BUC BADR UNIVERSITY IN CAIRO جامعة بدر بالقاهرة

Egyptian Journal of Physical Therapy and Rehabilitation (EJPTR)

Faculty of Physical Therapy

e-ISSN: 2974-3605
p-ISSN: 2974-3591

Observational studies

Relation between anthropometric measurements and balance in children with type 1 diabetes

Mohamed E Mohamed[1], Hanaa Mohsen Abd-Elfattah[2], Shimaa Atef [3], Amira M. Abd-Elmonem [1]*, Asmaa O Sayed[1]

[1] Department Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Giza, Egypt.

[2] Department of Physical Therapy for Pediatrics and Pediatric Surgery, Faculty of Physical Therapy, Badr University in Cairo, Egypt.

[3] Department of Endocrinology, Faculty of Medicine, Cairo University Egypt.

***Correspondence:** Amira M. Abd-Elmonem; **Email**: amira.mahmoud@cu.edu.eg

DOI: https://doi.org/10.21608/ejptr.2025.368220.1020

Citation: Mohamed ME., Abd-Elfattah HM., Ated S., Abd-Elmonem AM., Sayed AO. Relation between anthropometric measurements and balance in children with type 1 diabetes. Egyptian Journal of Physical Therapy and Rehabilitation. 2025 Aug.;5(1): 35-44

Received: 13/3/2025
Accepted: 23/3/2025
Published: Aug. 2025

Abstract

Background: Diabetes mellitus type 1 (T1D) is frequently associated with concurrent medical conditions that cause physical limitations.
Purpose: Investigate the relation between anthropometric measurements and balance in children with T1D using Human Assessment Computer (HUMAC) balance system. **Material and Methods:** The assessment procedures were collected from Outpatient Diabetes Clinic of Abu El-rish Hospital. Participants: Sixty children with type 1 diabetes, age ranged from 7 to 14 years, they had a disease from less than 5 years ago, didn't have other problems. Outcome measures: The (HUMAC balance system) HUMAC balancing system was used to evaluate the limitations of stability, pressure center, sensory organization, and balance.
Results: Children with higher body mass index (BMI) decreased sensory integration and balance were all statistically significant, when standing on soft surface and eye closed. There was significant when related the height to center of pressure (COP) score and sensory integration especially when standing on soft surface and eye closed.
Conclusion: Children with T1D who have higher BMI and height exhibit poor postural stability especially when standing on soft surface and eye closed. Early detection of these deficits is suggested to reduce the risk of complications in maturity.
Keywords: Anthropometric measurements; Diabetes; Diabetes mellitus type 1; HUMAC balance system; Postural stability.

Introduction:

A set of metabolism-related conditions known as diabetes mellitus (DM) are identified by elevated plasma glucose levels. Diabetes's persistent hyperglycemia; brought on by deficiencies in either insulin activity or production, or both; can contribute to permanent damage, malfunction, and organ failure, particularly to the kidneys, eyes, heart, nerves, and cardiovascular system **(1)**. According to Cho et al.**(2)**, individuals with diabetes are more likely to experience a variety of major, life-threatening health issues that raise healthcare costs, lower quality of life, and increase death rates.

An autoimmune condition known as T1D causes the beta cells in the pancreas to be destroyed. Higher levels of insulin and malfunctioning pancreatic beta cells combine to cause increasingly diminished glucose regulation, which is the main cause of type 2 diabetes (T2D), which is far more common **(3)**. While the primary cause of death for diabetics is hyperglycemia-induced damage to the macrovascular system, which includes the coronary and cerebral blood vessels. The microvascular circulation in the kidney, eyes, and nerves is considerably more frequently damaged by hyperglycemia **(4)**.

Complications associated with diabetes comprise sensory, motor, and autonomic neuropathies, which can impact several physiological systems, including the neuromuscular system. Diabetes-related sensorimotor neuropathy is manifested by loss of muscle mass, abnormal stride, the development of new pressure sites, and ultimately foot ulcers. Loss of feeling, skeletal abnormalities, misshapen feet, painless trauma, and ultimately foot ulceration are the hallmarks of sensory neuropathy **(5)**.

