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Factors associated with balance ability in Duchenne and Becker muscular dystrophies

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ABSTRACT

Background: Problems such as progressive muscle function loss, postural deteriorations, and contractures seen in patients with Duchenne and Becker muscular dystrophies (D/BMD) may affect children's balance ability, and impaired balance ability may lead to limitations in children's functional level.
Research question: What factors are associated with balance ability in children with D/BMD?
Methods: Twenty participants with D/BMD were included in the study. Participants' ages were asked; height, body weight, and body mass index (BMI) were recorded. Children's functional level was assessed with the Motor Function Measurement-32 (MFM-32), Brooke and Vignos Scales. Muscle strength of hip flexion and extension, knee flexion and extension, and ankle dorsiflexion was measured with a handheld dynamometer. Balance measurements were performed using the Balance Master System. The relationship between balance and continuous independent variables was determined using Spearman's test.
Results: The mean age of the participants was 8.57 ± 3.27 years. The balance abilities of children with BMD were better than those of children with DMD ($p < 0.05$). The balance diminished with age ($p < 0.05$), while there was a positive correlation between balance and weight, height, BMI ($p < 0.05$). There was a positive correlation between the balance and the MFM-32 total and subsection scores. Muscle strength was positively related to balance ($p < 0.05$).
Significance: The results showed the balance ability in children with D/BMD was affected by age, height, weight, BMI, functional level, and muscle strength. Based on the results of this study, balance and strength training should be an integral part of the rehabilitation of children with D/BMD.

1. Introduction

The predominant clinical symptom of Duchenne and Becker muscular dystrophies (D/BMD), which are X-linked recessive progressive neuromuscular diseases caused by mutations in the dystrophin gene, is gradual muscle weakness [1]. Duchenne muscular dystrophy (DMD) occurs in 1/5000 live male births and Becker muscular dystrophy (BMD) in 1/19000 live male births [2,3]. In DMD, mutations in the dystrophin gene result in the absence of the dystrophin protein, which stabilizes the sarcolemma during power generation, and progressive loss of muscle function is observed. While muscle functions are relatively preserved between 3 and 5 years of age in children with DMD, functional losses become more evident after six years of age, and the children start using wheelchairs at the beginning of their teens [3,4]. In Becker muscular dystrophy (BMD), which is a milder form of the disease, mutation in the same gene results in a decrease in the amount or functionality of the dystrophin protein. While some of the individuals diagnosed with BMD lose their ambulation at the end of their twenties, some cases preserve their ambulation with minor effects in late adulthood [2,4].

Balance is defined as keeping the body's center of gravity within the base of support, and it is undoubtedly associated with many functional activities such as walking, sitting, standing, and reaching in children [5,6]. Problems such as progressive muscle function loss, postural

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deteriorations, and contractures seen in patients with D/BMD may affect children's balance ability [2,4]. In addition, it is known that dystrophin is more concentrated in the cerebral cortex, cerebellum, and hippocampus regions of the brain. Deficiency or distortion of the functionality of dystrophin protein in these regions can affect balance ability as well as many executive functions. Therefore, balance assessments and training have a substantial place in the rehabilitation program of children with D/BMD and in evaluating the effectiveness of the treatments applied.

Balance is an integral part of functional activity in children as well as in individuals of all ages, and it is frequently used to evaluate the effectiveness of treatments applied to children with D/BMD. Studies have been conducted to identify factors associated with balance ability in many populations [7–9]. Age, height, weight, muscle strength, and functional level are some parameters found to be associated with balance in different populations [7–9]. Alkan et al. has shown that children with DMD in different functional levels have significantly different balance ability, but they did not examine the relationship between balance and functional level [10]. No study has been found in the literature examining the factors related to balance ability in children with D/BMD, which represents an important part of rehabilitation programs for these children and enables the evaluation of the effectiveness of many treatment methods. The aim of this study is to investigate the relation of factors such as demographic characteristics, functional level, and muscle strength with balance ability in children with D/BMD.

2. Methods

2.1. Study design and participants

In this research, a cross-sectional design was used. The sample size was calculated as a minimum of 16 participants by G* Power by taking 95% power, $\alpha = 0.05$, correlation pH1 = 0.75, and correlation pH0 = 0.00 [11,12]. Inclusion criteria were as follows: being diagnosed with D/BMD, being between the ages of 6–10, not having any systemic or neurological additional disease, and no functional impairment in auditory, vestibular, proprioceptive systems. Participants who did not meet the inclusion criteria and did not have the cooperation or functional competence to perform the assessment methods were excluded. The age range of 6–10 years was chosen based on the age at which patients with DMD began to lose function and initiated the use of a wheelchair [3,4].

2.2. Procedure

All participants and their families were informed, and their given informed consent was taken. The Ethical Board of the University of XX approved the study (ref no:2019/19-23). This study was conducted between 01 February 2021 and 30 January 2022 in XX University Faculty of Physical Therapy and Rehabilitation. All assessments were performed by a physiotherapist with five years of clinical experience.

2.3. Outcome measurements

2.3.1. Sociodemographic characteristics

Within the scope of the study, age, height, body weight, and body mass index (BMI) were recorded. The BMI percentile was calculated with the CDC BMI percentile calculator [13].

2.3.2. Functional level

The functional level of the children was evaluated with the MFM-32, Brooke Scale (BS) and Vignos Scale (VS) [14–16].

