disorder characterized by a velocity-dependent increase in tonic stretch reflex with excessive tendon jerks (Smania et al., 2010).

Children with DD can be classified as having hypotonia or spasticity, according to the distribution of muscle tone (Paquet et al., 2017). Children with hypotonia are characterized by low tone, decreased muscle strength and endurance, loose ligaments and joints, frog leg posture, wide-base gait, and increased postural sway (Kaler et al., 2020; Martin et al., 2007). In contrast, children with spasticity are characterized by high muscle tone, hyperexcitability, velocity-dependent increases in muscle tone, decreased muscle coordination, muscle co-contraction, W-sitting posture, scissor walking, and decreased postural sway (Picciolini et al., 2009). Children with spasticity and hypotonia are included in the same category, but their movements are opposite. Therefore, it is

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necessary to identify characteristics and problems and apply appropriate interventions.

Previous studies on the characteristics of children with DD have focused on comparisons between children with spastic CP and typically developing (TD) peers (Adjenti et al., 2017; Adjenti et al., 2018). Few recent studies have investigated the differences in movements in children with DD (Hadders-Algra, 2013; Kyvelidou et al., 2010). However, as the incidence of hypotonia in children is increasing in clinical practice, studies on its characteristics are needed. Therefore, we investigated the differences in abdominal and lower extremity muscle activity and thickness in children with spasticity, hypotonia, and TD peers.

MATERIALS AND METHODS

Participants

This study was conducted with TD peers of the same age as DD children aged 3–12 years who visited the Sky children's development center and children's home welfare center located in Yangsan, Korea. Inclusion criteria were as follows: (a) TD peers aged 3–12 years; (b) children aged 3–12 years with spasticity; (c) children aged 3–12 years with intellectual disability, chromosomal abnormalities, genetic problems, etc. with hypotonia; (d) children corresponding to level 2–4 of the gross motor function classification system; (e) children who could sit or maintain a sitting posture on their own; (f) children with DD who receive physical therapy 3–5 times a week; (g) TD peers attending daycare centers or schools; and (h) children who could perform simple verbal instructions from the researcher. The exclusion criteria were as follows: (a) children diagnosed with attention deficit disorder or autism, (b) children with audiovisual problems, (c) children with acute high fever or inflammation, and (d) children with uncontrolled seizures.

Thirty-five participants were divided into three groups (TD peers, children with spasticity, and children with hypotonia), and their abdominal and lower extremity muscle activity and thickness were measured. We explained the purpose and method of this study to the participants, and informed consent was obtained from them and their parents. This study was approved by the Research Ethics Committee of Kyungnam University (No.1040460-A-2021-043).

Muscle activity

Surface electromyography (EMG) (Trigo Wireless EMG, Delsys Inc., Natick, MA, USA) was used to measure muscle activity. The sampling of the EMG signal was set to 1,000 Hz, the frequency bandwidth was in the range of 20 to 1,000 Hz, and a 50-Hz notch filter was used. For muscle activity, the average value was obtained by processing the EMG data using root mean square (RMS), and the value was normalized to the reference voluntary contraction (RVC) (Pereira et al., 2011). RVC was determined using the following procedure: for the rectus abdominal muscle (RA), participants lay down in a supine position with the hip joint at 90° flexion and both knees raised to 90° (Dankaerts et al., 2004); for the quadriceps and hamstring muscle, participants were maintained in a quiet standing position for 5 sec (Ju, 2020), respectively. The RMS value was measured as muscle activity while maintaining the supine position (at rest) and when the head was raised to look at the knee until the scapula was raised from the floor in the hooklying position (during activity) for 5 sec. Muscle activity was measured for 3 sec, excluding the initial 1 sec and the last 1 sec. This was performed 3 times, and the average value was used. The RMS of each muscle was converted to percentage (% RVC) and used in the analysis of the results (Pereira et al., 2011).

The electrodes were positioned as follows: The RA was 2 cm next to the navel, the quadriceps (rectus femoris) was the central point between the knee and anterior superior iliac spine, and the hamstring (semitendinosus muscle) was attached to the middle of the line connecting the medial epicondyle of the femur and ischial tuberosity (Hermens et al., 2000). The electrode was attached after removing foreign substances using an alcohol swab to minimize the resistance generated by the skin.

