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IMPROVING STATIC BALANCE IN PATIENTS WITH TYPE 2 DIABETES MELLITUS

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Introduction

Type 2 diabetes mellitus (T2DM) is among the most prevalent chronic diseases globally and profoundly affects health status and quality of life, especially in the elderly population. In Romania, the PREDATOR 2017 study indicates a 12.4% prevalence of type 2 diabetes mellitus, highlighting the critical need for effective and individualized therapies in the management of problems related to this condition.Type 2 diabetes mellitus (T2DM) is among the most prevalent chronic diseases globally and profoundly affects health status and quality of life, especially in the elderly population. In Romania, the PREDATOR 2017 study indicates a prevalence of 12.4% of type 2 diabetes mellitus, highlighting the critical need for effective and individualized therapies in the management of problems related to this condition.

A significant difficulty for people with type 2 diabetes is maintaining postural balance, which is compromised by comorbidities such as diabetic neuropathy and diabetic retinopathy. These affect the sense of body position and responsiveness to environmental cues, significantly increasing the risk of falling. In this context, balance assessment and the formulation of appropriate intervention programs are crucial to avoid accidents and improve daily functionality.

The originality of the topic lies in the complex and functional methodology of balance assessment in patients with type 2 diabetes using objective techniques, including examination of center of mass (CoM) motion, plantar pressures and forces applied in a semi-flexed position. The study suggests a comparison of different biomechanical postures with the traditional Romberg test, indirectly assessing the muscular effort required to sustain an unstable static position, thus providing a new perspective on balance assessment. The differentiated characterization of plantar pressures according to comorbidities facilitates a more effective personalization of the treatment approach.

The impetus for the selection of this issue stems from the need to improve our understanding of the postural and motor characteristics of patients with type 2 diabetes and to determine the most appropriate intervention strategies. The study examines various therapeutic interventions by fusing proprioceptive and reactive training, tailored to the extent of each patient's sensory and motor deficits. Consequently, it emphasizes the importance of a tailored and multimodal therapeutic strategy. The impetus for the selection of this issue stems from the need to improve our understanding of the postural and motor characteristics of patients with type 2 diabetes and to determine the most appropriate intervention strategies. The study examines various therapeutic interventions by fusing proprioceptive and reactive training, tailored to the extent of each patient's sensory and motor deficits. Consequently, it emphasizes the importance of a tailored and multimodal therapeutic strategy.

The relevance of the topic is supported by various recent studies examining the correlation between diabetes, postural stability and fall risk (e.g. Sibley et al., 2015; Monteiro et al., 2023; Pijnappels et al., 2010). The research emphasizes the need for the integration of static and dynamic balance assessment techniques, along with the effectiveness of dual-load training and unstable surfaces for fall prevention. This research corresponds to contemporary trends, providing a practical framework for therapeutic application.

Consequently, the selected theme addresses a real need in the field of medical rehabilitation and offers significant improvements for optimizing interventions for people with type 2 diabetes mellitus.

Existing literature supports the multiple effects of type 2 diabetes on postural balance and indicates that interventions integrating exercise, psychosocial support and comprehensive biomechanical assessments can significantly reduce the risk of falls and improve quality of life for these patients.

Keywords: static balance, type 2 diabetes mellitus, proprioceptive exercises, baropodometry, elderly, fall risk.

Summary of Main Ideas: the fundamental problem addressed in this thesis is the improvement of static balance in patients with type 2 diabetes mellitus, with emphasis on the importance of non-pharmacological interventions for fall prevention. The working hypothesis is that a specific exercise program, based on proprioception stimulation, can improve postural control and reduce the risk of imbalance.

SUMMARY OF CHAPTERS

Chapter 2: Body balance

2.1 Definition and characteristics

Echilibrul este capacitatea de a menține corpul într-o poziție stabilă și controlată, fiind influențat de sistemele senzoriale, motorii și biomecanice.

Postural balance, or equilibrium, is a critical component of most daily activities. As with postural orientation to the environment, controlling the position of the trunk in space may be the primary goal of the postural balance system. Most studies have focused on the ability to remain upright. According to Epuran, (2002) there are several sources of destabilizing influences on the body: external forces due to gravity and interactions with the environment, as well as internal forces generated by the body's own movement. Thus all forces act to accelerate the body towards its center of mass. Balance is man's ability to maintain his own body in a controlled and stable position by compensatory movements.

Marcu and Matei (2005) draw attention to the fact not to confuse the "equilibrium" of a body with the "stability" of that body. A system is stable only when disturbing its equilibrium, it returns to its equilibrium position without falling. The bipedal position is not a strictly passive stabilization, it is not a rest position. The CoM continuously oscillates between falling backwards and forwards or to the side of the supporting polygon. The CoM is given by the gravity acting on the body through vertical lines of forces that vectorially associate to determine it. It can be defined as the point of body mass which in the orthostatic position is placed at the level of the lower trunk (at the S2 vertebra), on which this resultant acts as a directed and oriented force. A light pressure with the fingertips on this point will cause the anterior imbalance of the body, while lateral pressures at the same level will cause lateral imbalances.

Horak (2006) says that many cognitive resources are required in postural control. Orthostatic posture requires increased reaction times in standing compared to sitting with support. The more difficult the postural task, the more cognitive processing is required. The reaction times and performance in a poor cognitive condition make it more difficult to maintain postural posture. People who have limited cognitive fitness due to neurological disorders may have an increased frequency of falling episodes.

The two main functional goals of postural control are postural orientation and postural balance. According to Horak (2006) spatial orientation and postural control are based on the interpretation of convergent sensory information from the somatosensory, vestibular and visual systems. Postural balance involves the coordination of sensorimotor strategies to stabilize the CoM during both self-initiated and externally triggered postural stability disturbances.

There are three main types of balance body-righting movement strategies: two strategies hold the feet in place and the other strategy shifts the base of support by stepping individually. The first strategy or ankle strategy, in which the body moves from the ankle like an inverted pendulum, is appropriate to maintain balance for small displacements of the CoP Center of Pressure when the body is positioned on a firm surface. The second strategy, or hip strategy, is where the body exerts a torque at the hips to rapidly move the Center of Mass (CoM), is used when people are standing on moving surfaces (Horak, 2006).

2.2 Postural control

It involves spatial orientation and maintaining stability by integrating information from the visual, vestibular and proprioceptive systems.

Postural control is no longer considered as a set of righting and balancing reflexes. Rather, postural control is considered a complex motor skill derived from the interaction of multiple sensorimotor processes. The two main functional goals of postural control are postural orientation and postural balance. Postural orientation involves the active control of body alignment and tone with respect to gravity, support surface and internal references. Spatial orientation in postural control is based on the interpretation of convergent sensory information from the somatosensory, vestibular and visual systems (Horak, 2006).

Static Posturography provides an objective assessment of postural control by characterizing the sway of the body during standing. The signal emitted by the center of pressure (CoP) is recorded by a force platform and analyzed using many different models and techniques. Traditional approaches decompose the CoP signal into anteroposterior and mediolateral temporal series, corresponding to ankle movements through plantar flexion/dorsi flexion and hip adduction/abduction, respectively.

Balance strategies include:

- Ankle strategy: used for small perturbations on stable surfaces.

- Hip strategy: used for larger disturbances or on moving surfaces.

2.3 Sensory systems involved

2.3.1 The visual system makes a major contribution to the maintenance of balance by providing information about the environment, location, direction and speed of movement of the individual. Woolacott et al. (1986) analyzed two aspects of balance control in the older adult:

1) timing and amplitude coordination of muscle responses to postural perturbations and

2) the participant's ability to reorganize sensory information and subsequently modify postural responses as a consequence of changing environmental conditions.

The mobile platform recorded the postural responses of 12 elderly participants which were compared with the recordings of 16 young adults. The velocity of movement of this platform was 30 cm/second for 25 seconds and produced an antero-posterior sway of the ankle joint in the participants. The changes observed were as follows:

1. increases in absolute latency of distal muscle responses in all older adults

2. older adults' ability to balance under conditions of reduced or conflicting sensory information was also impaired. When confronted with inadequate visual information, with non-functional somatosensory information, half of the older group lost balance, (Woollacoot M.H. et al., 1986).

Freitas et al, (2011) analyzed the reflection of how aging influences balance and joint coordination for maintaining orthostatic posture. CoM position was measured with a force plate and visual feedback was analyzed in two conditions: eyes open and eyes closed. Body balance was assessed by analyzing the parameter measuring CoM displacement.