The MFM-32 is a valid and reliable scale that is specially developed to evaluate the motor functions of children and adults aged 6–60 years with neuromuscular disease. It offers clinicians and researchers the opportunity to evaluate their patients' functional abilities by focusing on what individuals can do rather than what they cannot. MFM-32 consists of 32 items divided into three subsections: D1 (min–max: 0–39): standing position and transfers, D2 (min–max: 0–36): axial and proximal motor function, D3 (min–max: 0–21): distal motor function. Each item is scored on a 4-point Likert scale (0 (cannot start the task or maintain the starting position) to 3 (completes the task in a normal pattern)). The minimum score that can be achieved on the scale is 0, the maximum score is 96, and higher scores indicate a better level of functioning [14]. The test-retest reliability (ICC) for the Turkish version was 0.76 and the Cronbach's alpha was 0.84 [14].

The BS is a frequently used scale to evaluate the upper extremity functions of patients with D/BMD. In the scale, upper extremity functions are scored between 1 (Starting with arms at the sides, the patient can abduct the arms in a full circle until they touch above the head) and 6 (Cannot raise hands to the mouth and has no useful function of hands). It provides the examination of upper extremity functions by dividing them into 6 classes [15].

The VS was developed to evaluate lower extremity functions. The scale provides scores of lower extremity functions between 1 (Walks and climbs stairs without assistance) and 10 (Is confined to a bed). With this scale, the functions of the lower extremity functions are divided into 10 classes [16].

2.3.3. Muscle strength

Hip flexion-extension, knee flexion-extension, and ankle dorsiflexion muscle strengths were evaluated with a hand-held dynamometer (Lafayette Instrument, Lafayette, IN, USA). Muscle strength measurements were performed in positions defined by Mentiplay et al. [17]. All assessments were performed by the same assessor with five years of clinical experience. Maximal voluntary isometric contraction was assessed as peak force and results were recorded in kilograms. Three measurements were made for all muscles and the average of these three measurements was recorded. The strength tests were performed for 5 s and there was a 20-s rest between trials [11]. While calculating the strength for each muscle group, the mean score for the right and left extremities was calculated [11].

2.3.4. Balance ability

Static and dynamic balance abilities of individuals were evaluated with the Balance Master System ver. 8.1. (NeuroCom International Inc. Clackamas, OR, USA). In the current study, the modified clinical test of sensory interaction on balance (mCTSIB) test was used to assess static balance, and the limit of stability (LoS) test and the tandem test to assess the dynamic balance. The details of the measurement were explained to the children by the researcher before all evaluations. All test conditions were shown by the researcher on herself. Then the participants were asked to do a self-test to make sure they understood the test. All tests have been performed in the standardized positioning with 3 repeats, and the averages of scores have been taken by the system software [18].

In the mCTSIB test, the participant was asked to stand as stationary as possible for 10 s on hard and soft surfaces under eye-open and eye-closed conditions, and the sway velocity per second was measured. In this test, an increase in sway velocity means a deterioration in balance ability [18].

At the beginning of the LoS test, the participant was asked to stand steadily with the center of gravity on the center point of the platform (firm surface). During the test, the participant moved the center of gravity in 8 directions without lifting his heels from the ground. The device evaluates seconds for the reaction time (LoS-RT), degrees per second for the movement velocity (LoS-MVL), and percent for the endpoint excursion (LoS-EPE), maximum excursion (LoS-MXE), and directional control (LoS-DCL). Increased LoS-RT decreased LoS-MVL, LoS-EPE, LoS-MXE, and LoS-DCL are associated with poor balance [18].

In the tandem test, the participant was asked to do heel-toe walking as fast as he could and to stand still at the end of forceplate. During the tandem test, the device gave commands to walk and stop. At the

beginning of the test, the patient was positioned in a tandem position; the patient was asked to walk as fast as possible to the end of the forceplate with the device's command "go"; and at the end of the test (at the end of the forceplate), the patient was asked to hold stay as still as possible in the tandem position in response to the device's command. Thus, the duration of the test depended on the walking speed of the participant. Step width, step speed, and end-sway were recorded for this test [18]. In this test, a larger step width and a larger end-sway are considered indicators of poor balance, while a higher step speed is associated with good balance [18].

2.4. Statistical analysis

Statistical analyzes were performed using the Statistical Package for the Social Sciences (SPSS®) Windows 24.0.0.0. The Shapiro–Wilk test was applied to test the normality assumption. Descriptive statistics were used to characterize the sample. Balance, functional level, and muscle strength of patients with DMD and BMD were compared using the Mann-Whitney U test. The relationship between balance and continuous independent were determined by performing the Spearman test due to non-parametric conditions. The level of correlation was interpreted as 0.00–0.10 to be a negligible correlation, 0.10–0.39 to be a weak correlation, 0.40–0.69 to be a moderate correlation, 0.70–0.89 to be a strong correlation, and 0.90–1.00 to be a very strong correlation [19]. The p values were deemed significant at < 0.05.

3. Results

3.1. Sample characteristics

Twenty participants with D/MD with a mean age of 8.57 ± 3.27 years were included in the study. All of them were under the %50th percentile according to the BMI percentile levels. The participants' 65% had a diagnosis of DMD, and 35% of them had a diagnosis of BMD (Table 1).

3.2. Balance, functional level, and muscle strength outcomes

The MCTSIB-sway velocity-complete of the total sample was 1.63 ± 0.89°/s, and the participants with BMD had a significantly better score than children with DMD. In the LoS test, children with BMD had significantly greater scores in LoS-MVL, LoS-EPE, LoS-MXE, and LoS-DCL. The tandem walk speed of the total sample was 16.74 ± 8.57, and the children with BMD were more rapid (Table 2).