Diabetes mellitus damages mechanoreceptors in the sole of the feet, alters proprioception, decreases the individual's capacity to maintain balance, and causes fatigue in the skeletal muscles of the lower extremities, all of which have an adverse effect on the structures and functions of the vestibular system, thereby affecting both static and dynamic balance **(6)**.

The ability of the body to maintain body posture without additionally assistance, with a possible risk of uncontrollably falling, is known as human postural stability function, and it is a crucial aspect of motor activity **(7)**. Disorders, musculoskeletal or neurological problems, anthropometric parameters, aging, consumption of medications, physical condition, and specific training (e.g., intense exercises) can all have an impact on postural balance systems. Extrinsic factors that can affect postural balance include the type of footwear and the type of the floor. Anthropometric characteristics can impact the motor processes associated with the adjustment as well as the body's stability limits. Postural balance correlates directly with certain anthropometric characteristics, such as body mass **(8)**.

According to Minges et al. **(9)**, overweight and obesity are currently common among young individuals with T1D and can have serious implications for health, including as cardiovascular problems and diagnosis of T2D. Approximately 50% of T1D patients are overweight or obese. In comparison to healthy controls, they also exhibit greater hip and waist circumferences **(10)**. The vestibular system is also frequently negatively impacted by metabolic disorders of T1D, primarily affecting the central part of the organ. As stated by Fernandes et al. **(11)** this change is associated with the number and kind of hypoglycemia episodes along with the severity and management of the illness. Various deficits, such as nephropathy, retinopathy, and neuropathy, compromise the individual's ability to perform daily activities appropriately and achieve a satisfactory level of activity. Another potential diabetic consequence that could raise the risk of falls is vestibular dysfunction **(12)**.

Investigating the correlation between anthropometric parameters and postural equilibrium in children with diabetes is crucial since it assists a multidisciplinary team design the appropriate strategy to enhance those children' functional abilities. The relationship between anthropometric measures and postural balance in children with diabetes is an area of little published research. However, to the best of our knowledge, not many researches have examined the relationship between anthropometric measures and postural equilibrium in children with diabetes. This study was conducted to evaluate and examine this relationship between anthropometric measurements [weight, height, body mass index (BMI)] and postural balance: (limits of stability (LOS), center of pressure (COP) and sensory integration) in children with T1D.

Materials and Methods:

Study design, duration and ethical considerations

A cross-sectional observational study was conducted between August 2022 and March 2023. The study protocol was approved by the Ethical Committee of the Faculty of Physical Therapy, Cairo University, Egypt (No: P.T.REC/012/003865). Children's participation was authorized by a signed written consent form with parent's/legal guardian's acceptance for participation before starting the study procedures. A permit was accepted and signed from head of the endocrinology and diabetes unit of Abu El-Rish Hospial, Cairo University.

Sample size estimation

To avoid type II error, sample size calculation was performed using G*POWER statistical software (version 3.1.9.2; Franz Faul, Universitat Kiel, Germany) [Exact tests- correlational study, α=0.05, power = 80%, and effect size = 0.36] and revealed that the appropriate sample size for this study was approximately 55 subjects.

Subjects

Subjects included sixty volunteer children withT1D. These children were selected from the Outpatient Clinic of Abu El-rish Hospital. Inclusion criteria were: 1) Age ranged from 7 to 14 years, 2) both sexes, 3) The duration of the disease is ranged between 3 to 5 years as over a 5-year period, diabetes duration and poor glycemic control were found to be more substantial risk factors for the development of subclinical neuropathy (13). Children were excluded if they had: 1) other hormonal diseases (hypothyroidism or hyperthyroidism), 2) hereditary sensory and autonomic neuropathy, 3) orthopedics problems and any other disease may affect the research, and/or 4) subjects participating in regular sports activities.

Assessment of anthropometric measurements

Demographic and anthropometric measurements including age, sex, weight, height, body mass index) and data were recorded from medical records. A standard weight and height scale (Hanson professional scale, Hanson co.Ltd. Beccles, U.K) was used to determine the weight in (kg) and height (cm). BMI is a value derived from the mass (weight) and height of a person. The BMI is defined as the body mass divided by the square of the body height, and is expressed in units of kg/m², resulting from mass in kilograms and height in meters. BMI is used differently for children. The BMI percentile charts were used children for both genders. BMI is age- and sex-specific and is often referred to as BMI-for-age.