2.3.2 Vestibular system

Detects head movements and position in space. Otoliths provide information about the vertical position during standing and signal the position of the head in relation to gravity. Another type of sensors are semicircular canals aligned with the three planes of the body: frontal, sagittal and horizontal. Neurons from both vestibular structures have direct, strong influences on motor neurons in the spinal cord that activate muscles (especially the extensor muscles) and thus contribute substantially to maintaining balance.

2.3.2 Proprioceptive system

It transmits information about the position of joints and muscles. The importance of this information is fully appreciated when someone experiences difficulty maintaining balance or walking when this information is absent. Normal individuals often experience temporary loss of these receptors when sitting in a fixed position for a long period of time, limiting blood supply to the lower limbs (Jančová, 2008).

Diabetic peripheral neuropathy is the most common complication associated with diabetes mellitus, affecting the peripheral sensory and motor nerves. Loss of sensory nerve function results in decreased sensory sensitivity in the extremities. While loss of motor axons with insufficient re-innervation is related to muscle strength deficit and atrophy of lower limb muscles. Leg somatosensory information and proprioception are determinants of motor control during balance and gait (Ahmad et al., 2019).

2.3.3 Musculoskeletal system

Provides stability through the muscles and joints of the foot and ankle.

Chapter 3: Balance assessment

3.1 **Assesment test**

1. Romberg Test: Assesses static balance with eyes open and closed, identifying sensory deficits. A person's balance, proprioception and fall risk issues can be assessed with the Romberg test. The duration of the Romberg test varies between 10 and 30 seconds depending on the authors.

2. Timed Up and Go Test (TUG): Measures mobility and dynamic balance.

Functional testing is done using the Timed up and go test (TUG) which is a simple clinical assessment designed to assess a person's mobility, balance and fall risk. The TUG provides information about a person's physical function, including gait, balance and overall ability to perform basic mobility tasks.

3.2 Static evaluation.

Static assessment of balance is performed by positioning the patient on the baropodometric plate in orthostasis. The biomechanical model used by the human body to maintain orthostatic balance is the inverted pendulum.

The ankle strategy is mainly used when the disturbance of balance is small and the supporting surface is firm. The hip strategy is used in correspondence with larger perturbations of balance, because the ankle strategy does not provide sufficient force to maintain postural stability. When the balance perturbation is large enough to shift the center of gravity away from the person's base of support, the stepping or jumping strategy is used to restore balance (Riscotti, 2011).

The common denominator in assessing human balance and body posture is the inverted pendulum model. If we focus on appropriate versions of the inverted pendulum model we can identify motor mechanisms that defend against any perturbation of balance. Winter, (1995) has seen that in the orthostatic position the Ankle Strategy applies only in the Anterio/Posterior direction and the hip strategy of loading/unloading abductor/adductor strategy is dominant in the Medio/Lateral direction when the feet are side by side. The critical importance of the hip abductor/adductors in balance in all phases of orthostatic stance and gait is evident.

3.3 Dinamic evaluation: Patient gait analysis, as a method of balance assessment, allows the examination of a person's ability to maintain body stability and control.

The gait cycle forms the basic functional unit of gait and consists of the time interval between the beginning of ground contact of one limb and the next ground contact of the same limb. The main phases of a gait cycle are: stance, transfer and double stance.

Each gait has two main phases: the double stance phase with both feet on the ground and the single-leg stance phase with one foot on the ground.

3.4 Evaluated parameters:

CoP (Center of Pressure): Indicates the distribution of forces on the supporting surface. The CoP is the point of application of the ground reaction force and is the weighted average of all the pressures exerted by the foot on the ground. If only one foot is supported, the CoP is below it; if both feet are on the ground, the CoP is positioned between them, proportional to the weight distribution. The location of the CoP under each foot reflects the neural control of the ankle muscles: activation of the plantar-flexors moves the CoP anteriorly, and activation of the ankle invertor muscles moves it laterally (Winter et al., 1995).

CoM (Center of Mass): Reflects the overall stability of the body. Clinical interest in body sway is based on the relationship between the CoM and the support surface, accessible by measuring the position of the center of pressure (CoP). CoP-CoM measurements are used in the diagnosis and monitoring of conditions such as cerebellar ataxia, vestibular dysfunction, diabetic neuropathy, Alzheimer's disease, multiple sclerosis, Parkinson's disease and stroke (Morasso et al., 2019). The ankle-hip coordination during postural rocking motion can be explained by Morasso et al. (2019) as an explicit attempt by the Central Nervous System to minimize the amplitude of the resulting angular acceleration of the CoM.

Chapter 4: Methods for improving static balance

4.1 Proprioceptiv training: Stimulates sensory systems to improve postural control. Includes exercises on unstable surfaces or with eyes closed. A program that combines strength, balance and body weight transfer should be part of an optimal fall prevention strategy. Amat et al. (2013) believe that postural stability is essential for daily activities such as walking, turning or climbing stairs.

According to Ahmad et al. (2019) sensorimotor training facilitates sensory information, corrects muscle imbalances and optimizes the motor program in the central nervous system. In treating patients balance exercises include static, dynamic and functional approaches.

A holistic approach to balance training emphasizes the role of the sensory-motor system in improving sensory input and optimal recruitment of muscles responsible for joint stability. Muscle imbalances can cause movement disorders and affect motor reprogramming in the central nervous system.

4.2 Physiotherapy exercise performed in the semi-flexed position of the lower limbs

Benefit: Toning the muscles of the lower body, improving stability and reducing the risk of falls. This exercise has as its starting position standing with feet flat on the floor, with knees and hips in an anatomically neutral position, the spine is extended upright, with the spine's natural curves preserved. The Squat movement begins with the lowering phase of the hips, along with bending the knees and ankles. Squat begins with the lowering of the hips, accompanied by bending the knees and ankles. The predominant guideline for correct execution is to lower the hips until they are parallel with the ground, ensuring that the hip joint is at least aligned with the knee joint (Myer et al., 2014).

Types of Squat exercises for physical activity: classic, bench/chair, elastic band around the knees, shoulder bar, sumo, high heel (on support), dumbbell, dumbbell, half squat, isometric wall, single leg (side or anterior lunge).

These exercises can be done isotonically and isometrically depending on the objectives.

Benefits of Squat exercise:

1. Toning the torso;
2. Reduce the risk of injury;
3. Burn calories;
4. Toning lower body muscles;
5. Variety helps motivation;

4.3 Isometric resistance exercise

Type 2 diabetes mellitus is known to impair microcirculation, the impact of isometric exercise on type 2 DZ remains under-investigated.

Results indicated that there were no significant differences in initial strength and endurance between groups ($p > 0.05$). However, endurance during the second contraction was significantly reduced in diabetic patients ($p < 0.01$). Heart rate increased more than threefold during exercise in control subjects compared with diabetic patients ($p < 0.01$). Diabetic patients had significantly higher blood pressure both at rest and during exercise ($p < 0.01$). In diabetic patients, forearm blood flow was consistently lower at all stages of the test ($p < 0.01$).

The findings indicate that diabetes impairs recovery after isometric exercise by decreasing muscle blood flow and altering sympathetic and parasympathetic responses. Further examination is needed to assess the degree of neurologic impairment and its effects on physical performance and peripheral circulation. (Petrofsky et al., 2005).

PART TWO - EXPERIMENTAL STUDIES

ORIGINAL CONTRIBUTIONS ON THE ROLE OF BAROPODOMETRIC ANALYSIS IN THE FUNCTIONAL ASSESSMENT OF PATIENTS WITH TYPE 2 DIABETES MELLITUS- FINDING STUDY

Introduction

Diabetes mellitus (DM) is a chronic condition affecting millions of people globally, with the majority of cases being type 2 DM. Recent estimates indicate over 537 million adults diagnosed, with a projected increase to 643 million by 2030 (Magliano & Boyko, 2021). Complications of diabetes extend beyond glycemic regulation, encompassing cardiovascular problems, neuropathy, and an increased risk of falls, particularly among the elderly. The main problems of the diabetic foot are peripheral arterial disease and diabetic neuropathy, with circulatory insufficiency facilitating the formation of diabetic foot ulcers (DFU).

Research indicates a 1.7-fold greater risk of falling in people with type 2 DZD compared to those without diabetes (Freire et al., 2024), due to reduced muscle strength, slower reaction times, and poor sensory feedback.

Balance assessment in the clinical setting is based on tests such as the Romberg and Berg scales, which mainly analyze static stability, without fully capturing the functional demands of daily activities. Proprioceptive training, although advantageous, may be more effective when integrated with other forms of exercise. Research indicates that static assessments, such as the Reach test, fail to adequately represent the complexity of everyday movements compared to dynamic assessments, such as the Timed Up and Go (TUG) or Four Square Step Test (FSST). Sibley et al. (2015) showed that dynamic tests more effectively identify balance impairments in people with neurological conditions by mimicking everyday activities such as walking or changing direction. Given the limitations of traditional tests, the semi-flexed position is proposed as an alternative to complement the Romberg test balance assessments.

