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Physiotherapy in the treatment of the metabolic syndrome associated with the right-sided scoliosis

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Abstract

The purpose of the work was to study the effect of targeted physical therapy in scoliotic disease on changes in carbohydrate metabolism in patients with metabolic syndrome. The dependence of visceral fat and glycated hemoglobin levels on the C-shaped right-sided thoracic scoliosis as stimulated through comprehensive physical therapy is being investigated. A hypodynamic lifestyle and a forced posture when sitting during working hours causes a change in the spinal rotation which deform the thorax and affect functioning of the organs.

Materials and Methods: the study involved 36 patients split into two groups. The level of glycated hemoglobin was higher than 5.93% in women and 6.05% in men. The same physical and diet therapy was prescribed for the two groups. However, the main study group combined targeted exercises and kinesio-taping to reduce the scoliosis.

Results: based on the distribution of χ^2 the classical method of processing statistical data was applied to the study, which is well applicable for a small amount of data. The statistical data showed a linear dependence between the Cobb angle and glycosylated hemoglobin level which was especially pronounced in women prior to physical therapy. The correlation between glycosylated hemoglobin level and the Cobb angle declined in both men and women with an improvement in posture.

Conclusions: with a decrease in the Cobb angle, the correlation between it and the level of glycosylated hemoglobin decreased in both men and women, which confirms the hypothesis that carbohydrate metabolism is associated with changes in the pancreas that occur due to rotational changes in the spine. By studying metabolic syndrome, even in small groups of patients, general practitioners will be able to expand the list of treatment recommendations.

Key words: metabolic syndrome, thoracic scoliosis, physical therapy, diet therapy, kinesio-taping, glycosylated hemoglobin.

Фізіотерапія в лікуванні метаболічного синдрому, пов'язаного з правобічним сколіозом

Мета: вивчити вплив таргетної лікувальної фізкультури при сколіотичній хворобі на зміни вуглеводного обміну у хворих на метаболічний синдром. Досліджується залежність рівня вісцерального жиру та глікованого гемоглобіну від С-подібного правобічного грудного сколіозу, стимульованого комплексною лікувальною фізкультурою. Гіподинамічний спосіб життя та вимушене сидяче положення в робочий час викликає зміну повороту хребта, що деформує грудну клітку та позначається на функціонуванні органів.

Матеріали та методи: у дослідженні взяли участь 36 пацієнтів, розділених на дві групи. Рівень глікованого гемоглобіну був вище

5,93% у жінок і 6,05% у чоловіків. Для обох груп була призначена однакова лікувальна фізкультура та дієта. Однак основна група дослідження поєднувала цілеспрямовані вправи та кінезіотейпування для зменшення сколіозу.

Результати: на основі розподілу χ^2 для дослідження застосовано класичний метод обробки статистичних даних, який добре застосовний для невеликої кількості даних. Статистичні дані показали лінійну залежність між кутом Кобба та рівнем глікозильованого гемоглобіну, яка була особливо виражена у жінок до фізіотерапії. Кореляція між рівнем глікозильованого гемоглобіну та кутом Кобба знизилася як у чоловіків, так і у жінок із покращенням постави.

Висновки: зі зменшенням кута Кобба кореляція між ним і рівнем глікозильованого гемоглобіну знижувалася як у чоловіків, так і у жінок, що підтверджує гіпотезу про зв'язок вуглеводного обміну зі змінами в підшлунковій залозі, які виникають внаслідок ротаційних змін у хребті. Вивчаючи метаболічний синдром навіть у невеликих групах пацієнтів, лікарі загальної практики зможуть розширити перелік рекомендацій щодо лікування.

Ключові слова: метаболічний синдром, грудний сколіоз, лікувальна фізкультура, дієтотерапія, кінезіотейпування, глікозильований гемоглобін.