When the functional level results of the participants are examined, it is noteworthy that the lowest score was obtained from the D1 subsection, and the total MFM-32 score of the children was 83.54 ± 12.84%. When the MFM-32 total score and subsection scores are examined, it is seen that the scores of children with DMD have significantly lower scores (Table 2).

Except for hip extension muscle strength, no significant difference was found between the muscle strength of children with DMD and BMD (Table 2).

3.3. Factors associated with balance

When it has examined the relationship of the balance with demographic characteristics; there was a strong correlation between the weight and mTCSIB sway velocity in eyes open (EO) condition on the foam surface, mTCSIB sway velocity complete, LoS-EPE, LoS-MXE, tandem walk speed ($p < 0.05$, Table 3). There were moderate correlations between some anthropometric characteristics and balance scores tested under different conditions ($p < 0.05$, Table 3).

There was a strong correlation between the MFM-32 total score and mTCSIB sway velocity in EO condition on the firm-foam surfaces, LoS-EPE ($p < 0.05$, Table 3). There was a moderate correlation between the MFM-32 total score and mTCSIB sway velocity in eyes closed (EC) condition on the firm-foam surfaces, mTCSIB sway velocity complete, LoS-MVL, LoS-MXE, LoS-DCL, tandem step width, tandem walk speed ($p < 0.05$, Table 3).

There was a moderate correlation between the hip flexion strength and the mTCSIB sway velocity in EO on the foam, LoS-DCL; between the hip extension strength and mTCSIB sway velocity in EO and EC on the firm surface, mTCSIB sway velocity in EO on the foam surface, mTCSIB sway velocity complete, LoS-EPE, LoS-MXE, tandem walk speed; between the knee flexion strength and the mTCSIB sway velocity in EO on the firm-foam surface, tandem-end sway; between the knee extension strength and the mTCSIB sway velocity in EO on the firm surface;

Table 1
Sociodemographic characteristics and general functional classification of the participants.

	Mean ± SD or frequency	Median (IQR 25/75)
1. Age		
DMD	7.46 ± 1.5	7 (6.00/8.50)
BMD	7.46 ± 1.5	9 (7.00/10.00)
Total	8.57 ± 1.27	8.00(6.25/9.00)
2. Weight (kg)		
DMD	19.79 ± 3.71	19.00(17.00/21.50)
BMD	32.29 ± 7.97	32.00(25.00/35.00)
Total	24.16 ± 8.14	21.50 (18.13/30.00)
3. Height (cm)		
DMD	113.62 ± 9.49	114.00(106.50/118.50)
BMD	116.57 ± 49.50	135.00(125.00/138.00)
Total	114.65 ± 28.86	117 (110.25/132.50)
4. BMI[1]	16.03 ± 2.03	16.05 (15.19/16.95)
Underweight (0–5 percentiles) %(n)	20 (4)	–
Healthy weight (5–85 percentiles) %(n)	80 (16)	
Overweight (85–95 percentiles) %(n)	–	–
Obese (95–100 percentiles) %(n)	–	–
5. Diagnosis		
DMD %(n)	65.00 (13)	–
BMD %(n)	35.00 (7)	
Vignos Scale[2]		
Level 1-%(n)	50.00 (10)	–
Level 2-%(n)	10.00 (2)	
Level 3-%(n)	25.00 (5)	
Level 4-%(n)	5.00 (1)	
Level 5-%(n)	10.00 (2)	
Brooke Scale[3]		
Level 1-%(n)	70.00 (14)	–
Level 2-%(n)	30.00 (6)	

BMD: Becker muscular dystrophy, BMI: Body mass index, DMD: Duchenne muscular dystrophy, IQR: interquartile range, SD: standard deviation.
[1] The BMI percentile was calculated with the CDC BMI percentile calculator [13].
[2] Vignos Scale level 1: Walks and climbs stairs without assistance; Vignos Scale level 2: Walks and climbs stair with aid of railing; Vignos Scale level 3: Walks and climbs stairs slowly with aid of railing (over 25 s for 8 standard steps); Vignos Scale level 4: Walks unassisted and rises from chair but cannot climb stairs; Vignos Scale level 5: Walks unassisted but cannot rise from chair or climb stairs [15].
[3] Brooke Scale level 1: Starting with arms at the sides, the patient can abduct the arms in a full circle until they touch above the head; Brooke Scale level 2: Can raise arms above head only by flexing the elbow (shortening the circumference of the movement) or using accessory muscles [16].

Table 2
Balance, functional level, and muscle strength of the participants.