1.1 Research design

In this study, the research design was observational, with the application of standardized test conditions (Romberg open/closed eyes test, hard/soft surface) and controlled manipulation of body position (lower limbs semi-flexed position) in order to assess postural balance by objective parameters (CoM body motion).

1.2 Research aim

The aim of this study is to compare the results obtained from postural balance assessments in patients with T2DM, using classical tests (Romberg test) and the test with controlled change in the position of the lower limbs (semiflexion).

1.3 Research objectives

To identify the effects on CoM motion produced by positioning the patient with DZ Type 2 in different assessment conditions: orthostatic position with eyes closed versus eyes open, hard surface versus soft surface and lower limb semi-flexed position.

To analyze the comorbidities associated with DZ Type 2 on the force distribution on the supporting surface of the foot during rolling on the baropodometry plate.

To determine the risk of falling in patients with DZ Type 2 using the balance assessment test with the lower limb semi-flexed position.

1.4 Research hypotheses

The main hypothesis (H1 - Working Hypothesis) states that patients with DZT2 will show, in the assessment position with the lower limbs semi-flexed, a CoM movement over a smaller area compared to the classical Romberg test.

The null hypothesis (H0 - Alternative/Negative Hypothesis) states that there is no significant difference in the CoM motion of patients with DZT2 assessed in the lower limb semiflexed position and the Romberg test.

1.5 Organization of research

This study included a sample of 106 patients diagnosed with DZ Type 2, selected from patients who presented to the diabetology office of Gilău commune, Cluj county. The final distribution of participants was 51 males and 55 females. Comorbidities of patients with DZ Type 2 were grouped into 7 diagnoses as described in the List of abbreviations and symbols. The distribution of the patients according to the comorbidities of DZ Type 2 was as follows: 29 patients with Hypertension- Hypertension (Diagnosis 1), 10 patients with Diabetic Neuropathy (Diagnosis 6), 4 patients with Dyslipidemia (Diagnosis 5), 63 patients with Ischemic Heart Disease (Diagnosis 7) and 36 of the patients had Composite Diagnosis which provides the presence of three secondary diagnoses presented above.

In this study, sampling was done conveniently, patient selection was done sequentially, without prior control for demographic variables, so that the final sex and age distribution was determined naturally.

Each patient was trained prior to testing to understand the protocol and the assessment was performed in a controlled environment, maintaining the same conditions for each participant (diabetes physician's office).

1.6 Equipment used

The following equipment was used to evaluate the patients in this study: BTS P WALK system. The BTS Pwalk baropodometry board, consisting of a 675x540x5 mm size board containing a number of 2304 sensors, sensor size 1x1 cm, sensor type: resistive, pressure 30-400 kPa, acquisition frequency 100 Hz, AC/USB adapter power supply, in weight 7 kg. The system provides quantitative data on the static and dynamic support of the foot, information useful in identifying excessive loads on the foot as well as postural asymmetries.

1.7 Evaluation protocols

- Body composition assessment the patient is positioned on the BIA scale;
- Static baropodometric assessment: the Romberg test performed on the baropodometric

plate BTS P WALK, the modified Romberg test (1.5 cm thick isoprene sponge placed on the baropodometric plate) and the semi-flexed position of the lower limbs;

- Dynamic assessment: Walking on the baropodometer plate by stepping allowing contact of a single foot on the BTS P WALK plate.

Body composition assessment involves the following assessment protocol.

The patient places their bare feet on the Tanita scale and waits for the generation of the assessment report which takes 30 seconds.

The Romberg test involves positioning the patient in an orthostatic position with eyes open (EO) and eyes closed (EC) on a hard surface (H). We added new variables to this test by assessing the patient's position on the soft surface (S) and the patient's position in semi-flexion (H-Sqt).

The assessment was performed once for each protocol, and the time allocated to each protocol is 30 seconds, with the subject placed in the orthostatic position with bipodal support, with the legs positioned at shoulder level.

Static evaluation involves the following working protocols:

- Protocol 1. The subject was positioned on the baropodometer plate (H) and instructed to maintain this position with eyes closed (EC);
- Protocol 2. The subject was positioned on the baropodometer plate (H) and instructed to maintain this position with eyes open (EO);
- Protocol 3. The subject was placed on the baropodometric plate (H) in the semi-flexed position, with the soles at shoulder level, arms extended forward, and the subject was instructed to maintain this position with eyes open (EO);
- Protocol 4. The baropodometric plate was covered with a 1.5 cm thick sponge (S) and the subject was instructed to maintain this position with eyes closed (EC);
- Protocol 5. The baropodometric plate was covered with a 1.5 cm thick sponge (S) and the subject was instructed to maintain this position and then with eyes open (EO).

The order of the assessment protocols and the 30-second pause between protocols allows the patient to adapt to the orthostatic assessment conditions. The lower-limb semi-flexed position is maintained for 30 seconds with eyes open and on the hard contact surface.

4.4 Discuss

4.1 Discussions about balance assessment

The results in Table 1 show significant differences in body composition between men and women. In terms of age there were no significant differences between the two groups. Muscle mass and body weight was significantly higher in males than females. Timon et al. (2021) along with Fukunaga et al. (2022) also found that muscle mass was consistently higher in men, due to testosterone levels, and high levels of endurance-type physical activity.

In women the data show that fat mass is significantly higher than men, which is also found in the study by Pereira et al. (2021) emphasizing the physiological tendency of women to accumulate more adipose tissue in the peripheral areas of the body. Zhou et al. (2023) analyzed the influence of morphological characteristics on center of mass (CoM) position and their impact on postural stability. In his study Chen et al. (2020) personalized intervention programs to improve balance according to the morphological profile of the patient with DZ type 2.

In Table 2 the results obtained disprove the working hypothesis of this study because the mean CoM area measured in the semi-flexed position of the lower limbs is higher than the mean CoM area measured in the orthostatic position with eyes closed and hard contact surface.

The analysis of CoM area values at the trunk level (Aria_B) in the three test conditions highlights an increase in postural imbalance as a function of motor task difficulty and absence of sensory information. In assessment protocol 4 (S_EC_Aria_B), the CoM area had the highest mean value, suggesting that lack of vision and stable support is a major impairment of postural control.

Evaluation protocol 3 (H_EO_Semiflexion) had higher CoM motion than protocol 2 or the classic Romberg test (H_EC) but significantly lower than protocol 4 (S_EC). This result suggests that postural modification by semiflexion, although biomechanically demanding, does not generate as much imbalance as the complete absence of visual and proprioceptive information.

Following their studies Martins et al, (2020) concluded that this position of semiflexion of the lower limbs implies an increased postural muscle demand and alters the segmental alignment, which may affect the weight distribution on the support surface and the CoM control strategy. For patients with DZ type 2 assessed CoM movement can be influenced by both the absence of sensory input and a neuromuscularly demanding position and the combination of these two factors may increase the risk of falling. Chau et al. (2013) identified that people made good use of vision as a compensatory so that they could achieve relatively normal performance during balance testing.

In this study, 25% of the participants (n = 26) did not vary significantly by test area. This observation may be attributed to the living environment where DZ type 2 patients live, in particular frequent exposure to rough terrain. People living in rural areas, accustomed to daily walking on a variety of surfaces (mud, leaves, stones), may develop better stability by effectively training the body's musculature and balance mechanisms.

Sergiou, (2020) investigates the particularities of the environment that are related to the spatial and temporal configuration of events in the external world. Each external environment is associated with a certain degree of predictability, thus the environment with a high degree of predictability is spatially and temporally secure and stable.

In another study Rashed et al. (2019) analyzed the balance difficulties of elderly patients and one of these difficulties is fear of falling.

The risk of falling increased with age and with decreasing hours spent outdoors. Therefore, spending time outdoors is important to reduce the risk of falling concluded Kanzaki-Soououdi, (2009).

The slower the subject is, the longer the delay in reacting, the more often the subject has to react to catch up (Gagey, 2017). Thus, center of gravity velocity is not only a biomechanical indicator, but also an expression of complex postural adjustment strategies.

Each assessment protocol explores a distinct aspect of postural control: sensory domain (eyes closed) or motor domain (isometric contraction). According to the principles of posturology, the patient's response depends on the correct integration of sensory information and the ability of neuromuscular adjustment to the demands imposed.

A good balance is a rapid synergistic interaction between various physiological and cognitive interactions, elements that allow a rapid and precise response to a perturbation in the external environment (Trisan, 2017).