Introduction

Metabolic syndrome (MS) is a serious public health problem and a challenge for physiologists and clinicians around the world due to the growing urban population, poor diet, obesity and sedentary lifestyle of the majority of the population (Herningtyas et al., 2019). In the European region, the prevalence of MS varies from 20 to 35%. It is diagnosed 2.5 times more often in women than in men and progresses with age (Kolyada et al., 2019; Kalmykova et al., 2023; Mankovsky, 2007). Despite the data already available (Namazi et al., 2018), the processes underlying the MS development need further investigation. Metabolic risks can be provoked by insulin resistance (IR) stimulated by excess glucose and lipids which can alter biochemical reactions through the action of lipids and the serine/threonine-specific protein kinase (Muoio et al., 2008). Differences in genotype, nutrition, levels of physical activity, bad habits, family history of diabetes have long been known to affect MS prevalence (Mendrick, 2018; Ivanenko et al., 2020). MS refers to a group of metabolic disorders, which are based on primary IR and compensatory systemic hyperinsulinemia which result in complex metabolic, hormonal and clinical disorders, namely arterial hypertension, abdominal obesity, hyperlipidemia, all of them constituting high risk factors for the development of cardiovascular diseases (Rask Larsen et al., 2018; Yanushpolska et al., 2020).).

The most influential organizations involved in healthcare (Nazar et al., 2016; Zhang et al., 2018; James et al., 2020; Mechanick et al., 2018; Zimmet et al., 2005) have given their own definition of MS, but these definitions differ substantially (McCracken et al., 2018). MS is a comorbid condition with many clinical manifestations; therefore, studies of the MS are still ongoing and the researchers should consider development of new therapeutic strategies as their top priority (Aguilar-Salinas et al., 2019). A holistic approach is required for MS diagnosis and therapy, taking into account the possible causes of the syndrome. The human body can be considered not only from a biochemical point of view, but also with regard to the change in the center of gravity due to the excess weight and further changes in the human musculoskeletal system. Scientists are already investigating the dependence of scoliosis on the presence and degree of IR in animals and humans (Silva et al., 2012; Aftzoglou et al., 2017). Since MS is a comorbid condition and develops along with IR, changing the Cobb angle in MS patients through physical therapy and examining subsequent changes in glucose tolerance is an important issue to be explored.

The aim of the study was to investigate the dependence of the change in carbohydrate metabolism in MS patients on the reduction of the C-shaped scoliosis angle due to targeted physical therapy. Right-sided C-shaped scoliosis occurs most frequently among all population groups. With a hypodynamic lifestyle and a forced sitting posture during working hours, the load on the back muscles is not uniform which contributes to rotational changes in the spine. We put forward a hypothesis that biomechanical rotational changes in the position of the spine lead to a thoracic deformity which alters physiological parameters of the organs.

Material and methods of research

The biomechanical rotational changes in the spine are assumed to deform the thorax and affect functioning of the organs. Each patient suffering from MS has been followed for 3.5 months at V. T. Zaitsev Institute of General and Emergency Surgery at the National Academy of Medical Sciences of Ukraine and V. N. Karazin Laboratory of Laser Biology and Laser Medicine which has long been studying the course and rehabilitation of the diabetic foot syndrome. All work was conducted with the formal approval of the local human subject or animal care committees (institutional and national), and that clinical trials have been registered as legislation requires.

Participants

The study involved 36 patients split into two groups. The main group of 12 women and 12 men with MS manifestations underwent targeted physical therapy to correct their body weight, including asymmetrical exercises and kinesis taping (KT) to reduce the Cobb angle. The second group of 6 women and 6 men with MS manifestations was prescribed general physical therapy for body weight correc-

tion. The average age of the female population was 27±3.4 years, for male patients it reached 33±2.4 years. In both groups, all patients had stage II thoracic (apex at the level of T8-T9) right-sided fixed scoliosis which was non-progressive and compensated. To determine the Cobb angle, the Adams test and the Scoliosis Track scoliometer were used. The degree of rotation of the spinal turn was also determined with the GIMA mpm00356 scoliometer. Both measurement methods are equally precise as the angle data were the same for all patients. Prior to the start of the study, patients in both groups were tested for glycosylated hemoglobin (HbA1c). Its levels were above 5.7% in all patients, in three men its values exceeded 6.4% which may indicate type 2 diabetes mellitus (DM2). OMRON BF 511 key body parameter monitor determined the visceral fat ratio (VFR) of each patient from both groups, the value indicative of abdominal obesity. Based on the interpretation of the visceral fat level according to the manufacturer of the monitor (Instruction Manual, 2021), before the start of the study all patients from both groups had an excessive visceral fat accumulation. An elevated arterial pressure or arterial hypertension of the 1st degree (Instruction Manual, 2021, p. 8-9) was registered in all the patients. Patients from both groups had a sedentary lifestyle at the beginning of the study.