Assessment of balance

In the current study, a computerized dynamic post urography called the HUMAC (commuter sports medicine, Inc., Stoughton, MA) was used. It is distinct technology used for postural control evaluation and treatment. This widely available, reasonably priced force plate offers both numerical data and visual feedback to the patient and examiner. With eight programs to select from, the system offers a number of reporting choices with unbiased, educational data to give medical professionals knowledge regarding the patients' improvement. This information is used for both baseline and follow-up analysis (14, 15). For the current investigation, the COP test, the mCTSIB, and LOS test were conducted.

Stability test: It measures the participant's ability to stabilize his/her balance at locations around their neutral position which means that higher values indicate better performance. Results are reported as the percent of time a subject holds his COP in each of the eight flashing targets in clockwise order (right/left and anterior/posterior weight distribution). These targets are eight specific points in which the current target flashes green when the participant is on-target and flashes yellow when he is off-target. The HUMAC system provides a countsdown of the hold time to inform the participant knows when he/she should move to the next target.

Average velocity and Path length: The average rate at which an object or bodily part moves over a certain time period. Average velocity can be estimated for individual body segments (e.g., arms, legs) or for the entire body during a given motion or activity in the context of human movement analysis. The COP path length represents the distance moved by the COP, which means that smaller values indicate better performance (16).

The mCTSIB test: This test was used to assess the sensory integration of balance in the condition of eyes open and eyes closed, first the child was instructed to stand on the platform ,the therapist started the test after determining the position of the two feet and set the anatomical zero then instruct the child to look at target on the wall placed at level of her eyes for 30 seconds (as it was proved that 30 seconds to 60 seconds were enough duration for data analysis then he/she was instructed to close his/her eyes for another 30 seconds on firm surface and then repeat for another 30 second eyes open, eyes closed on foam surface (17).

Statistical Analysis

Descriptive statistics was utilized in presenting the subjects demographic and collected data. Pearson Correlation Coefficient was conducted to investigate the correlation between weight, height and BMI and HUMAC. The level of significance for statistical tests was set at $p < 0.05$. All statistical measures were performed through the statistical package for social sciences (SPSS) version 25 for windows.

Results:

Subject characteristics:

Sixty children with T1D participated in this study group. Their mean ± SD age, weight, height and BMI were 11.28 ± 2.23 years, 39.44 ± 15.54 kg, 141.45 ± 14.20 cm and 18.95 ± 4.16 kg/m². Participant characteristics are presented in table (1).

HUMAC measurement of subjects

The mean value ± SD of stability score, COP and path length were 41.60 ± 12.84, 92.17 ± 3.73 cm, 15.19 ± 5.92 cm and average velocity respectively, while the mean value ± SD of EOSS, ECSS, EOFS and ECFS were 89.68 ± 7.31, 83.83 ± 6.14, 80.90 ± 6.49 and 76.80 ± 7.91 respectively (Table 2).

Correlation between weight, height and BMI and HUMAC

The correlations between weight and HUMAC measurements were moderate positive significant correlation with ECSS (r = 0.321, p = 0.012) and ECFS (r = 0.362, p = 0.004), while were weak positive non-significant correlation with stability score (r = 0.097, p = 0.463), COP (r = 0.167, p = 0.201), path length (r = 0.089, p = 0.498), EOSS (r = 0.031, p = 0.811) and with EOFS (r = 0.095, p = 0.471). The correlation between weight and average velocity was weak negative non-significant correlation (r = -0.211, p = 0.105). (Table 3).

The correlations between height and HUMAC measurements were moderate positive significant correlation with COP (r = 0.324, p = 0.012), ECFS (r = 0.399, p = 0.002) and ECSS (r = 0.300, p = 0.020). While the correlations were weak positive non-significant correlation with stability score (r = 0.086, p = 0.516), path length (r = 0.059, p = 0.656), EOSS (r = 0.024, p = 0.856) and with EOFS (r = 0.066, p = 0.615). The correlation between weight and average velocity was weak negative non-significant correlation (r = -0.177, p = 0.176). (Table 3).