Abdominal muscle thickness

Abdominal muscle thickness was imaged using B-mode ultrasonography (SONON, Healcerion, Seoul, Korea). The thickness of the external oblique (EO), internal oblique (IO), and transversus abdominis (TrA) was measured by placing a 10-MHz linear probe horizontally on the upper iliac crest at the center line of the axilla on the dominant side (Ha and Sung, 2016). The participants maintained the hooklying position (at rest) according to the examiner's instructions and then lifted their heads from the hooklying position (during activity). In addition, they maintained the sitting position. The thickness of the right abdominal muscle was measured at the end of exhalation. Muscle thickness is a vertical line connecting the upper and lower endpoints of the fascia, as shown in the white image. Measurements were performed using calipers built into the application, and the values were recorded in millimeters. The rate of change in muscle thickness (%) was calculated from the muscle thickness measured at rest and during the activity. The formula used is as follows (Koppenhaver et al.,

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2009).

Change rate of muscle thickness (%) = (muscle thickness during activity–muscle thickness at rest)/muscle thickness at rest × 100

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA). All data were reported as mean ± standard deviation. The Kolmogorov–Smirnov test was used to determine the normality of the measured values. We used nonparametric statistical tests as variables were not normally distributed. The Kruskal–Wallis rank test was used to compare muscle activity and thickness between the three groups and the Mann–Whitney *post hoc* test was performed when there was a significant difference. The effect size was calculated and expressed as eta squares (η^2) based on H-statistics. The statistical significance level was set at $P < 0.05$, in all statistical analyses.

Table 1. General characteristics of participants

	TD	Children with spasticity	Children with hypotonia	*P*-value
Gender, male:female	9:4	4:8	4:6	
Age (mo)	79.84 ± 17.33	95.75 ± 22.99	83.20 ± 23.08	0.074
Height (cm)	118.73 ± 11.77	120.08 ± 12.12	115.80 ± 11.93	0.700
Weight (kg)	24.37 ± 6.78	23.33 ± 8.53	19.75 ± 6.10	0.309
GMFCS, I:II:III:IV:V		0:6:4:2:0	0:5:3:2:0	

Values are presented as mean ± standard deviation.
TD, typically developing; GMFCS, gross motor function classification system.

RESUTLS

General characteristics of participants

Table 1 shows the general characteristics of the participants.

Muscle activity in at rest and during activity

At rest, RA activity was significantly higher in children with spasticity and hypotonia than in their TD peers ($P = 0.004$, $\eta^2 = 0.28$). Quadriceps activity was significantly higher in children with spasticity than in children with hypotonia ($P = 0.003$, $\eta^2 = 0.30$). During activity, quadriceps activity was significantly higher in children with spasticity than in the other groups ($P = 0.026$, $\eta^2 = 0.16$) (Table 2).

Muscle thickness in at rest and during activity

During activity, the EO was significantly thicker in children with spasticity than in the other groups ($P = 0.032$, $\eta^2 = 0.15$); however, the TrA was significantly thicker in TD peers than in children with spasticity ($P = 0.025$, $\eta^2 = 0.16$). The change rate in muscle thickness, the TrA was significantly thicker in TD peers than in children with spasticity ($P = 0.025$, $\eta^2 = 0.16$) (Table 3).

Muscle thickness in sitting position

In sitting, the EO was significantly thicker in children with spasticity than in the other groups ($P = 0.000$, $\eta^2 = 0.48$); however, the IO was significantly thinner in children with spasticity than in the other groups ($P = 0.002$, $\eta^2 = 0.32$). The change rate in muscle

Table 2. Muscle activation at rest and during activity in the supine position (%)