All patients in research described in our paper has given written consent to the inclusion of material pertaining to themselves, that they acknowledge that they cannot be identified via the paper and that we have fully anonymized them.

Methods and Procedure

Therapeutic diet. The results of randomized controlled trials can allow us to estimate the effectiveness of diet in reducing HbA1c in the prediabetic state (American Diabetes Association, 2014) and in the development of DM2 (Duarte-Gardea et al., 2018; Al-Ozairi et al., 2018; Kalmykov et al., 2021). In DM2 treatment, diet can accelerate recovery with no hypoglycemic drugs or side effects (Sami et al., 2017). The diet was aimed at reducing the weight of the patients, taking into account the anticipated energy losses. However, when choosing a diet suitable for all patients from both groups, it was important to consider comorbidities that diet could affect. Cardiovascular system plays the most important part in diagnosing changes in the patient's condition. It is also the most dynamic system that should be taken as a reference point. Since all patients had higher blood pressure values it was decided to follow the DASH (Dietary Approaches to Stop Hypertension) diet that meet most of the requirements (Challa et al., 2022; Steinberg et al., 2017). An individual diet was developed for each patient based on preferences, social and financial status, availability of food depending on the season. However, all the differences remained within the DASH diet requirements in terms of the quantity and quality of nutrients.

Dietary supplements (DS) were included in the diet in order to accelerate metabolism. Additionally, a possible decrease in calcium levels was diagnosed through percussion or tapping the facial nerve area (in front of the tragus) with a reflex hammer, in all the patients with MS with no exception, facial muscle contraction was observed (Chvostek type I and II). Based on this symptom, all patients were recommended calcium citrate 1000 mg for women and 1300 mg for men, which corresponds to the daily dose and contains an organic form of salt which is better absorbed by the body. Vitamin D3 was also recommended at the highest tolerated daily dose of 4000 IU (Grant, 2011) for both women and men. To restore the electrolyte balance after physical therapy, each participant took the organic salt of potassium and magnesium, 600 mg each, in the form of a drink. In comparison to a tablet, a drink is absorbed better since it requires less time to go through the lesser curvature of the stomach into the intestine. A combination of myo-inositol (550 mg) and d-chiro-inositol (13.8 mg) was also introduced in the patients' diet in the form of DS to reduce IR (Troisi et al., 2019). The patients followed these recommendations for 3 months. Also, all patients underwent a course of balneotherapy with moderately mineralized CO_2-rich magnesium–sodium–bicarbonate–sulphate-type mineral water (5-10 g/l) during the first month of therapy, and it was recommended to repeat the course 2 months after the completion of the study. Since it was during the second month that the patients lost most weight, DSs were recommended to restore the level of L-glutathione. A dosage of L-glutathione 250 mg/day was prescribed. All DSs were taken c.c. or as described above. All the DSs recommended came from manufacturers with a GMP production standard.

Physical therapy. Physical therapy in the control group for 3 months was aimed at increasing physical activity of patients. The goal was to increase the pressure in the abdominal cavity. Therefore, each patient was asked to do static and dynamic breathing exercises in the morning after waking up and at 21:00 in the evening. Physical therapy sessions (1 hour) were held on the basis of the Correct Movement Studio twice a week during the first month and three times in the following two months. The first part of the session was dedicated to static exercises (muscle tension in different body positions while holding a weight), dynamic exercises, balance exercises and muscle stretching took the other half of the session. Such a combination of exercises was chosen to increase pressure in the abdomen and work on visceral fat. All muscle groups were involved symmetrically.

Physical therapy in the main study group was carried out according to the scheme proposed for the control group. However, the exercises were targeted at overcoming the effects of scoliosis. In this case, both dynamic and static exercises were aimed at reducing the postural imbalance of the back muscles, paravertebral muscles, and trunk muscles. Their purpose was also to strengthen

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Physical rehabilitation and recreational health technologies
Vol. 8 No 3

muscles of the neck, upper and lower scapular detentors, pectoral and rhomboid muscles to reduce the asymmetry of the shoulder blades.