The data in Table 4 shows that all comparisons analyzed with Wilcoxon test have statistically significant differences, which indicates that the contact surface, visual information influences the CoM movement.

A limitation of this study was that patients could not perform the eyes-closed balance assessment on a hard versus soft surface, thus preventing a comparison of the results obtained with those obtained in other assessment protocols.

4.2 Discussion about the analysis of plantar pressures during walking in patients with DZ type 2 and different comorbidities grouped by types of diagnosis

The results of the statistical analysis for force, surface area, pressure and time of support on each area of the foot while walking on the baropodometry board show that most of the parameters analyzed did not show statistically significant differences between groups according to the presence of type 2 diabetes mellitus comorbidities, including hypertension, dyslipidemia, ischemic heart disease or neuropathy.

The force parameter values for T1-T2, M1-M5, MF, MH, and LH regions of both legs had p-index values greater than 0.05. For example, Force_Stg_T1, Force_Dr_MF and Force_Dr_MH did not show significant variation between subgroups.

A relatively uniform distribution of values between the groups was observed for the parameter Aria. No statistically significant differences were observed in the measured Aria of the metatarsal (M1-M5), toes (T1-T2), mid-foot area (MF) and heel area (MH, LH). The p-values for Arie_Stg_M1 ($p = 0.882$) and Arie_Dr_T2 ($p = 0.533$) support this trend.

The parameter Pressure showed values that did not differ significantly, regardless of the area analyzed. Pressure measured in M1-M5, MF, MH and LH did not show significant variations related to comorbidities, as p-values were often greater than 0.2. For example, Pressure_Dr_M2 ($p = 0.153$) and Pressure_Stg_M5 ($p = 0.419$) did not show statistically significant differences.

The Time parameter, which indicates the duration of force applied to each area of the sole during gait, predominantly showed p-values greater than 0.05. For instance, Time_Force_Stg_M2 ($p = 0.067$), Time_Force_Dr_MF ($p = 0.121$) and Time_Arie_Stg_M3 ($p = 0.206$) did not indicate significant differences between the analyzed groups.

The results show that the impact of type 2 diabetes mellitus-related comorbidities on plantar support parameters is not significant enough due to the fact that the values are quite similar between groups.

The values recorded in metatarsal area M3, midfoot MF and toes 2,3,4,5 indicate significant differences in body weight load distribution during foot support. Unsupported by kinetic and kinematic assessments these data only reflect when the patient exerted force on a particular region of the foot.

The right foot shows more loading in the distal areas (toes and metatarsals), whereas the left foot is more loaded in the midfoot. This asymmetry, observed in a sample of 106 patients evaluated in this study, may reflect a bias in weight distribution during unipodal support between the two lower limbs.

The value of the parameter Arie_Stg_Timp_MF, indicates the relatively short duration of mid-foot contact during a step. The statistical significance of the parameter indicates that the observed differences in mid-foot contact time values are not the result of random variations within the evaluated sample.

This value indicates a relatively large foot contact area in the medial area of the right heel. The statistical significance indicates a real variation and the high area value indicates a higher support on this heel area in some patients.

Analysis of the values between area and pressure shows that metatarsal area 3 of the right foot is used frequently during plantar support, while the midfoot area of the left foot is used less frequently and on a smaller area, but with high pressure in some patients. This asymmetry may signal a compensatory gait pattern.

Next, the t-test was performed for two independent samples where the first sample was the group of patients with DZ type 2 and secondary diagnosis of Hypertension (n=30) and the second group was the other study participants (n=76) who did not have the diagnosis of Hypertension. Upon analysis, the t-test results for all data measurements showed that they were not statistically significant, as the p-values (Sig. 2-tailed) were all greater than 0.05. Based on these data, we cannot conclude that the presence of Diagnostic 1 has a significant impact on the analyzed variables (force, area, pressure).

The data, regardless of whether or not they had normal distribution, showed that statistically significant p-index values for the parameters Aria, Force, Pressure and Time were recorded for Diagnosis 3, diabetic neuropathy, only on the T1 and T2 finger area 3,4,5.

Also after analyzing the results, regardless of how the data were distributed, we observed that the parameters Air, Force, Pressure and Time, which are statistically significant, are found in the metatarsal area, from M1 to M5.

For the posterior area of the foot, no statistically significant p-index values were observed for the parameters Surface, Force, Pressure and Time.

4.5 Conclusions

4.5.1 Conclusions about the balance assessment

The working hypothesis of this study is rejected because patients had less CoM movement during the Romberg test than during the semiflexion test.

Fall risk can also be revealed by other tests that complement the classic sensory tests. Future research could integrate the principles of posturology into rehabilitation programs for patients with diabetes. Exercises adapted to visual, vestibular and proprioceptive stimuli could improve postural stability. Sensorimotor training, performed on unstable surfaces or with eyes closed, can stimulate beneficial neurophysiological adaptations. This is important for patients with peripheral neuropathy, who have impaired balance control. In addition, the analysis of muscle activity during these exercises could provide valuable information about the strategies used to maintain stability and reduce the risk of falls.

4.5.2 Conclusions on analyzing plantar pressures during walking

Postural balance assessment in patients with diabetes, especially in the presence of comorbidities, is an essential step in preventing diabetic foot complications and the increased risk of falling.

The results of the study showed that the Metatarsal 1 and toe area had values with high statistical significance, which shows the importance of this area for support during walking in patients with the Diabetic Polyneuropathy Diagnosis.

The data analysis shows that in patients with type 2 DM and secondary diagnosis of dyslipidemia, ischemic heart disease, arterial hypertension, p-index values with statistical significance of the parameters Area, Force, Pressure, Time were recorded only on the metatarsal area, from M1 to M5. This aspect highlights the fact that when the foot rolls on the ground, the contact area of the metatarsal area is subjected to body forces and pressures for a longer period of time compared to the midfoot area or the posterior foot area.

The analysis of the distribution of plantar pressures and baropodometric parameters provides valuable information about compensatory support strategies and areas of functional overload.

Future studies could analyze the biomechanics of the ankle joint, which together with the distribution of plantar pressures and contact areas could highlight possible functional imbalances at the level of this joint. Additional monitoring and analysis of the dynamics of the ankle joint, in contexts of support and propulsion, could provide relevant information for the prevention of deformities and complications in the diabetic foot.

The risk of falling in patients with diabetes mellitus and associated comorbidities can also be identified through additional tests that complement classic sensory assessments. Future research could include the integration of posturology principles into rehabilitation programs for this category of patients.

STUDY 2

EFFECT OF ISOMETRIC EXERCISES ON STATIC BALANCE IN PATIENTS WITH TYPE 2 DIABETES MELLITUS

Falls are a leading cause of injury and activity limitation in older adults, and the associated adverse effects result in significant reductions in personal and social functioning, thus becoming an economic burden. Approximately 30% of urban residents over the age of 65 will have a fall episode each year. In the elderly, falls cause over 40% of all deaths from home injuries, and 20-30% of mild injuries lead to severe injuries, including fractures (Barry et al., 2014).

According to studies by Agostini et al. (2013), the integrated contribution of the visual, vestibular and proprioceptive systems, through the information provided, allows the perception of position and the adjustment of the body's balance.

Diabetic sarcopenia, a condition related to the loss of muscle mass, is now the leading cause of death worldwide (Glovaci et al., 2019). The increased prevalence of obesity has introduced a new challenge, namely sarcopenic obesity (Izzo et al., 2021).

In people with diabetes, peripheral neuropathy often affects sensory feedback, leading to balance difficulties and an increased risk of falling. Evidence shows that proprioceptive training can improve balance in patients with diabetic neuropathy (Iram et al., 2021).

Facilitating sensory inputs that allow the correction of muscle imbalance and ensuring a correct motor program at the level of the central nervous system is done with the help of sensorimotor training. Balance exercises are sensorimotor and consist of static, dynamic, and functional approaches to treating patients (Ahmad et al., 2019).

In the preparation and execution stage of movement, proprioceptive feedback is important to aid both habitual and high skill performance. Recently it has been shown that somatosensory processes are altered during the acquisition of a new motor skill when learning involves physical practice (Ackerley et al. 2021).

Sensory input, central processing and neuromuscular responses are factors by which balance is controlled. Loss of muscle strength, range of motion, contracture and exercise intolerance can cause arthritis in the lower extremities of the body. This can reduce the efficiency of the motor response, generating difficulty in maintaining CoM within the support surface, which in turn can decrease balance and increase the risk of falling (Silva et al., 2010).

Training on uneven surfaces provides additional benefits by strengthening cognitive perception and sensorimotor skills (Sluga et al., 2024). Sensorimotor training improves proprioception and somatosensory signals, addressing muscle imbalances and optimizing motor control in the central nervous system. These exercises, including static, dynamic and functional balance techniques, are well established in rehabilitation (Ahmad et al., 2019).