The correlations between BMI and HUMAC measurements were weak positive significant correlation with ECSS (r = 0.263, p = 0.042) and ECFS (r = 0.294, p = 0.023), while were weak positive non-significant correlation with stability score (r = 0.106, p = 0.421), COP (r = 0.016, p = 0.903), path length (r = 0.118, p = 0.369), and with EOFS (r = 0.098, p = 0.455). The correlations with BMI were weak negative non-significant correlation with average velocity was (r = -0.203, p = 0.120) and with EOSS (r = -0.011, p = 0.937). (Table 3).

Table 1. Participant characteristics.

	Mean ± SD	Maximum	Minimum
Age (years)	11.28 ± 2.23	16	7
Weight (kg)	39.44 ± 15.54	79	21
Height (cm)	141.45 ± 14.20	169	118
BMI (kg/m²)	18.95 ± 4.16	32.04	13.02
	N	**%**	
Sex distribution, n (%)			
Girls	32	53.3	
Boys	28	46.7	

SD, Standard deviation

Table 2. Descriptive statistics of HUMAC measurement:

	Mean ± SD	Minimum	Maximum
Stability score	41.60 ± 12.84	19	66
COP	92.17 ± 3.73	77	97
Path length (cm)	15.19 ± 5.92	7.49	38.36
Average velocity (cm/s)	0.99 ± 0.27	0.51	1.74
EOSS	89.68 ± 7.31	56	98
ECSS	83.83 ± 6.14	67	95
EOFS	80.90 ± 6.49	68	97
ECFS	76.80 ± 7.91	53	88

SD, Standard deviation

Table 3. Correlation between weight, height and BMI and HUMAC:

	Weight		Height		BMI	
	r - value	**P- value**	**r - value**	**P- value**	**r - value**	**P- value**
Stability score	0.097	0.463	0.086	0.516	0.106	0.421
COP	0.167	0.201	0.324	0.012*	0.016	0.903
Path length (cm)	0.089	0.498	0.059	0.656	0.118	0.369
Average velocity (cm/s)	-0.211	0.105	-0.177	0.176	-0.203	0.120
EOSS	0.031	0.811	0.024	0.856	-0.011	0.937
ECSS	0.321	0.012*	0.300	0.020*	0.236	0.42*
EOFS	0.095	0.471	0.066	0.615	0.098	0.455
ECFS	0.362	0.004*	0.399	0.002*	0.294	0.023*

r value: Pearson correlation coefficient; p value: Probability value, * significant at $p < 0.05$.

Discussion:

The current study's objectives were to investigate the relation between anthropometric measurements and balance in children with T1D. In this regard, certain proxies of anthropometric measurements (weight, height, BMI) and postural balance: (LOS, COP and mCTSIB) were assessed. The primary findings of the current study were that: (1) Moderate positive significant between height and COP; (2) Weak positive non-significant correlation between BMI, limits of stability and COP; (3) Weak positive significant correlation between BMI, ECSS and ECFS.

The age of the children and the duration of the diagnosis were among the criteria that were used for selecting the participants for this current research, which may have an impact on results. Since postural control resembles that of an adult from six to ten years old, their ages ranged from seven to fourteen years. This is consistent with the findings of Kolar **(18)**, who noted that the development of the phasic muscles' postural function is complete by the age of four years old. These muscles play an increasingly significant role in posture and its stabilization as the CNS matures.

A common way to assess obesity is via the BMI, which is computed as weight (kg) divided by height squared (m^2). It is commonly acknowledged as a useful tool for determining one's current body weight status and is associated with a number of health outcomes, such as mortality, T2D, and cardiovascular disease. It is unclear, therefore, how BMI and postural balance relate to individuals with T1D. Although obesity is widely recognized as a predictive indicator of impaired postural alignment in the general population, it is still controversial how BMI affects postural balance in individuals with T1D **(19)**.

The results of earlier studies, which showed that height is one anthropometric parameter related to stabilization and balance, support the findings of the current study. Furthermore, it has been demonstrated that height affects spinal alignment in T1D patients. Greater COP acceleration during postural exercises is seen in taller individuals, which may indicate a higher level of instability in their capacity to control their balance **(20)**.

Our results are consistent with earlier study conducted that, Santos et al. **(20)**) who conducted studies included T1D patients to investigate the association between height and COP displacement. They stated that, stability was impaired in those who were taller due to larger COP displacements in the A/P plane.