Kinesio-taping (KT) for lymphatic drainage of the abdomen (shown in Fig. 1, d) was performed in the control group for 21-23 consecutive days during the second month of physical therapy with a regular change of tapes every 3 or 4 days (the tapes were changed 7 times). The main study group completed not only KT for lymphatic drainage according to the same scheme as the control group. An additional 21-day course of corrective back taping was also used to reduce the muscle tone, stretch the muscles on the left side and increase the muscle tone and strength on the right side. It was necessary to stimulate and relax the lower muscle fibers of the trapezius muscle, the large and small rhomboid muscle, the lower serratus muscles on the corresponding sides. Corrective KT for lymphatic drainage in the main study group was carried out for 21-25 consecutive days during the second month of physical therapy with a regular change of tapes every 3 or 4 days (change of tapes for 7 times). To assess the improvement of blood microcirculation, we used an IR camera (Fluke Ti400), since earlier such an analysis of the temperature distribution proved to be good when we studied changes in blood microcirculation in the legs of patients with diabetic foot syndrome after laser stimulation (Beloshenko et al., 2020).

Statistical analysis

One of the principals aims of the study was to confirm the hypothesis of a possible dependence of the HbA1con the Cobb angle through calculating the χ^2 criterion (Berry et al.,1996; DeGroot, 2012; Rice, 2016). The data obtained on the Cobb angle, VFC, HbA1clevels were divided into 4 bins (Taylor, 1997). We further calculated the frequency of each parameter falling into one of the four bins. The frequency analysis data are shown in Figs. 1-4.

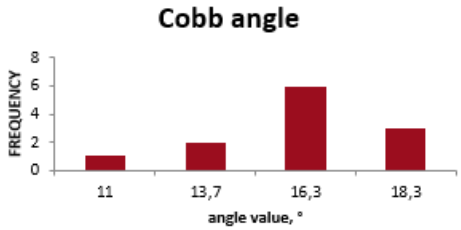

Figure 1. Histogram of the Cobb angle distribution among patients before the therapy.

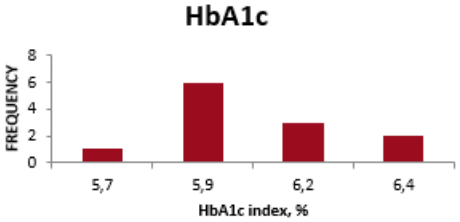

Figure 2. Histogram of the glycosylated hemoglobin distribution among patients before the therapy.

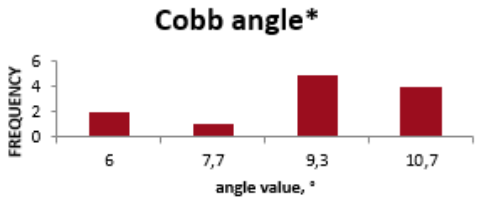

Figure 3. Histogram of the Cobb angle distribution among patients after therapy.

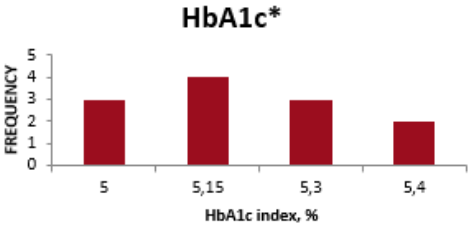

Figure 4. Histogram of the glycosylated hemoglobin distribution among patients after therapy.

Based on the central limit theorem with a large number of degrees of freedom, the distribution of the random variable χ^2 can be approximately described by the Student's distribution. But since the data presented in this article is limited, it is statistically justified to use a more general approach based on the distribution of χ^2. Figures 2 and 3 illustrate that before therapy, the indicators corresponded to Gaussian distribution (DeGroot, 2012) which was confirmed by the χ^2 test which showed a value of 1,95. Thus, the hypothesis of normal distribution is valid because $\chi^2 \leq n$, where n=4 is the number of bins (Taylor, 1997). Therefore, we can calculate the coefficient of correlation between the Cobb angle and HbA1cusing the following formula (Statistical Correlation, 2023):

$$Corr[\text{Cobb angle}, Hb\ \text{A1c}] = \frac{E[\text{Cobb angle}, Hb\ \text{A1c}] - E[\text{Cobb angle}]E[\ Hb\ \text{A1c}]}{\sigma[\text{Cobb angle}]\sigma[Hb\ \text{A1c}]}$$

Where E[Cobb angle, HbA1c], E[Cobb angle] and E[HbA1c] – expected values of [Cobb angle, HbA1c], [Cobb angle], [HbA1c], respectively.

σ[Cobb angle], σ[HbA1c] – standard deviation of [Cobb angle], [HbA1c], respectively.