Proprioceptive training is a time-effective and low-impact alternative to traditional exercise methods. It can relieve pain, slow the progression of osteoarthritis, and improve joint and muscle function (Prabhakar et al., 2020).

Also, the use of force plates and other technical devices allows for accurate assessment of postural stability, enabling the development of proprioceptive training protocols (Thukral et al., 2021).

Although proprioceptive training alone may not produce significant improvements in postural stability for patients with DZ type 2 and diabetic neuropathy, but combining it with other exercise modalities could produce beneficial results (Souza et al, 2012).

Isometric exercise is a tool to assess diabetic damage, endothelial damage can be assessed by lack of sweating and blood flow changes in the skin and limbs. While the equipment to measure sweating and blood flow is quite sophisticated, measurement of galvanic skin resistance could be a viable tool if performed during isometric exercise (Petrofsky et al., 2009).

Improved muscle function allows patients to perform submaximal physical tasks, resulting in a reduced cardiovascular load. Increasing muscle strength and endurance with resistance training can improve quality of life through patients' ability to independently perform daily activities. Body weight resistance training is an appropriate resistance training modality for patients with hypertension (Mandic et. al, 2012).

The cardiovascular system is not overloaded when resistance training imposes stress on peripheral muscles. Strength training induces the following important adaptations in normal subjects and in patients with hypertension:

- leads to an increase in motor unit recruitment and in the frequency of motor unit firing;
- preferential recruitment of fast twitch muscle fibers;
- hypertrophy of muscle fibers (Degache et al., 2007).

As confirmed by data from Hulsmann et al. (2004), there is a good correlation between systemic performance (VO2 max and workload) and local exercise load (muscle strength). Flexor strength index is a better predictor of long-term outcome than workload or VO2 max. Isometric strength of the extensor and flexor muscles, increases the significance of the association between maximal torque and the severity of ETS disease. Daily activity and physical training predominantly affect the extensor muscle groups.

The lower-limb semiflexion exercise is a lower-body multi-joint exercise used to strengthen the gluteus maximus, iliopsoas, quadriceps, quadriceps, semitendinosus, soleus and gastrocnemius muscles. This closed kinetic chain exercise was developed to improve lower limb function.

Common techniques for variations of the lower-limb semiflexion exercise include changes in leg stance width, foot placement angle, hip depth, and additional loading (Schutz et al., 2014).

The lower-limb semiflexion exercise has as its starting position sitting with the feet flat on the floor, with the knees and hips in an anatomically neutral position, the spine is extended in an upright position, with the preservation of its natural curves. The movement of the lower-limb semi-flexion exercise begins with the lowering phase of the hips, together with flexion of the knees and ankles. The most common recommendation for correct execution is to lower the thigh until it is parallel to the ground and the hip joint is at least level with the knee joint (Myer et al., 2014).

Next, it is necessary to analyze how the researched themes, previously exposed, are applied in the case of the patient with DZ type 2.

2.1 **Research aim**

The purpose of the preliminary study is to evaluate the effect of isometric exercises performed in fixed positions on unstable surfaces on static balance.

2.2 **Research objectives**

- Development of an isometric exercise program to improve static balance;
- Assessment of static balance level in patients with DZ type 2 before and after intervention;
- Identification of the level of functionality of patients with DZ type 2;
- Implementation of the exercise program and analysis of its effectiveness on static balance.

2.3 **Research hypotheses**

The preliminary research hypothesis involves the improvement of static balance with the help of an isometric exercise program. To evaluate the balance in patients with DZ type 2 we analyzed the value of the parameter Aria CoM, because it is an important parameter and used in many specialized studies. With the obtained results we do not want to have qualitative conclusions of the balance but we want the values of the Aria Com parameter to decrease.

2.4 **Research materials and methods**

In this study we constructed a 6-week longitudinal experiment consisting of two groups.

The experimental method used in this study allowed us to verify the preliminary research hypothesis by analyzing the data obtained at baseline and final assessment. This method involves manipulating specific variables, causing certain rebalancing reactions, in order to observe their effects on patients with DZ type 2.

2.5 **Equipment used**

The BTS Pwalk baropodometry board, consisting of a 675x540x5 mm board containing 2304 sensors, sensor size 1x1 cm, sensor type: resistive, pressure 30-400 kPa, acquisition frequency 100 Hz, AC/USB adapter power supply, 7 kg.

A reversible air ball for balance that has a length and width of 33 centimeters, a height of 3 centimeters, a weight of 0.5 kilograms and is made of PVC material.

A balance cushion having a weight of 0.34 kilograms, composition of TPE of density 50 (kg/m3) and dimensions: 40 cm length X 33 cm width X 5 cm thickness.

2.6 **Evaluation protocols**

The Romberg test involves positioning the patient in an orthostatic position on the baropodometric plate (H). The subject was instructed to maintain this position for 30 seconds, both eyes closed (EC) and eyes open (EO). The assessment was performed once for each protocol.

2.7 **Variables measured**

CoM Area Initial CoM Eyes Open (mm^2) = Center of Mass (CoM) area assessed before the intervention program, when the patient is positioned in orthostatic position with eyes open;

Final CoM Area Eyes Open (mm^2) = Center of Mass (CoM) area assessed after the intervention program, when the patient is positioned in orthostatic position with eyes open;

Initial CoM area Eyes closed (mm^2) = Center of Mass (CoM) area assessed before the intervention program, when the patient is positioned orthostatically with eyes closed;

Final CoM area Eyes closed (mm^2) = Center of Mass (CoM) area assessed after the intervention program, when the patient is positioned orthostatically with eyes closed.

2.8 **Intervention Protocol**

As means of realization, the physiotherapy program contains isometric exercises performed in fixed positions. The static exercises are derived from the fundamental positions such as orthostatism and sitting and have been used to tone the muscles of the lower limbs. Stable sitting and kneeling postures are used in the form of corrective and hypercorrective postures because they are less tiring. After toning the muscles we used orthostatic exercises.

2.9 **Discussion**

Following the Wilcoxon test, patients in the control group (CG) showed significant changes in CoM movement. The value of the positive ranks indicates that all group members experienced significant differences between the final and initial evaluations, with measurements performed both with eyes closed and eyes open.

The p-value results indicate significant changes in CoM movement for the patients in the experimental group (EG). The value of the negative ranks shows that 27 patients had improvements in CoM movement between the final and initial evaluations when the assessment was conducted with eyes closed. During the eyes-open evaluation, the negative rank value indicates that 26 patients had differences between the final and initial evaluations.

Based on the analysis of the test results, we can state that patients who did not follow the intervention program showed positive changes in CoM movement, just like those who completed the intervention program. The analysis of the negative rank values confirms that these changes were present in all 29 members of the group, unlike in the experimental group, where significant changes were observed in only 26 participants.

By comparing the experimental group with the control group using the Mann-Whitney test, we analyzed whether the intervention had a significant effect on CoM movement.

The data from Table No. 52 show that the p-value was not significant for any of the evaluated parameters. This indicates that there are no statistically significant differences between the results obtained after the intervention in the experimental group and those achieved through the daily activities recommended by the physician in the control group. Both groups in this study started from the same baseline, as the p-value for the CoM Area parameter showed very small differences between groups, and at the end of the intervention, the p-values remained similarly close.

These data highlight the importance of daily activities performed by patients living in rural areas who lead active lifestyles.

In their study, Chau et al. (2013) observed that patients who do not manage their diabetes often experience postural instability due to prolonged periods of elevated blood glucose levels. Changes in static balance maintenance strategies include reduced activity at the ankle joint (ankle strategy) and increased activity at the hip joint (hip strategy).

Reducing the risk of falling requires implementing an exercise program that also supports this compensatory mechanism. In our study, we focused on the muscle groups around the hip joint, but to achieve statistically significant results, a longer implementation period is needed.

Malwanage et al. (2024), in their study, implemented sensorimotor rehabilitation in combination with gait training, strength training, and balance training. As such, the exclusive effect of sensorimotor training on improving the desired outcome cannot be directly determined. The observed improvement may result from the combined effects of the various exercise programs.

The proprioceptive reeducation program (PRP) developed in the present study confirms that its effect directly targets the improvement of proprioceptive deficits in individuals with diabetic neuropathy. Since improved proprioception can lead to correct motor programming and effective motor control of movement, the improvement in activities of daily living (ADL) following the PRP is justified.