Based on previous researches, though, that postural condition of balance cannot be anticipated only by height since, as was said earlier, postural stabilizing is a multifaceted process comprising multiple body systems. In order to properly evaluate postural stability among individuals with T1D, an extensive evaluation of several factors is crucial, particularly physical characteristics, muscle power, and sensory capabilities **(21)**. When studying postural balance in individuals with T1D, it is important to take into account several anthropometric parameters, as demonstrated by the association between height and COP displacement during postural sway activities **(20)**.

The present study's observations demonstrate that there is no significant association between postural balance and BMI. This is at contradiction with the result of Azzeh et al. **(22)**, who found that in young, healthy people, a greater BMI was associated with diminished stability limits. In the study, a computerized dynamic posturography system was used to assess stability in 110 young volunteers. The results showed that LOS was considerably lower in participants with a higher BMI than in those with a lower BMI.

Moreover, Cancela-Carral et al. **(13)** declared that insufficient control of balance and significant postural sway correlated to increase BMI. The composition of body fat could be one of the reasons. A greater percentage of fat is concentrated in the waist and abdominal area in those with higher BMIs, which might have implications on the body's COG. As consequently, balance control may be impaired, particularly in circumstances that require for greater steadiness, such standing on an uneven surface or closing one's eyes.

The mechanisms behind the link between BMI and in T1D patients remain unknown. Several probably mechanisms, however, have been hypothesized regarding the relation between BMI and postural balance including increased joint stress, proprioception impairment, reduced muscular strength and higher insulin resistance **(23-25)**.

The results of the current study demonstrated positive correlation between BMI and closed eye sensory integration of balance tests. Multiple body systems are integrated to assist with the complex process of balance, such as the vestibular (inner ear), proprioceptive (sensory feedback from muscles and joints), and visual systems. If one or more of these organs malfunctions, equilibrium may be disrupted particularly while the eyes are closed **(26)**.

This also matches previous investigations that demonstrated children with T1D had lower balance control than healthy controls, particularly while their eyes were closed. The T1D group exceeded the healthy controls regarding postural sway when the eyes were closed either on solid or foam surfaces. Due to diminished sensory feedback from muscles and joints, vestibular function—which is in controlling balance and spatial orientation—may be impacted by T1D **(27,28)**.

The current study's findings can be explained by the fact that postural sway and stability are maintained and controlled by these tests relying on vestibular (closed eyes) and visual (open eyes) cues. Kluding et al **(29)** suggested that, children having T1D may be more susceptible to postural instability than their non-diabetic peers. Peripheral neuropathy, or damage to nerves other than the brain and spinal cord, altered sensory feedback, declined muscle strength, and other conditions can all cause postural imbalance issues in children with T1D.

Conclusion:

The current study's findings demonstrated that children with higher BMI had lower sensory integration and balance when standing on a solid/ soft surface with their eyes closed. There was a statistically significant relationship between height and COP score and sensory integration, particularly when standing on a solid/soft surface with eyes closed.

Limitations:

This present study had limitations that may affect the reliability and applicability of its findings. The inclusion of children aged 7 to 14 with T1D offers a considerable source of variation. Within this age range, developmental phases, treatment responses, and health behaviors can all vary substantially. To acquire more exact insights, narrowing down the age categories or including age-related parameters in the research would have been advantageous. Additionally, a significant shortcoming is the failure to document critical data such as Hemoglobin A1c test levels and insulin units for diabetic children. These variables are critical in understanding illness management and treatment outcomes. Without this information, it is difficult to draw meaningful conclusions about the effects of diabetes on the health of these children.

Implications of physiotherapy practice:

Children with T1D who have a greater BMI and height have poor postural stability, especially when standing on a solid/ soft surface with their eyes closed. Early diagnosis of these deficiencies is recommended to lower the risk of balance impairments and risk of fall.

Conflict of interest disclosure:

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

Acknowledgments:

The authors would like to acknowledge all subjects and their families as participated in this work for their valuable contribution in this study.