The coefficient of correlation between the two values was $Corr$[Cobb angle, HbA1c]=0,75~1, which indicates a linear correlation between the value of Cobb angle and HbA1cin the blood (Berry, 1996).

Results of the study

The data obtained during the study were processed statistically. First of all, Cobb angle, visceral fat coefficient VFC, HbA1cindex were assumed to be continuous data following the Gaussian distribution. The expected value and standard deviations are presented in Tables 1, 2.

The test result comparison showed a reduction in visceral accumulations. In the main study group, VFC of only 2 patients (~8%) did not correspond to the normal range (Instruction Manual, 2021, p. 8-9), in the control group, most patients mani-

Table 1. Diagnostic parameters of patients before therapy (E[X]±2σ)

	Main study group			Control group		
	Cobb angle,°	**VFC**	**HbA1c, %**	**Cobb angle,°**	**VFC**	**HbA1c, %**
female	15,6±4,7	13±4	5,95±0,38	14,3±3,1	10±2	5,93±0,47
male	16,3±3,8	15±4	6,21±0,69	15,8±4,6	13±3	6,05±0,50

Table 2. Diagnostic parameters of patients after therapy (E[X]±2σ)

	Main study group			Control group		
	Cobb angle,°	**VFC**	**HbA1c, %**	**Cobb angle,°**	**VFC**	**HbA1c, %**
female	8,7±3,4	8±3	5,1±0,29	13,3±3,3	8±2	5,43±0,21
male	9,4±2,8	8±2	5,25±0,4	13,0±4,4	10±1	5,5±0,60

fested a decrease in VFC, however, 3 men and 1 woman (~33%) were out of the normal range as well. The Cobb angle in the control group did not decrease, while in the main group, the Cobb angle in all patients decreased to a value corresponding to stage 1. The HbA1clevel in all patients of both groups decreased to the normal range. Nevertheless, in the main group, the decrease proved greater with no single patient having a threshold value, in the control group two patients showed a threshold level of HbA1c.

KT for lymphatic drainage was used to improve the tissue trophism and accelerate blood circulation in the abdominal cavity. Fig. 5 shows a thermogram of a patient from the main study group where the temperature of skin in the abdominal area is different before the first procedure, immediately after removing the tapes in the evening on the 3rd day and the morning after. Before the first procedure, the temperature in this area was 3.6°C lower (Fig. 5a) than the temperature immediately after removing the tapes after 3 days (Fig. 5b). This confirms an increase in microcirculation due to KT. The temperature the morning after removing the tapes was also 1.8°C higher than the initial value (Fig. 5c), which shows a lasting effect produced by KT.