In patients with diabetic neuropathy, reduced functional capacity is associated with poor proprioception. The results of this study found that patient gender does not influence the effectiveness of the PRP, showing that both women and men can achieve comparable benefits from its application. The PRP proved effective in enhancing both static and dynamic proprioception in the lower limbs, with no significant differences found between the right and left sides.

2.10 **Conclusion**

The working hypothesis is not confirmed because there are no statistically significant differences between the experimental group and the control group.

Future research could examine how training protocols that combine visual stimuli with complex postural movements—such as the use of balance platforms—might improve patient stability.

These findings could contribute to the development of more personalized exercise programs aimed at reducing fall risk and improving quality of life for elderly patients with diabetes.

Since most patients live in relatively predictable environments, they may still face fall risks due to factors such as peripheral diabetic neuropathy.

EXPERIMENTAL STUDY NO. 3

THE ROLE OF DUAL-TASK PROPRIOCEPTIVE TRAINING AND REACTIVE TRAINING ON THE CORE-TEX BALANCE PLATFORM IN IMPROVING STATIC BALANCE IN PATIENTS WITH TYPE 2 DIABETES

Combined training – involving both cognitive and motor exercises – significantly contributes to maintaining alertness and attention in the elderly during activities aimed at improving walking balance. When performing multiple tasks simultaneously or navigating variable terrains, the walking pattern has been found to change significantly compared to walking on uniform surfaces, with statistically significant differences ($p < 0.0001$) (Anandh et al., 2021).

Balance, gait technique, and walking speed in patients with various neurological disorders can be improved through motor-cognitive rehabilitation programs based on a dual-task approach.

Fall risk management in patients with neurological conditions gains valuable experimental support from the results obtained in this study, which implemented an intervention program based on the dual-task approach (Spano et al., 2022)

The ability to perform two or more cognitive tasks simultaneously indicates the use of a dual-task approach. Everyday activities, such as talking on the phone or carrying objects while walking, involve managing tasks concurrently. Performance in dual-task activities can be compromised if there are structural changes in the prefrontal regions of the brain, which are associated with attention and executive functions in older adults (Braver & Barch, 2002, as cited in Yildiz et al., 2024).

The 8-week dual-task training program focused on motor-cognitive and motor-motor activities showed results without statistically significant differences in improving balance, reducing fear of falling, optimizing gait, and increasing muscle strength. Both interventions led to notable progress in balance capacity, but only the motor-cognitive program demonstrated significant improvement in gait parameters. Therefore, it can be concluded that both types of training may be recommended to enhance these functions in the older adult population (Akin et al., 2021).

Optimizing various components of neuromotor control through reactive balance training (RBT) involves repeated exposure to postural perturbations to train and refine balance maintenance responses. So far, RBT is the only exercise technique that has been shown to enhance the reactive mechanisms needed to prevent falls caused by imbalance, through fast and coordinated whole-body movements aimed at counteracting the displacement of the center of mass during balance loss (Barzideh et al., 2020).

The meta-analysis has demonstrated that balance training interventions provide benefits comparable to those obtained through strength training programs in improving dynamic balance. Balance-focused programs incorporate functional exercises targeting various body regions and include sensory training components, whereas strength exercises focus exclusively on strengthening the muscles around the ankle joint affected by sprains (Molla-Casanova et al., 2021).

3.1 **Research purpose**

The final study aims to verify the effects on static balance of exercises within the dual-control proprioceptive training and training performed on the Core-tex reactive training platform. To assess the balance of patients with type 2 diabetes, we analyzed the value of the Aria CoM parameter, given that this is a relevant and frequently used indicator in the literature. The purpose of this experimental study is not to issue qualitative conclusions about balance, but to analyze a decrease in the values of the Aria CoM parameter.

3.2 **Research objectives**

• Development of an exercise program with a dual approach to improve static balance;
• Development of an exercise program on the Core-tex reactive training platform;
• Evaluation of the level of static balance in patients with type 2 diabetes before and after the intervention;
• Identification of the level of functionality of patients with type 2 diabetes;
• Implementation of the exercise program and analysis of its impact on static balance.

3.3 **Research hypotheses**

The working hypothesis of the final research states that there are significant differences in CoM movement in patients with type 2 diabetes between a dual attention control exercise program and an exercise program performed on the Core tex reactive training platform. Through the results obtained, we do not want to have qualitative conclusions about balance, but we want the values of the CoM Area parameter to decrease.

3.4 **Research organization**

In this stage of the study, we conducted an experiment consisting of three groups of patients with type 2 diabetes with whom we conducted two different intervention programs.

At the Elderly Care Foundation (FIV) in Cluj Napoca, 11 Tazlău Street, we conducted the initial balance assessment using the Romberg test followed by the implementation of the proprioceptive training program with exercises that have dual attention control. At the end of the 8 weeks, we conducted the final assessment of the patients participating in the study with the same type of tests.

At the Senior Day Center No. 1 within the Social Assistance Directorate of the City Hall of Cluj Napoca, during the 8 weeks, we performed an initial balance assessment using the Romberg test. After the assessment, we started implementing the kinetic reactive balance training program on the Core-Tex platform. At the end of the training period, we performed the final assessment of the participants with the same Romberg test applied in the initial assessment.

At the Pensioners' Club in the Mărăști neighborhood, which was the control group, we performed the initial and final balance assessment using the Romberg test with an 8-week break between assessments. Members of this control group, during the 8 weeks, followed the family doctor's instructions, which included: performing moderate physical activities for 150 minutes per week; maintaining a stable weight to facilitate blood sugar control and prevent complications; regular blood sugar monitoring to adjust the diet; exercise and drug treatment; adopting a balanced diet, with a reduced consumption of refined sugars and white flour products.

The independent variable is the intervention program aimed at improving static balance, applied only to the experimental groups. The repeated measurements (initial and final) are represented by the Romberg test and are used to evaluate the changes in the dependent variable. The dependent variable is represented by the value of the CoM Area parameter, such as plantar pressures, which are measured before and after the intervention program to observe its effects.

The three groups included 89 patients with type 2 diabetes from the urban area of Cluj Napoca, Cluj County. The sampling was carried out randomly based on the recommendation received from the family doctor who has patients with type 2 diabetes on file, and on a voluntary basis, with each patient expressing their agreement to participate in the study. We aimed for participants to be part of the age category of people who have left professional activity, and their minimum age to be 65 years. We also aimed for the people participating in the study to have the same level of activity, therefore all patients live in Cluj Napoca and participate in the activities of the neighborhood pensioner clubs. The selection by gender category was made randomly depending on the availability to participate in the study program.

In order to understand the level of complexity of the intervention program, each patient was instructed before starting which evaluation protocols the exercises in the kinetic program were to be performed. The intervention program was carried out in a controlled environment, maintaining the same conditions for each participant (kinesiotherapy room of the Senior Center no. 1 in Cluj Napoca, the physiotherapy room of the Elderly Care Foundation and the locker room of the Pensioners' Club in the Mărăști neighborhood). The time interval for carrying out the intervention program for the two groups involved in the study was between 9 A.M. and 14 P.M.

Participants signed an informed consent regarding voluntary participation in this study.

We included 89 patients with type 2 diabetes mellitus from the urban area of Cluj County. Inclusion criteria included a confirmed diagnosis of type 2 diabetes mellitus, age over 60 years, and the ability to perform the Romberg test.

The first group (1) was the Control Group (CG), which followed the diabetologist's instructions and consisted of 15 men and 15 women.

The second group (2) Study Group number 1 (GE1), which performed the dual-command proprioceptive training, consisted of 14 men and 16 women.

The third group (3) Study Group number 2 (GE2), which performed the reactive training on the Core-Tex platform, consisted of 14 men and 15 women.

Patients with diabetes-related cardiac complications or leg ulcers did not participate in this study. The study received approval from the UBB Ethics Committee (approval no. 6652/24.06.2021).

3.5 **Materials and research methods**

The experimental method allows the verification of the final research hypothesis through provoked observation that determines a particular approach to the assessments. This method involves the manipulation of specific variables, causing certain rebalancing reactions, in order to observe their effects on patients.

The statistical-mathematical method allows the analysis and interpretation of the data obtained from the assessments. In this research, we used the IBM SPSS Statistics 23 program (Statistical Package for Social Sciences) to perform the statistical analyses. The analysis included both descriptive and analytical methods.

3.6 **Equipment used**

BTS Pwalk baropodometry board, composed of a board of Size 675x540x5 mm containing a number of 2304 sensors, sensor size 1x1 cm, Sensor type: resistive, Pressure 30-400 kPa, acquisition frequency 100 Hz, power supply AC/USB adapter, 7 kg.

Reversible balance ball, with air that has a length and width of 33 centimeters, a height of 3 centimeters, and a weight of 0.5 kilograms composed of PVC material.