	**	*Total Sample Mean ± SD (n = 20)*	*Total Sample* Median (IQR 25/75) *(n = 20)*	*DMD Mean ± SD (n = 13)*	*DMD* Median (IQR 25/75) *(n = 13)*	*BMD Mean ± SD (n = 7)*	*BMD* (IQR 25/75) *(n = 7)*	p^a
Balance	MCTSIB-sway velocity-EO-firm(°/s)	1.01 ± 0.71	0.85(0.60/1.15)	1.24 ± 0.78	1.00(0.80/1.40)	0.59 ± 0.21	0.60(0.40/0.80)	**0.004***
	MCTSIB-sway velocity-EC-firm(°/s)	1.25 ± 0.88	0.95(0.80/1.70)	1.48 ± 0.97	1.10(0.90/1.70)	0.83 ± 0.49	0.70(0.60/1.00)	0.210
	MCTSIB-sway velocity-EO-foam(°/s)	1.62 ± 0.92	1.40(1.00/2.08)	1.95 ± 0.99	1.60(1.30/2.20)	1.01 ± 0.27	0.90(0.80/1.20)	**0.004***
	MCTSIB-sway velocity-EC-foam(°/s)	2.55 ± 1.19	2.30(1.63/3.10)	2.98 ± 1.26	2.60(2.15/3.50)	1.76 ± 0.44	1.60(1.50/3.00)	**0.015***
	MCTSIB-sway velocity-complete(°/s)	1.63 ± 0.89	1.40(1.03/1.93)	1.94 ± 0.95	1.60(1.35/2.20)	1.06 ± 0.29	1.00(0.80/1.20)	**0.004***
	LoS-RT-complete (s)	0.88 ± 015	0.90(0.77/1.01)	0.88 ± 0.17	0.90(0.73/1.02)	0.81 ± 0.16	0.78(0.71/0.93)	0.303
	LoS-MVL-complete (°/s)	4.26 ± 1.84	3.70(2.50/3.70)	3.43 ± 1.51	2.90(2.35/4.45)	5.40 ± 1.64	5.50(3.70/7.00)	**0.017***
	LoS-EPE-complete (%)	54.78 ± 13.88	51.00(43.75/65.00)	44.15 ± 6.05	44.00(38.00/48.50)	69.71 ± 7.87	68.00(62.00/79.00)	**0.000***
	LoS-MXE-complete (%)	74.78 ± 17.53	71.50(60.00/88.00)	64.62 ± 10.15	64.00(59.00/70.00)	91.71 ± 11.01	91.00(84.00/103.00)	**0.001***
	LoS-DCL-complete (%)	57.83 ± 15.61	60(44.25/70.25)	48.69 ± 13.80	45.00(37.00/62.00)	68.86 ± 11.45	70.00(55.00/81.00)	**0.009***
	**Tandem-step width (cm)	12.04 ± 6.04	10.30(7.08/15.13)	13.29 ± 6.99	10.40(7.90/10.40)	10.07 ± 3.78	10.10(6.50/13.50)	0.258
	**Tandem-walk speed (cm/s)	16.74 ± 8.57	13.40(10.80/23.68)	11.93 ± 4.29	11.50(9.50/13.20)	24.30 ± 8.26	25.10(16.40/30.80)	**0.002***
	**Tandem-end sway (°/s)	7.74 ± 4.97	6.60(4.58/8.03)	7.90 ± 6.14	5.30(3.80/8.00)	7.50 ± 2.64	7.40(5.40/8.10)	0.298
Functional level	Standing and transfers (%)	72.31 ± 23.42	76.92(50.64/94.87)	59.17 ± 18.24	64.10(46.15/76.92)	96.70 ± 1.94	97.44(94.87/97.44)	**0.000***
	Axial and proximal motor function (%)	93.33 ± 8.23	94.44(94.44,94.87)	89.96 ± 8.45	94.44(81.94/94.44)	99.60 ± 1.05	100(100/100)	**0.000***
	Distal motor function (%)	87.62 ± 11.91	90.48(80.95/95.24)	83.15 ± 12.69	85.71(78.57/90.48)	95.92 ± 1.80	95.24(95.24/95.24)	**0.003***
	Total (%)	83.54 ± 12.84	84.38(71.88/96.88)	75.96 ± 9.09	72.92(69.79/84.38)	97.62 ± 1.26	96.88(96.88/97.92)	**0.000***
Muscle strength	Hip flexion (kg)	3.16 ± 2.31	2.88(2.03/4.04)	2.33 ± 1.56	2.75(0.65/3.63)	4.69 ± 2.79	3.80(2.90/6.80)	0.062
	Hip extension (kg)	2.30 ± 2.88	0.70(0.00/4.44)	1.04 ± 1.99	0.00(0.00/1.98)	4.62 ± 2.94	3.55(2.35/6.20)	**0.005***
	Knee flexion (kg)	3.15 ± 2.07	3.35(2.30/4.33)	2.65 ± 1.92	3.15(0.00/4.18)	4.10 ± 2.13	3.35(2.30/4.55)	0.360
	Knee extension (kg)	3.66 ± 3.26	3.30(2.51/4.09)	2.69 ± 1.65	3.45(0.93/3.83)	5.46 ± 4.73	3.10(2.55/6.00)	0.451
	Dorsiflexion (kg)	4.45 ± 0.69	5.00(4.00/5.00)	4.31 ± 0.75	4.00(4.00/5.00)	4.71 ± 0.49	5.00(4.00/5.00)	0.311

*: $p < 0.05$, SD: standard deviation, min: minimum, EO: eyes open, EC: eyes closed, °: degree, s: second, %: frequency, cm: centimeter, MCTSIB: modified clinical test of sensory interaction on balance, LoS: Limit of stability, RT: reaction time, MVL: movement velocity, EPE: endpoint excursion, MXE: maximum excursion, DCL: directional control, BMD: Becker muscular dystrophy, DMD: Duchenne muscular dystrophy, IQR: interquartile range.
**Two patients with DMD could not perform the tandem test.
[a] p values for between DMD and BMD.

between the dorsiflexion strength and the mTCSIB sway velocity in EO on the firm-foam surface, mTCSIB sway velocity in EC on the foam, mTCSIB sway velocity complete, tandem-end sway ($p < 0.05$, Table 3).