Variable	TD[a]	Children with spasticity[b]	Children with hypotonia[c]	Kruskal–Wallis test		Mann–Whitney *post hoc*	η^2
				χ^2	*P*-value		
At rest							
RA	16.89 ± 13.30	49.95 ± 37.98	38.12 ± 16.43	10.974	0.004*	a < b, c	0.28
Quadriceps	103.49 ± 33.74	147.05 ± 62.25	69.20 ± 44.82	11.702	0.003*	b > c	0.30
Hamstring	90.16 ± 50.35	164.53 ± 156.49	97.73 ± 50.71	1.620	0.445		
During activity							
RA	95.30 ± 20.93	108.34 ± 37.83	103.14 ± 40.73	0.835	0.659		
Quadriceps	169.15 ± 149.33	339.42 ± 179.76	124.25 ± 84.85	7.262	0.026*	a, c < b	0.16
Hamstring	105.85 ± 35.58	94.64 ± 62.14	96.29 ± 46.29	1.113	0.573		
During activity – at rest							
RA	78.41 ± 25.07	58.38 ± 53.50	65.02 ± 42.06	1.946	0.378		
Quadriceps	65.66 ± 136.91	192.37 ± 171.59	55.01 ± 78.11	4.230	0.121		
Hamstring	15.68 ± 41.94	-69.89 ± 164.26	-1.44 ± 68.23	2.675	0.263		

Values are presented as mean ± standard deviation.
TD, typically developing; RA, rectus abdominal muscle.
*$P < 0.05$.

Table 3. Abdominal muscle thickness at rest and during activity in the supine position

Variable	TD[a]	Children with spasticity[b]	Children with hypotonia[c]	Kruskal–Wallis test		Mann–Whitney *post hoc*	η^2
				χ^2	*P*-value		
At rest (mm)							
EO	2.89±0.94	3.87±1.25	3.26±0.82	4.762	0.092		
IO	4.68±1.64	5.98±1.52	4.67±1.33	4.993	0.082		
TrA	2.47±0.80	2.14±0.52	1.92±0.54	2.347	0.309		
During activity (mm)							
EO	3.16±1.02	4.82±1.87	3.07±1.03	6.863	0.032*	a, c<b	0.15
IO	5.88±2.05	6.10±2.06	4.77±1.30	2.252	0.324		
TrA	2.68±0.67	1.95±0.55	2.01±0.43	7.383	0.025*	a>b	0.16
Change rate of muscle thickness (%)							
EO	14.76±34.99	29.69±49.88	-1.18±39.25	3.082	0.214		
IO	33.27±42.31	4.30±31.77	7.83±36.27	5.255	0.072		
TrA	13.50±26.48	-8.89±11.31	8.49±20.30	7.363	0.025*	a>b	0.16

Values are presented as mean±standard deviation.
TD, typically developing; EO, external oblique; IO, internal oblique; TrA, transversus abdominis.
*$P<0.05$.

Table 4. Abdominal muscle thickness in sitting position

Variable	TD[a]	children with spasticity[b]	children with hypotonia[c]	Kruskal–Wallis test		Mann–Whitney *post hoc*	η^2
				χ^2	*P*-value		
At rest (mm)							
EO	2.89±0.94	3.87±1.25	3.26±0.82	4.762	0.092		
IO	4.68±1.64	5.98±1.52	4.67±1.33	4.993	0.082		
TrA	2.47±0.80	2.14±0.52	1.92±0.54	2.347	0.309		
Sitting (mm)							
EO	3.04±0.79	6.30±2.51	2.86±1.19	17.607	0.000*	b>a, c	0.48
IO	4.25±1.92	2.14±0.52	3.55±1.60	12.331	0.002*	b<a, c	0.32
TrA	2.26±0.66	2.53±0.91	1.87±0.94	4.709	0.095		
Change rate of muscle thickness (%)							
EO	11.67±32.28	74.04±69.82	-8.09±40.24	11.390	0.003*	b>c	0.29
IO	-0.65±49.04	-62.50±12.52	-15.95±57.48	13.650	0.001*	a>b	0.36
TrA	-0.53±43.50	20.29±36.08	5.55±57.39	3.206	0.201		

Values are presented as mean±standard deviation.
TD, typically developing; EO, external oblique; IO, internal oblique; TrA, transversus abdominis.
*$P<0.05$.

thickness, the EO was significantly greater in children with spasticity than in children with hypotonia ($P=0.003$, $\eta^2=0.29$). The IO was significantly greater in TD peers than in children with spasticity ($P=0.001$, $\eta^2=0.36$) (Table 4).