A plastic bottle with a volume of 330 ml, a paper cup with a volume of 250 ml.

A balance cushion weighing 0.34 kilograms, composed of TPE with a density of 50 (kg/m3) and dimensions: 40 cm long X 33 cm wide X 5 cm thick.

Laser pointer with red light beam.

Plastic marker with the following dimensions: 15 cm long X 15 cm wide X 20 cm high.

Foam wand 118 cm long.

Android tablet on which the Bubble level application from the Play Store is installed.

Foam ball with a diameter of 25 cm and a weight of 50 grams.

PVC ball with a diameter of 10 centimeters and a weight of 500 grams.

The Core-Tex reactive training platform (figure 16) which is distinguished from other equipment by the concept of "reactive variability", constantly providing varied stimulation for the muscles, nervous system and joints. The equipment allows a rapid and variable change in the way the body reacts during use of the balance platform. The balance platform responds quickly to the movements generated by the patient, the way it responds is very varied. Its construction includes a semicircular platform placed on a steel frame equipped with three mechanisms based on metal balls, allowing multidirectional and multiplanar movements.

3.7 **Testele de evaluare folosite**

Testul Romberg presupune poziționarea pacientului într-o poziție ortostatică pe placa baropodometrică (figura 17). Subiectul a fost instruit să mențină această poziție pentru 30 de secunde, atât cu ochii închiși (EC), cât și cu ochii deschiși (EO). Evaluarea a fost realizată o singură dată pentru fiecare protocol.

3.8 **Measured variables**

The BTS G Studio software generates a map where each zone of the foot is represented as follows:

• Zone T 1= corresponds to zone M1 (metatarsal 1)

• Zone T 2= corresponds to zone M2 (metatarsal 2)

• Zone T 3= corresponds to zone M3 (metatarsal 3)

• Zone T 4= corresponds to zone M4 (metatarsal 4)

• Zone T 5= corresponds to zone M5 (metatarsal 5)

• Zone T 1.5= corresponds to the intermediate zone between M1 and M2

• Zone T 2.5= corresponds to the intermediate zone between M2 and M3

• Zone T 3.5= corresponds to the intermediate zone between M3 and M4

• Zone T 4.5= corresponds to the intermediate zone between M4 and M5

• Zone T 6= corresponds to the forefoot where all zones from M1 to M5 have equal values of force

• Zone T 7= corresponds to a situation where the force was applied to both M1 and M5

3.9 **Kinetic program for experimental group 1**

Exercise 1. Warm-up exercises for the cervical area

Exercise 2. Warm-up exercises for the ankle joint

Exercise 3. Stretching exercises

Exercise 4. Balance exercises with double load by using a tablet with the Bubble Level application with your hands and supporting your feet on an unstable surface

Exercise 5. Balance exercises with double load by using a laser pointer with your hands and supporting your feet on an unstable surface

Exercise 6. Balance exercises with double load by using a glass of water with a bottle with your hands and supporting your feet on an unstable surface.

Exercise 7. Balance exercises with double load by using a foam wand with your hands and supporting your feet on an unstable surface.

Exercise 8. Balance exercises with double load by throwing-catching the ball and supporting your feet on an unstable surface.

3.10 **Kinetic program for experimental group 2**

Exercise 1. Balance exercises by maintaining the orthostatic position on the Core-Tex platform.

Exercise 2. Balance exercises by maintaining the orthostatic position on the Core-Tex platform and using the hands simultaneously.

3.11 **Conclusions**

Study 1

This study investigated how comorbidities of type 2 diabetes mellitus can influence the distribution of plantar pressures. Through a comparative approach of plantar pressures depending on the presence of certain comorbidities such as hypertension, dyslipidemia, diabetic polyneuropathy.

The results of the study show that men had a significantly higher muscle mass, while women had an increased fat mass. Support on unstable surfaces or with eyes closed due to the lack of sensory input (visual and proprioceptive) influenced the area described by the CoM.

The semiflexion posture is demanding from a biomechanical point of view but did not generate a movement of the CoM over a larger area as happened in the case of the evaluation of patients with type 2 diabetes mellitus in the absence of sensory information.

Daily activities of patients from rural areas carried out in varied environmental conditions allow an adaptation of destabilizing factors and thus a reduction in the risk of falls.

The distribution of body weight on the plantar surface during walking was performed by analyzing plantar pressures, which allowed us to differentiate, depending on comorbidities, the areas of maximum pressure. Patients with arterial hypertension did not present statistically significant differences in the one that monitors plantar pressures on certain areas of the foot. On the other hand, patients with the comorbidity of hypercholesterolemia presented an increased pressure on the medial area of the heel and in the metatarsal region of the left foot.

Patients with diabetic polyneuropathy presented or distributed body weight towards the hallux, patients with ischemic heart disease had or overloaded the metatarsal area M1 and M2. Non-parametric analysis of data resulting from the evaluation of walking on a baropodometry plate shows changes in weight distribution depending on these comorbidities.

This information shows us the importance of a personalized approach to the rehabilitation process of patients with type 2 diabetes.

Physical therapy programs that aim to develop balance through neuromuscular control must be complemented by strategies that maintain functional mobility and prevent tissue complications (plantar ulcers).

Study 2

The effectiveness of a proprioceptive exercise program was analyzed by analyzing changes in the movement of the center of mass (CoM). Following the results, the experimental group together with the control group obtained significant changes between the two assessments. From this we can conclude that daily activities have a favorable impact on the balance of patients in rural areas, comparable to an exercise program.

These results indicate the future adaptation of intervention programs by changing the duration, complexity and frequency of exercises.

The use of unstable platforms combined with exercises that combine visual stimuli can increase the effectiveness of physiotherapy programs.

Adapting exercises according to the functional level of the patient, understanding the life context, behavioral factors are necessary to improve control over the body's CoM.

Study 3

The analysis of the effects of the dual-control proprioceptive training program on the area described by the CoM allows the observation of improvements that occurred in men and women in experimental group 1, especially during the assessment of balance with eyes closed. The effectiveness of the intervention was supported by the results obtained from the non-parametric Wilcoxon and Kruskal-Wallis tests on the analyzed parameters.

Experimental group 2 did not achieve statistically relevant changes in the analyzed parameters also due to the fact that the training on the Core-tex board was performed with eyes open. Postural control was performed mainly on visual information, which limited the use of proprioceptive information.

The initial differences between the groups show that patients in the control group had good values of the evaluated parameters from the beginning of the study and were able to maintain them without structured training.

The composite strength parameter (Dr_MComp_Forța and Stg_MComp_Forța) revealed differentiated adaptations depending on the test conditions and the group of affiliation. The decrease in the value of this parameter on the metatarsal area in some participants may signal either a weight gain or an overload of the dominant limb.

The efficiency of the reactive training, performed by experimental group 2, is conditioned by the way of implementing the exercises (with or without visual input) as well as by the initial level of activity of the patients.

GENERAL CONCLUSION

The three studies included in this research highlight that CoM movement in patients with type 2 diabetes is influenced by gender, comorbidities, the context of daily activities and the type of therapeutic intervention implemented.

Measurement of CoM movement, plantar pressures, and forces exerted during the semiflexion position allowed an understanding of how patients respond to complex motor tasks and sensory limitations, allowing the development of personalized intervention programs.

The originality of these studies consists in a complex functional assessment of CoM movement in positions with a biomechanical model different from the classic Romberg test, which allow indirect assessment of the muscle strength necessary to maintain the fixed semiflexion position of the legs.

Another original aspect is the evaluation of plantar pressures for each type of comorbidity existing in the patient with type 2 diabetes. This personalized evaluation allows the analysis of the postural patterns that patients form over time and can help establish the optimal intervention plan necessary for the treatment of the diabetic foot.

This study allowed, through data analysis, to highlight the duration of loading of the overstressed plantar areas during walking by measuring the contact time of each area of the foot with the ground. This analysis model together with data from kinetic and kinematic analysis can provide valuable information related to the biomechanics of the foot during walking.

By implementing the intervention programs of these studies, we observed the importance of approaching several complementary types of intervention because no program proves to be superior to the other, instead each program can offer benefits depending on the situation of each patient.

Daily activities performed in varied environments, dual-load proprioceptive training performed on unstable surfaces, and the effects of reactive training on the Core-Tex board performed with eyes closed have been shown to be effective in preventing falls.

The results obtained in these studies contribute to the development of interventions focused on the needs and particularities of patients with type 2 diabetes.