4. Discussion

The current study aimed to investigate the factors related to balance ability in children with D/BMD. The results of the current study show that balance ability is related to some demographic properties, functional level, and muscle strength in children with D/BMD. It is well known BMD has a milder prognosis, and in line with that, in the current study, it was found that children with BMD had better static and dynamic balance abilities. A relationship was found between age and dynamic balance. Functional level, hip flexor-extensor, knee flexor-extensor, and ankle dorsiflexor muscle strengths were correlated with static and dynamic balance abilities in children D/BMD.

Lue et al. have indicated that, children with BMD with mean age of 22.9 ± 9.8 years have higher level functional abilities than children with DMD with mean age of 12.4 ± 4.6 years [20]. In line with this, the functional level of children with BMD were found to be better than children with DMD in the current study. Jacques et al. have found that adults with BMD had more muscle strength than adults with DMD. Except for hip extension muscle strength, no considerable difference was found between the muscle strength of children with BMD and DMD in this research [21]. This result is not surprising given the younger age of children with DMD, and the milder prognosis of BMD [4,22]. Although progressive balance loss is known to occur in DMD and BMD, the authors did not find a study in the literature comparing balance abilities in children with DMD and BMD [4]. In the current study, static and dynamic balance ability under various conditions was found to be greater in children with BMD than in children with DMD.

In children, balance ability begins to develop in infancy, and it still develops gradually until the age of seven; however, the improvement of balance like adult ability proceeds to 16 years [23,24]. However, given the progressive nature of D/BMD and the progressive loss of motor function with age, regression of balance with age is reasonable for this

Table 3
Balance related factors in children with D/BMD.

		Sociodemographic characteristics				Functional level				Muscle strength				
n = 20		Age	Height	Weight	BMI	MFM32-D1	MFM32-D2	MFM32-D3	MFM32-Total	Hip flexion	Hip extension	Knee flexion	Knee extension	Dorsiflexion
MCTSIB-sway velocity-EO-firm(°/s)	r	-0.067	-0.386	**-0.693***	**-0.557***	**-0.705***	**-0.642***	**0.683***	**-0.786***	-0.361	**-0.453***	**-0.488***	**-0.451***	**-0.536***
	p	0.779	0.092	**0.001**	**0.011**	**0.001**	**0.002**	**0.001**	**0.000**	0.118	**0.045**	**0.029**	**0.046**	**0.015**
MCTSIB-sway velocity-EC-firm(°/s)	r	-0.066	**-0.364**	**-0.636***	-0.375	**-0.518***	-0.426	**-0.486***	**-0.513***	-0.374	**-0.482***	-0.301	-0.323	-0.359
	p	0.778	**0.115**	**0.003**	0.104	**0.019**	0.061	**0.030**	**0.021**	0.104	**0.031**	0.197	0.165	0.120
MCTSIB-sway velocity-EO-foam(°/s)	r	-0.012	-0.425	**-0.738***	-0.373	**-0.668***	**-0.587***	**-0.644***	**-0.702***	**-0.467***	**-0.624***	**-0.460***	-0.436	**-0.557***
	p	0.961	0.061	**0.000**	0.105	**0.001**	**0.006**	**0.002**	**0.001**	**0.038**	**0.003**	**0.041**	0.054	**0.011**
MCTSIB-sway velocity-EC-foam(°/s)	r	-0.052	-0.359	**-0.671***	-0.223	-0.436	**-0.528***	-0.420	**-0.486***	-0.248	-0.402	-0.343	-0.287	**-0.447***
	p	0.828	0.120	**0.001**	0.345	0.055	**0.017**	0.065	**0.030**	0.291	0.079	0.139	0.219	**0.048**
MCTSIB-sway velocity-complete(°/s)	r	-0.070	**-0.453***	**-0.775***	-0.413	**-0.602***	**-0.570***	**-0.595***	**-0.640***	-0.367	**-0.527***	-0.403	-0.373	**-0.515***
	p	0.767	**0.045**	**0.000**	0.071	**0.005**	**0.009**	**0.006**	**0.002**	0.111	**0.017**	0.078	0.105	**0.020**
LoS-RT-complete (s)	r	0.314	0.141	-0.126	**-0.605***	-0.399	0.000	-0.172	-0.306	-0.141	-0.065	0.111	0.044	-0.038
	p	0.177	0.553	0.597	**0.005**	0.081	1.000	0.469	0.190	0.553	0.785	0.641	0.855	0.873
LoS-MVL-complete (°/s)	r	0.137	0.308	**0.496***	0.137	**0.450***	**0.469***	**0.536***	**0.454***	-0.060	0.340	-0.202	-0.197	0.057
	p	0.566	0.187	**0.026**	0.564	**0.046**	**0.037**	**0.015**	**0.044**	0.801	0.143	0.393	0.405	0.811
LoS-EPE-complete (%)	r	0.320	**0.459***	**0.715***	0.252	**0.772***	**0.714***	**0.634***	**0.747***	0.353	**0.619***	0.065	0.077	0.347
	p	0.169	**0.042**	**0.000**	0.284	**0.000**	**0.000**	**0.003**	**0.000**	0.126	**0.004**	0.786	0.747	0.134
LoS-MXE-complete (%)	r	0.203	0.356	**0.712***	0.401	**0.727***	**0.490***	**0.484***	**0.630***	0.254	**0.612***	0.107	0.076	0.385
	p	0.390	0.124	**0.000**	0.080	**0.000**	**0.028**	**0.031**	**0.003**	0.281	**0.004**	0.654	0.750	0.094
LoS-DCL-complete (%)	r	0.328	0.148	0.422	0.118	**0.615***	**0.661***	0.214	**0.648***	**0.644***	0.399	0.410	0.290	0.404
	p	0.158	0.533	0.064	0.620	**0.004**	**0.002**	0.364	**0.002**	**0.002**	0.081	0.073	0.214	0.078
**Tandem-step width (cm)	r	0.095	-0.168	-0.345	-0.430	-0.409	-0.297	-0.448	**-0.469***	-0.128	-0.084	-0.159	-0.154	-0.307
	p	0.708	0.506	0.161	0.075	0.092	0.232	0.062	**0.049**	0.612	0.740	0.529	0.542	0.215
**Tandem-walk speed (cm/s)	r	0.085	0.402	**0.748***	0.480	**0.623***	**0.583***	0.431	**0.576***	0.224	**0.476***	-0.072	-0.133	0.123
	p	0.736	0.098	**0.000**	0.044	**0.006**	**0.011**	0.074	**0.012**	0.371	**0.046**	0.777	0.598	0.628
**Tandem-end sway (°/s)	r	**0.596***	0.322	0.189	-0.005	0.058	0.072	0.133	-0.014	-0.152	0.039	**-0.508***	-0.386	**-0.475***
	p	**0.009**	0.193	0.452	0.984	0.819	0.777	0.600	0.954	0.547	0.878	**0.031**	0.114	**0.046**