References:

1. **American Diabetes Association**. Diagnosis and classification of diabetes mellitus. Diabetes care. 2010 33 (Suppl 1): S62–S69. https://doi.org/10.2337/dc10-S062
2. **Cho NH, Shaw JE, Karuranga S, Huang Y, da Rocha Fernandes JD, Ohlrogge A W, Malanda B**. IDF Diabetes Atlas: Global estimates of diabetes prevalence for 2017 and projections for 2045. Diabetes research and clinical practice. 2018 138: 271–281. https://doi.org/10.1016/j.diabres.2018.02.023
3. **Blair M.** Diabetes Mellitus Review. Urologic Nursing. 2016 36 (1), 27-36.
4. **Deshpande AD, Harris-Hayes M, Schootman M**. Epidemiology of diabetes and diabetes-related complications. Physical therapy 2008 88(11): 1254–1264. https://doi.org/10.2522/ptj.20080020
5. **Ferriolli E, Pessanha FP, Marchesi JC**. Diabetes and exercise in the elderly. Medicine and sport science. 2014 60: 122–129. https://doi.org/10.1159/000357342
6. **Ibrahim ZM, Ali OI, Moawd SA, Eid MM, Taha MM**. Low Vibrational Training as an Additional Intervention for Postural Balance, Balance Confidence and Functional Mobility in Type 2 Diabetic Patients with Lower Limb Burn Injury: A Randomized Clinical Trial. Diabetes, metabolic syndrome and obesity: targets and therapy. 2021 14: 3617–3626. https://doi.org/10.2147/DMSO.S307414
7. **Stanek E, Truszczynska-Baszak A, Drzał-Grabiec J, Tarnowski A**. Postural balance assessment in children aged 7 to 9 years, as related to body weight, height, and physical activity. Biomedical Human Kinetics. 2015 7 (1):135–141. https://doi.org/10.1515/bhk-2015-0020
8. **Greve JM, Cuğ M, Dülgeroğlu D, Brech GC, Alonso AC**. (2013) Relationship between anthropometric factors, gender, and balance under unstable conditions in young adults. BioMed research international, 2013, 850424. https://doi.org/10.1155/2013/850424
9. **Minges KE, Whittemore R, Grey M**. Overweight and obesity in youth with type 1 diabetes. Annual review of nursing research. 2013 31: 47–69. https://doi.org/10.1891/0739-6686.31.47
10. **Szadkowska A, Madej A, Ziółkowska K, Szymańska M, Jeziorny K, Mianowska B et al.** Gender and Age - Dependent effect of type 1 diabetes on obesity and altered body

composition in young adults. Annals of agricultural and environmental medicine: AAEM. 2015 22 (1): 124–128. https://doi.org/10.5604/12321966.1141381