BIBLIOGRAPHY

Ackerley, R., & Samain-Aupic, L. (2022). Passive proprioceptive training alters the sensitivity of muscle spindles to imposed movements. *eNeuro, 9*(1), 0249-21. https://doi.org/10.1523/ENEURO.0249-21.2021

Agostini, V., Chiaramello, E., & Knaflitz, M. (2013). Circular components in center of pressure signals. *Motor Control, 17*, 355-369. https://doi.org/10.1123/mcj.17.4.355

Ahmad, I., Shalini, V., Noohu, M. M., Shareef, M. Y., & Ejaz, H. (2020). Sensorimotor and gait training improves proprioception, nerve function, and muscular activation in patients with diabetic peripheral neuropathy: A randomized control trial. *Journal of Musculoskeletal and Neuronal Interactions, 20*(2), 234-238.

Ahmad, I., Noohu, M. M., Verma, S., Singla, D., & Hussain, M. E. (2019). Effect of sensorimotor training on balance measures and proprioception among middle and older age adults with diabetic peripheral neuropathy. *Gait & Posture, 74*, 114–120. https://doi.org/10.1016/j.gaitpost.2019.08.018

Akin, H., Senel, A., Taskiran, H., & Mutlu, E. K. (2021). Do motor-cognitive and motor–motor dual task training efect differently balance performance in older adults? European Geriatric Medicine, 12, 371–378. https://doi.org/10.1007/s41999-020-00434-8

Amat-Martínez, A., Hita-Contreras, F., Lomas-Vega, R., Caballero-Martínez, I., Alvarez, P. J., & Martínez-López, E. (2013). Effects of 12-week proprioception training program on postural stability, gait, and balance in older adults: A controlled clinical trial. *Journal of Strength and Conditioning Research, 27*(8), 2180-2188. https://doi.org/10.1519/JSC.0b013e31827da35f

Amemiya, A., Noguchi, H., Oe, M., Ohashi, Y., Ueki, K., Kadowaki, T., Mori, T., & Sanada, H. (2014). Elevated plantar pressure in diabetic patients and its relationship with their gait features. *Gait & Posture, 40*(4), 408–414. https://doi.org/10.1016/j.gaitpost.2014.05.063

Anandh, S., Varadharajulu, G., Alate, M. M., & Mane, D. A. (2021). *Effect of dual task training on balance and gait over regular and diversified land surfaces in independent elderly*. International Journal of Current Research and Review. http://dx.doi.org/10.31782/IJCRR.2021.13113

Armstrong, D. G., Boulton, A. J. M., & Bus, S. A. (2017). Diabetic foot ulcers and their recurrence. *New England Journal of Medicine, 376*(24), 2367–2375. https://doi.org/10.1056/NEJMra1615439

Barzideh, A., Marzolini, S., Danells, C., et al. (2020). Effect of reactive balance training on physical fitness poststroke: Study protocol for a randomised non-inferiority trial. *BMJ Open, 10*, e035740. https://doi.org/10.1136/bmjopen-2019-035740

Barry, E., Galvin, R., Keogh, C., Horgan, F., & Fahey, T. (2014). Is the Timed Up and Go test a useful predictor of risk of falls in community-dwelling older adults: A systematic review and meta-analysis. *BMC Geriatrics, 14*(1). https://doi.org/10.1186/1471-2318-14-14

Brognara, L., Sempere-Bigorra, M., Mazzotti, A., Artioli, E., Julián-Rochina, I., & Cauli, O. (2023). Wearable sensors-based postural analysis and fall risk assessment among patients with diabetic foot neuropathy. *Journal of Tissue Viability, 32*(4), 516-526. https://doi.org/10.1016/j.jtv.2023.10.002

Boulton, A. J. M., Armstrong, D. G., Albert, S. F., Frykberg, R. G., Hellman, R., Kirkman, M. S., & Wukich, D. K. (2008). Comprehensive foot examination and risk assessment: A report of the task force of the foot care interest group of the American Diabetes Association. *Diabetes Care, 31*(8), 1679–1685. https://doi.org/10.2337/dc08-9021

Bus, S. A., Lavery, L. A., Monteiro-Soares, M., Rasmussen, A., Raspovic, A., Sacco, I. C., & van Netten, J. J. (2019). Guidelines on the prevention of foot ulcers in persons with diabetes (IWGDF 2019 update). *Diabetes/Metabolism Research and Reviews, 36*(S1), e3269. https://doi.org/10.1002/dmrr.3269

Campolettano, E. T., Madigan, M. L., & Rowson, S. (2020). Reliability of center of pressure-based measures during dual-task postural control testing in a youth population. *The International Journal of Sports Physical Therapy, 15*(16), 1036. https://doi.org/10.26603/ijspt20201036

Chau, R. M. W., Ng, T. W. H., Kwan, R. L. C., Choi, C. H., & Cheing, G. (2013). Risk of fall for people with diabetes. *Disability and Rehabilitation, 35*, 1975-1980.

Chebel, E., & Tunc, B. (2021). Deep neural network approach for estimating the three-dimensional human center of mass using joint angles. *Journal of Biomechanics, 126*, 110648. https://doi.org/10.1016/j.jbiomech.2021.110648

Chen, S. M., Shen, F. C., Chen, J. F., Chang, W. D., & Chang, N. J. (2019). Effects of resistance exercise on glycated hemoglobin and functional performance in older patients with comorbid diabetes mellitus and knee osteoarthritis: A randomized trial. *International Journal of Environmental Research and Public Health, 17*(1), 224. https://doi.org/10.3390/ijerph17010224

Cicchella, A. (2020). Development of the biomechanical technologies for the modeling of major segments of the human body: Linking the past with the present. *Biology (Basel), 9*(11), 399. https://doi.org/10.3390/biology9110399

Comfort, P., & Kasim, P. (2007). Optimizing squat technique. *Strength and Conditioning Journal, 29*(6), 10-13. https://doi.org/10.1519/00126548-200712000-00001

Degache, F., et al. (2007). Enhancement of isokinetic muscle strength with a combined training programme in chronic heart failure. *Clinical Physiology and Functional Imaging, 27*, 225-230. https://doi.org/10.1111/j.1475-097x.2007.00741.x

Demirchyan, G. I., Mkrtchyan, H., & Petrosyan, T. (2025). Tai Chi exercises with multi-parameter balance feedback enhance recovery in athletes after orthopedic injuries: A case study. DOI:10.7752/jpes.2025.01001

Donath, L., et al. (2012). Comparison of COP path length evaluation between two devices. *Gait & Posture, 36*, 439-443. https://doi.org/10.1016/j.gaitpost.2012.04.001

Epuran, M. (2002). *Motricitate şi psihism: Fascicula 2. Psihomotricitatea.* Facultatea de Educaţie Fizică şi Sport

Espejo-Antúnez, L., Pérez-Mármol, J.M., Cardero-Durán, M.L.A., Toledo-Marhuenda, J.V., Albornoz-Cabello, M., (2020). The Effect of Proprioceptive Exercises on Balance and Physical Function in Institutionalized Older Adults: A Randomized Controlled Trial. *Arch Phys Med Rehabil*, 101(10):1780-1788. doi: 10.1016/j.apmr.2020.06.010

Ewan, T., Battaglia, G., Patti, A., Brusa, J., Leonardi, V., Palma, A., Bellafiore, M., (2019). Physical activity programs for balance and fall prevention in elderly A systematic review. *Medicine*, 98:27. DOI: 10.1097/MD.0000000000016218

Fernando, M., Crowther, R., Lazzarini, P., Sangla, K., Cunningham, M., Buttner, P., & Golledge, J. (2013). A systematic review and meta-analysis of findings from the gait cycle, muscle activity and dynamic barefoot plantar pressure. *Clinical Biomechanics, 28*(8), 831–845. https://doi.org/10.1016/j.clinbiomech.2013.08.004

Freitas, S. M. S. F., & Duarte, M. (2011). Joint coordination in young and older adults during quiet stance: Effect of visual feedback of the center of pressure. *Gait & Posture, 35*, 83-87. https://doi.org/10.1016/j.gaitpost.2011.08.011

Freire, L. B., Brasil-Neto, J. P., da Silva, M. L., Miranda, M. G. C., Cruz, L. M., Martins, W. R., & da Silva Paz, L. (2024). Risk factors for falls in older adults with diabetes mellitus: systematic review and meta-analysis. *BMC Geriatr,* 24. https://doi.org/10.1186/s12877-024-04668-0

Frykberg, R. G., Zgonis, T., Armstrong, D. G., Driver, V. R., Giurini, J. M., Kravitz, S. R., ... & Vanore, J. V. (2006). Diabetic foot disorders: A clinical practice guideline (2006 revision). *Journal of Foot and Ankle Surgery, 45*(5 Suppl), S1–S66. https://doi.org/10.1053/j.jfas.2006.07.001