*: $p < 0.05$, EO: eyes open, EC: eyes closed, MCTSIB: modified clinical test of sensory interaction on balance, LoS: Limit of stability, RT: reaction time, MVL: movement velocity, EPE: endpoint excursion, MXE: maximum excursion, DCL: directional control, BMI: body mass index, MFM32: Motor Function Measurement-32, D1: standing position and transfers, D2: axial and proximal motor function, D3: distal motor function
**Two patients with DMD could not perform the tandem test.

population [3,4]. Kelly et al. have shown that the balance ability of children with DMD regress with age [25]. Also, Alkan et al. have indicated the functional ability of older children with DMD worse than younger ones [10]. In this research, it has been seen that tandem end-sway increase with age, which means that balance ability diminishes with age. However, in this study, no relationship was found between age and other balance parameters. It is believed that the reason is that the patients diagnosed with BMD, the milder form of the disease, are older and their balance ability is significantly better.

The relationship between height and balance in children is not well understood. Skrzypinska et al. have found no significant relationship between balance and height in children [26]. Butz et al. have found a positive relationship between balance and height, but in their research, height was not one of the factors that determine balance ability [27]. On the other hand, Kolic et al. have found both positive and negative relationships between height and some balance parameters [24]. The present study is the first to investigate the relationship between anthropometric characteristics and balance in children with D/BMD, and according to the results of this study, balance is positively affected with increasing height. However, when interpreting the results of this study, it should be considered that the result may have been due to the fact that the children with BMD were taller.

The relation between weight and balance is controversial. In the literature, lots of studies suggested that balance diminishes as the weight gain [24,28,29]. On the other hand, some studies suggest that weight gain may positively affect balance by increasing bone development or providing a large support surface [30,31]. In the current study, it was observed that the balance of children with DMD improved with weight gain. These findings are not surprising given that 80% of children are on age-appropriate percentiles. Because previous studies have stated that weight gain, especially resulting in high BMI, negatively affects balance [24,28,29] In the current study, since the children were in the normal percentile range, weight gain may have positively affected balance as a factor supporting appropriate development. Also, it is noteworthy that, in this research, children with BMD have a heavier weight.

There are studies have suggested that high BMI correlated with poorer balance ability in children [24,31,32]. In the current study, it was seen that balance scores increased as BMI raised. However, it is considerable that all the participants in this research under the %50th percentile level. In other words, the fact that no child is in the high BMI class and that the children in the normal BMI level are closer to the lower rank may be the possible reason for the present results.

This is the first study to examine the relationship between balance and functional level in children with D/BMD. Alkan et al., in their study, included children with DMD at levels I-III according to VS, have stated that especially the children at level III had worse balance ability [10]. In this study, strong relations were found between many balance parameters and the MFM-32 total score, subsection scores. As the MFM-32 total score and subsection scores increased, the balance scores also improved. In addition, the parameters with the highest correlation coefficient among the parameters examined in relation to balance were the MFM-32 total score and sub-scores. Based on the results of this study, it can be said that there is a strong relationship between balance ability and functional level.

Alfano et al. investigated the relationship between balance and knee muscle strength in their study involving 25 ambulatory BMD patients aged 13–70 years. They have reported that knee muscle strength is an important parameter for balance ability in patients with BMD [11]. Kaya et al. have also noted that muscle strength is important to provide dynamic stability in neuromuscular disease groups in which proximal involvement is predominant, such as in D/BMD [33]. In the current study, it was found that different values for balance components develop with increasing muscle strength. The increase in muscle strength has a positive effect on balance of children with D/BMD.

This study has several limitations. Since our study is cross-sectional, we cannot explain the cause-effect relationship of the factors associated with balance. In addition, the children with DMD and BMD in this study were distributed differently in terms of age, height, and weight, which makes it difficult to comment on the relationship between these factors and balance ability. The relatively small number of participants in the study is a factor that may affect the generalizability of the results, especially in statistical methods comparing outcomes of children with DMD and BMD. However, the fact that D/BMD belongs to the rare disease group caused the sample size limited to 20 subjects. We hope that the present study will be a first step for further investigations, perhaps with multicenter studies with larger sample sizes, to provide more robust evidence. The strength of the present study is that it is the first study to investigate balance-related factors in children with D/BMD and to use an objective method to assess balance.