11. **Fernandes L, Andrade C, Adan L, Cruz M, Araújo M, Casais-e-Silva L, et al**. Associations between hearing handicap, metabolic control and other otoneurological disturbances in individuals with type 1 diabetes mellitus. Int J Diabetes Dev Ctrie. 2015 35 (3):171–176.
12. **D'Silva LJ, Whitney SL, Santos M, Dai H, Kluding PM.** The impact of diabetes on mobility, balance, and recovery after repositioning maneuvers in individuals with benign paroxysmal positional vertigo. Journal of diabetes and its complications. 2017 31(6): 976–982. https://doi.org/10.1016/j.jdiacomp.2017.03.006
13. **Cancela-Carral JM, Ayán C, Sturzinger L, Gonzalez G**. Relationships Between Body Mass Index and Static and Dynamic Balance in Active and Inactive Older Adults. Journal of geriatric physical therapy. 2019 42(4), E85–E90. https://doi.org/10.1519/JPT.0000000000000195
14. HUMAC BALANCE (n.d.). Retrieved October 13, 2017, from http://www.csmisolutions.com/products/balance-assessment/humac-balance
15. **Blosch C, Schäfer R, de Marées M, Platen P.** Comparative analysis of postural control and vertical jump performance between three different measurement devices. PLOS ONE. 2019 14 (9): e0222502. https://doi.org/10.1371/journal.pone.0222502
16. **Lemay JF, Gagnon DH, Nadeau S, Grangeon M, Gauthier C, Duclos C**. Center-of-pressure total trajectory length is a complementary measure to maximum excursion to better differentiate multidirectional standing limits of stability between individuals with incomplete spinal cord injury and able-bodied individuals. *Journal of neuroengineering and rehabilitation*. 2014 11, 8. https://doi.org/10.1186/1743-0003-11-8
17. **Anson E, Bigelow RT, Studenski S, Deshpande N, Agrawal Y**. Failure on the Foam Eyes Closed Test of Standing Balance Associated With Reduced Semicircular Canal Function in Healthy Older Adults. Ear and hearing. 2019 40 (2): 340–344. https://doi.org/10.1097/AUD.0000000000000619
18. **Kolar P**. Facilitation of agonist–antagonist co-activation by reflex stimulation methods. Rehabilitation of the Spine. 2007 531-565.
19. **Yin L, Qin J, Chen Y, Xie J, Hong C, Huang J, Xu Y, Liu Z, Tao J**. Impact of Body Mass Index on Static Postural Control in Adults With and Without Diabetes: A Cross-Sectional Study. Frontiers in endocrinology. 2021 12: 768185. https://doi.org/10.3389/fendo.2021.768185
20. **Santos DA, Diniz MF, Lima RF, Lima RM, Martins WR, de Oliveira FP, et al**. Association between postural balance and body mass index in individuals with type 1 diabetes. Revista da Associação Médica Brasileira. 2015 61 (4): 310-315. https://doi.org/10.7570/jomes22061
21. **Qin J, Zhao K, Chen Y, Guo S, You Y, Xie J, Xu Y, Wu J, Liu Z, Huang J, Chen LD, Tao J**. The Effects of Exercise Interventions on Balance Capacity in Patients with Type 2 Diabetes Mellitus: A Systematic Review and Meta-Analysis. Inquiry : a journal of medical care organization, provision and financing. 2021 58: 469580211018284. https://doi.org/10.1177/00469580211018284
22. **Azzeh FS, Kensara OA, Helal OF, Abd El-Kafy EM.** Association of the body mass index with the overall stability index in young adult Saudi males. Journal of Taibah University Medical Sciences. 2017 12(2): 157–163. https://doi.org/10.1016/j.jtumed.2016.11.011

23. **Piva SR, Susko AM, Khoja SS, Josbeno DA, Fitzgerald GK, Toledo FG**. Links between osteoarthritis and diabetes: implications for management from a physical activity perspective. Clinics in geriatric medicine. 2015 31 (1): 67–viii. https://doi.org/10.1016/j.cger.2014.08.019
24. **Pasquier V, Dubois M, Boirie Y, Lacour JR, Taillardat M**. Effect of obesity and type 2 diabetes on exercise-induced decrease in postural balance in older subjects. Diabetes & Metabolism. 2019 45 (5): 442–449. https://doi.org/10.1016/j.diabet.2018.10.009
25. **Vasudev A, Saxena A, Hingorani A**. Diabetes and balance disorders: An updated review. Diabetes Therapy. 2019 10 (6): 2051–2062. https://doi.org/10.1007/s13300-019-00735-6
26. **Mergner T, Schweigart G, Maurer C, Blümle A**. Human postural responses to motion of real and virtual visual environments under different support base conditions. Experimental brain research. 2005 167(4): 535–556. https://doi.org/10.1007/s00221-005-0065-3
27. **Chiang JL, Maahs DM, Garvey KC, Hood KK, Laffel LM, Weinzimer SA, Wolfsdorf JI, & Schatz D.** Type 1 Diabetes in Children and Adolescents: A Position Statement by the American Diabetes Association. Diabetes care. 2018 41(9): 2026–2044. https://doi.org/10.2337/dci18-0023
28. **Zhuang Y, Hong Z, Wu L, Zou C, Zheng Y, Chen L, Yin L, Qin J**. Influence of age on static postural control in adults with type 2 diabetes mellitus: a cross-sectional study. Frontiers in endocrinology. 2023 14: 1242700. https://doi.org/10.3389/fendo.2023.1242700
29. **Kluding PM, Bareiss SK, Hastings M, Marcus RL, Sinacore DR, Mueller MJ**. Physical Training and Activity in People With Diabetic Peripheral Neuropathy: Paradigm Shift. Physical therapy. 2017 97 (1): 31–43. https://doi.org/10.2522/ptj.20160124