DISCUSSION

Children with DD have a wide range of diseases, and spasticity or hypotonia affects muscle tone. We investigated the difference in contraction of the abdominal and lower extremity muscles according to muscle tone, which is one of the main factors of motor DD.

Spasticity causes deformity of muscle morphology (Chapman et al., 2008), coactivation of antagonists, and decreased muscle activation during movement (Buckon et al., 2002; Damiano et al., 2002; Elder et al., 2003). Hypotonia has negative motor signs due to a lack of muscle tone and excessive joint relaxation (Ghibellini et al., 2015; Sanger et al., 2006), which are associated with kinematic inaccuracy (looseness) and balance problems (Galli et al., 2011; Horlings et al., 2009). Adjenti et al. (2017) reported that the RA muscle at rest and during activity showed that children

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with CP had a similar recruitment pattern to their TD peers and that the RA muscle of children with spastic CP was least affected by spasticity. Prosser et al. (2010) reported that trunk and hip muscle activity in children with CP during walking was higher than that in TD peers because of changes in trunk and hip muscle activation patterns, increased rates of motor unit firing, increased number of recruited motor units, and decreased motor unit synchronization. Furthermore, Wakeling et al. (2007) reported that quadriceps femoris and hamstring muscle activity increased during walking in children with CP compared to TD peers and that greater co-activation occurred between agonist and antagonist muscles in children with CP. In the present study, RA activity at rest was significantly lower in TD peers than in the other groups. These results support the study by Damiano and Moreau (2008), who stated that healthy muscles exhibit lower EMG frequencies, that is, lower activity. Quadriceps activity was significantly higher in the spasticity group than in the other groups. Quadriceps activity in children with spasticity is thought to increase as a result of co-contraction to increase the overall stiffness during activity (Holt et al., 1996). The TD peers and the hypotonia group exhibited similar patterns in muscle contraction. This is because spasticity appears as a loss of supraspinal control mechanism (Ganguly et al., 2021) whereas hypotonia does not.

Abdominal muscles are divided into global and local muscles. Among them, EO corresponds to a global muscle and IO and TrA correspond to local muscles (Oliva-Lozano and Muyor, 2020; Panjabi, 2003). Among them, the TrA plays the most important role in trunk stability and postural control (Hides et al., 1996). Poor abdominal muscle activation is evident in children with spasticity and hypotonia and is, often accompanied by excessive lumbar lordosis and anterior pelvic tilt (Ha and Sung, 2022; Kim and Seo, 2015). In previous studies, the abdominal muscles in children with spasticity at rest were thicker than those of their TD peers (Adjenti et al., 2018; Ohata et al., 2008). This is because children with CP show hypertonia in the trunk as compensation strategies due to peripheral muscle weakness (Hagberg et al., 2001). In the present study, the EO was thicker in children in the spasticity group than in the other groups during activity and in sitting. But the TrA during activity was thinner in children with spasticity than in the TD peers and the IO was thinner in children with the spasticity than those of their TD peers in sitting. The change rate of TrA during activity was significantly greater in TD peers than in children with spasticity. In sitting, the change rate of EO was significantly greater in children with spasticity than in children with hypotonia, and the change rate of IO was significantly greater in TD peers than in children with spasticity. Excessive activity of the EO in children with spasticity is a result of excessive use of the global muscle without the use of local muscles. Spinal stability is thought to be reduced by TrA and IO thinning. In children with hypotonia, abdominal muscle thickness was similar to that of TD peers.

In summary, we found that muscle activity and thickness differed according to the muscle tone. Therefore, the characteristics of muscle tone should be considered when interventions are applied. A limitation of this study is that it is difficult to generalize the contents because of the small number of participants, and various muscles around the trunk and hips could not be observed. In addition, the posture during the activity did not vary. Future studies that complement these points should be conducted.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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