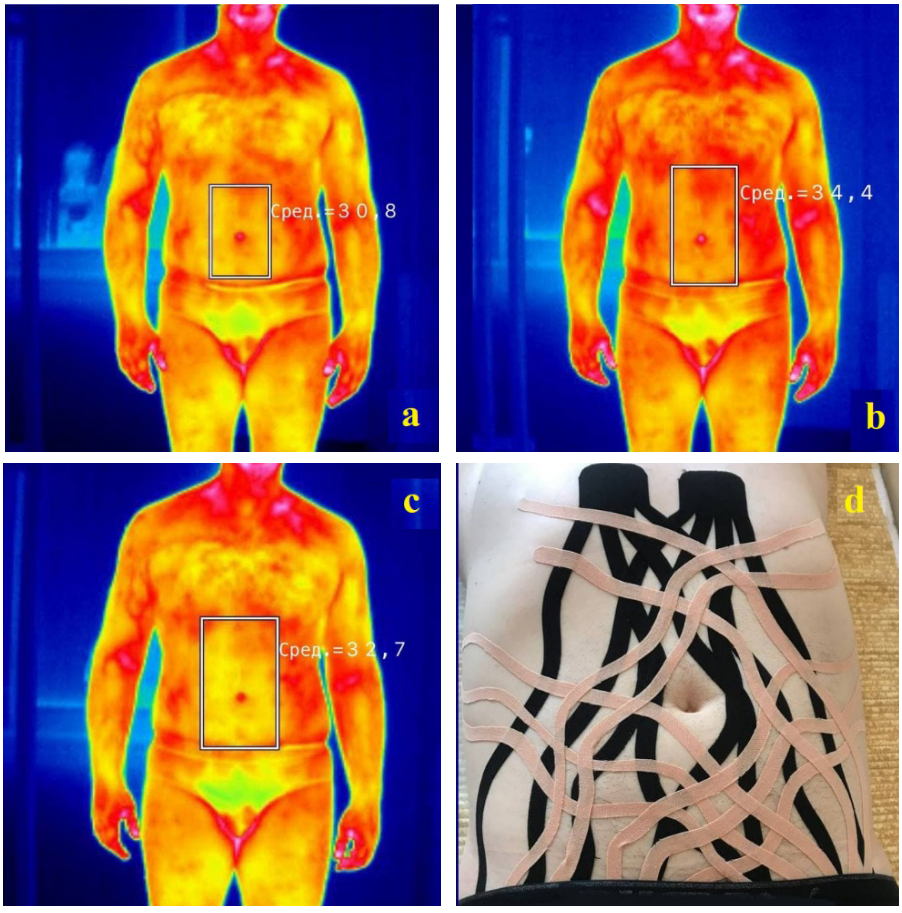

Figure 5. Change in thermodynamic equilibrium before and after KT and lymphatic drainage. a) thermogram of the patient before taping; b) thermogram of the patient after removing the tapes on day 3; c) thermogram of the patient on the next day after removing the tapes; d) photograph of the patient's torso during KT for lymphatic drainage.

Discussion

Patients with scoliosis showed statistically significant changes in glycated hemoglobin levels with changes in Cobb angles. Physical therapy with a targeted approach and complexity resulted in significant improvements. On the other hand, analysis of the data after therapy according to Figures 3 and 4 suggests a non-parametric distribution which cannot be described by a Gaussian distribution since the sample size was insufficient for a detailed analysis. It can be assumed that if *Corr*[Cobb angle*, *Hb*A1*c**]=0,56, then, after therapy, the Cobb angle* and *Hb*A1*c** parameters do not show any direct interdependence (Taylor, 1997).

Both groups also have noted an improvement in their psycho-emotional and physical condition as well as an increased social and professional activity. Although the level of HbA1c alone is not a sufficient criterion for determining the DM2 severity (American Diabetes Association, 2021), antidiabetic drugs are widely prescribed to patients with similar HbA1c values around the world (Tanabe et al., 2017; (American Diabetes Association, 2012). Physical therapy has already proved efficient for various pathological conditions (Dibben et al., 2023; Nomura et al., 2018; Carbone et al., 2019). A multidisciplinary approach is crucial in diagnosis and treatment of patients suffering from MS and DM2. Due to digitalization in medicine, including the development of new applications for patients with type 2 diabetes or patients with MS (Fleming, 2020), we consider it necessary to expand the functionality of such applications to propose physical therapy along with the conventional recommendation of antidiabetic drugs.

Conclusions

According to the results of the study, HbA1cvalues in men are closer to the normal range in comparison to women, even with a higher VFC. Before treatment, the Cobb angle and HbA1c showed a direct interdependence in women. The Cobb angle and HbA1c correlated in all patients before therapy. However, after therapy no correlation was found. The use of the above methods of statistics makes it possible to determine the presence of a linear dependence of continuous random variables, taking into account a small amount of data, which indicates the reliability of the results. The statistically significant difference is observed with reaching minimal clinically important difference.

The proposed therapy proved effective as a multidisciplinary approach to diagnosis and treatment gave an opportunity to significantly improve the patients' condition. Nevertheless, prescription of DS, especially in threshold concentrations, requires a more detailed examination of each patient for the best possible result. For example, we consider it appropriate to check the calcium concentration in the blood of the entire cohort when prescribing vitamin D3 at a concentration above the maximum tolerable level and when detecting a symptom of Chvostek.

Right-sided C-scoliosis affects the concentration of HbA1c. Consequently, when correcting the body weight, especially in patients with MS, it is essential to take into account the condition of the spine and back muscles and their ability to evenly distribute weight and reduce the displacement vector for the center of mass in relation to biomechanical deformation of the thorax to alleviate pressure on the pancreas.

Author's contribution

Conceptualization, RI and GK; methodology, RI; software, BK; check RR, VY; formal analysis, BK; investigation, RI; resources, GK; data curation, RI and BK; writing - rough preparation, RI; writing - review and editing, RI; visualization, RR and BK; supervision, RR and BK; project administration, VY. All authors have read and agreed with the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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