5. Conclusions

In conclusion, balance ability in children with D/BMD was influenced by age, height, weight, BMI, functional level, and muscle strength. Studies including only DMD and/or BMD cases are needed to better understand the relationship between balance and these factors in this population. Weight gain that does not result in abnormal BMI appears to have a positive effect on balance in these children. For this reason, referring children with BMI values below the normal percentile to appropriate professionals may have a positive effect on their balance skills. Based on the results of this study, it was concluded that muscle strength is an essential factor for balance, and it is considered that strength training performed in accordance with the training guidelines for these children should be included in rehabilitation programs. Given the close relationship between balance and functional level, it was concluded that balance training should be an integral part of the rehabilitation program for patients with D/BMD.

Ethics approval

The Ethical Board of the University of Dokuz Eylul approved the study in conformity with the Declaration of Helsinki principles (ref no:2019/19–23).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Consent to participate

At the beginning of the study, all participants were informed, and their verbal consent was taken.

Ethical publication statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

Disclosure of conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

References

[1] P.J. Taylor, S. Maroulis, G.L. Mullan, R.L. Pedersen, A. Baumli, G. Elakis, et al., Measurement of the clinical utility of a combined mutation detection protocol in carriers of Duchenne and Becker muscular dystrophy, J. Med. Genet. 44 (2007) 368–372, https://doi.org/10.1136/jmg.2006.047464.

[2] M.L. Mah, L. Cripe, M.K. Slawinski, S.A. Al-Zaidy, E. Camino, K.J. Lehman, et al., Duchenne and Becker muscular dystrophy carriers: evidence of cardiomyopathy by exercise and cardiac MRI testing, Int. J. Cardiol. 316 (2020) 257–265, https://doi.org/10.1016/j.ijcard.2020.05.052.

[3] K.R.Q. Lim, Q. Nguyen, T. Yokota, Genotype-phenotype correlations in duchenne and becker muscular dystrophy patients from the Canadian neuromuscular disease registry, J. Pers. Med. 10 (2020) 1–18, https://doi.org/10.3390/jpm10040241.

[4] M.A. Waldrop, K.M. Flanigan, Update in Duchenne and Becker muscular dystrophy, Curr. Opin. Neurol. 32 (2019) 722–727, https://doi.org/10.1097/WCO.0000000000000739.

[5] R. Humphriss, A. Hall, M. May, J. Macleod, Balance ability of 7 and 10 year old children in the population: results from a large UK birth cohort study, Int. J. Pediatr. Otorhinolaryngol. 75 (2011) 106–113, https://doi.org/10.1016/j.ijporl.2010.10.019.

[6] C. Condon, K. Cremin, Static balance norms in children, Physiother. Res. Int. 19 (2014) 1–7, https://doi.org/10.1002/pri.1549.

[7] M. Kurt, E. Tatlici, T.T. Simsek, Anthropometric and demographic properties affect balance in healthy adults: an observational study, J. Sports Med. Phys. Fit. 61 (2021) 818–828, https://doi.org/10.23736/S0022-4707.20.11422-1.

[8] S. Panibatla, V. Kumar, A. Narayan, Relationship between trunk control and balance in children with spastic cerebral palsy: a cross-sectional study, J. Clin. Diagn. Res. 11 (2017) YC05–YC08, https://doi.org/10.7860/JCDR/2017/28388.10649.

[9] N.P. Vaghela, J.N. Mehta, D. Rana, Relationship between anthropometrics characteristics and dynamic balance in children of Anand City, Gujarat, J. Clin. Diagn. Res. (2018), https://doi.org/10.7860/JCDR/2018/33920.11516.

[10] H. Alkan, A. Mutlu, T. Fırat, N. Bulut, A.A. Karaduman, Ö.T. Yılmaz, Effects of functional level on balance in children with Duchenne Muscular Dystrophy, Eur. J. Paediatr. Neurol. 21 (2017) 635–638, https://doi.org/10.1016/j.ejpn.2017.02.005.

[11] L.N. Alfano, L.P. Lowes, K.M. Flanigan, J.R. Mendell, Correlation of knee strength to functional outcomes in Becker muscular dystrophy, Muscle Nerve 47 (2013) 550–554, https://doi.org/10.1002/mus.23660.

[12] K.J. Nicholson, A.A. Reyes, M. Sherman, S.N. DIvi, A.R. Vaccaro, Power analysis for null hypothesis significance testing, Clin. Spine Surg. 34 (2021) 63–65, https://doi.org/10.1097/BSD.0000000000001079.

[13] CDC, MI percentile calculator for child and teen: results on a growth chart. Centers for Disease Control and Prevention, 2018. ⟨https://www.cdc.gov/healthyweight/bmi/resultgraph.html?&method=english&gender=m&age_y=12&age_m=0&hft=4&hin=0.25&twp=46⟩.

[14] H.S. İnal, E. Tarakçi, D. Tarakçi, G. Aksoy, S. Mergen Kiliç, H. Beşer, et al., Turkish version of the motor function measure scale (MFM-32) for neuromuscular diseases: a cross-cultural adaptation, reliability, and validity study, Turk. J. Med. Sci. 47 (2017) 1826–1833, https://doi.org/10.3906/sag-1603-91.

[15] M.H. Brooke, R.C. Griggs, J.R. Mendell, G.M. Fenichel, J.B. Shumate, R. J. Pellegrino, Clinical trial in Duchenne dystrophy. I. The design of the protocol, Muscle Nerve 4 (1981) 186–197, https://doi.org/10.1002/mus.880040304.

[16] P.J. Vignos, G.E. Spencer, K.C. Archibald, Management of progressive muscular dystrophy of childhood, JAMA: J. Am. Med. Assoc. 184 (1963) 89–96, https://doi.org/10.1001/jama.1963.03700150043007.

[17] B.F. Mentiplay, L.G. Perraton, K.J. Bower, B. Adair, Y.H. Pua, G.P. Williams, et al., Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study, PLoS One 10 (2015), e0140822, https://doi.org/10.1371/journal.pone.0140822.

[18] B.D. Balci, G. Akdal, E. Yaka, S. Angin, Vestibular rehabilitation in acute central vestibulopathy: a randomized controlled trial, J. Vestib. Res. 23 (2013) 259–267, https://doi.org/10.3233/VES-130491.

[19] P. Schober, C. Boer, L.A. Schwarte, Correlation coefficients, Anesth. Analg. 126 (2018) 1763–1768, https://doi.org/10.1213/ANE.0000000000002864.

[20] Y.J. Lue, R.F. Lin, S.S. Chen, Y.M. Lu, Measurement of the functional status of patients with different types of muscular dystrophy, Kaohsiung J. Med. Sci. 25 (2009) 325–333, https://doi.org/10.1016/S1607-551X(09)70523-6.

[21] M.F. Jacques, G.L. Onambele-Pearson, N.D. Reeves, G.K. Stebbings, J. Smith, C. I. Morse, Relationships between muscle size, strength, and physical activity in adults with muscular dystrophy, J. Cachex. Sarcopenia Muscle 9 (2018) 1042–1052, https://doi.org/10.1002/jcsm.12347.

[22] M.M.H.P. Janssen, A.C.H. Geurts, I.J.M. de Groot, Towards a short questionnaire for stepwise assessment of upper limb function, pain and stiffness in Duchenne muscular dystrophy, Disabil. Rehabil. 40 (2018) 842–847, https://doi.org/10.1080/09638288.2016.1274336.

[23] V.L. Cumberworth, N.N. Patel, W. Rogers, G.S. Kenyon, The maturation of balance in children, J. Laryngol. Otol. 121 (2007) 449–454, https://doi.org/10.1017/S0022215106004051.

[24] J. Kolic, K. O'Brien, K. Bowles, R. Iles, C.M. Williams, Understanding the impact of age, gender, height and body mass index on children's balance, Acta Paediatr. 109 (2020) 175–182, https://doi.org/10.1111/apa.14933.

[25] C.R. Kelly, J.B. Redford, S. Zilber, P.A. Madden, Standing balance in healthy boys and in children with Duchenne muscular dystrophy, Arch. Phys. Med. Rehabil. 62 (1981) 324–327.

[26] A. Turon-Skrzypinska, A. Uździcki, T. Przybylski, A. Szylinska, M. Marchelek-Myśliwiec, A. Rył, et al., Assessment of selected anthropometric parameters influence on balance parameters in children, Medicina 56 (2020) 176, https://doi.org/10.3390/medicina56040176.

[27] S.M. Butz, J.K. Sweeney, P.L. Roberts, M.J. Rauh, Relationships among age, gender, anthropometric characteristics, and dynamic balance in children 5 to 12 years old, Pediatr. Phys. Ther. 27 (2015) 126–133, https://doi.org/10.1097/PEP.0000000000000128.

[28] I. Villarrasa-Sapiña, X. García-Massó, P. Serra-Añó, C. Garcia-Lucerga, L. M. Gonzalez, E. Lurbe, Differences in intermittent postural control between normal-weight and obese children, Gait Posture 49 (2016) 1–6, https://doi.org/10.1016/j.gaitpost.2016.06.012.

[29] O. Hue, M. Simoneau, J. Marcotte, F. Berrigan, J. Doré, P. Marceau, et al., Body weight is a strong predictor of postural stability, Gait Posture 26 (2007) 32–38, https://doi.org/10.1016/j.gaitpost.2006.07.005.

[30] M.E. Tinetti, J.T. Doucette, E.B. Claus, The contribution of predisposing and situational risk factors to serious fall injuries, J. Am. Geriatr. Soc. 43 (1995) 1207–1213, https://doi.org/10.1111/j.1532-5415.1995.tb07395.x.

[31] A.J.Y. Lee, W.H. Lin, The influence of gender and somatotype on single-leg upright standing postural stability in children, J. Appl. Biomech. 23 (2007) 173–179, https://doi.org/10.1123/jab.23.3.173.

[32] S. Lara, S. Graup, R. de Souza Balk, L.P. Teixeira, A.D. Farias, G.B. Alves, et al., Association between postural balance and anthropometric indexes in elementary schoolchildren, Rev. Paul. Pediatr. 36 (2018) 59–65, https://doi.org/10.1590/1984-0462/;2018;36;1;00011.

[33] P. Kaya, I. Alemdaroŀlu, Ö. Yilmaz, A. Karaduman, H. Topaloŀlu, Effect of muscle weakness distribution on balance in neuromuscular disease, Pediatr. Int. 57 (2015) 92–97, https://doi.org/10.1111/ped.12428.