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BASELINE HETEROGENEITY OF METABOLIC SYNDROME IN MIDDLE-AGED WOMEN: A COMPREHENSIVE PRE-INTERVENTION ASSESSMENT

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Metabolic syndrome (MS) is a multifactorial pathological condition characterized by the coexistence of abdominal obesity, insulin resistance, dyslipidemia, arterial hypertension, and chronic low-grade systemic inflammation. The problem of MS is particularly relevant in middle-aged women due to age-related endocrine changes, accumulation of visceral adipose tissue, and the formation of an unfavorable cardiometabolic profile. The aim of the study was to perform a comprehensive assessment of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters in middle-aged women with metabolic syndrome and to determine manifestations of baseline heterogeneity of the studied condition. Women with MS demonstrated significantly higher body mass, BMI, waist circumference, total and visceral fat content, glucose, insulin, HbA1c, triglycerides, total cholesterol, CRP, IL-6, TNF-α, leptin, and arterial blood pressure values compared with healthy women. At the same time, adiponectin levels were significantly lower. Intragroup analysis revealed the presence of metabolic and inflammatory heterogeneity among women with MS. The obtained findings confirm the development of systemic cardiometabolic dysregulation in women with MS and substantiate the feasibility of personalized intervention approaches aimed at correcting insulin resistance, adipose tissue dysfunction, and systemic inflammation.

Key words: *metabolic syndrome, middle-aged women, abdominal obesity, insulin resistance, dyslipidemia, systemic inflammation, arterial hypertension, cardiometabolic risk.*

Connection of the publication with planned research work.

The study is carried out at the Department of Medical Biology and Sports Dietetics of the National University of Physical Education and Sport of Ukraine and is part of the research project for 2023–2027 under topic 2.8. “Influence of endogenous and exogenous factors on the course of adaptive reactions of the organism to physical loads of different intensity” (state registration number 012U108187).

Introduction.

Metabolic syndrome (MS) is a complex multifactorial pathological condition characterized by the coexistence of abdominal obesity, insulin resistance, dyslipidemia, arterial hypertension, and chronic low-grade systemic inflammation [1, 2, 3, 4]. According to current concepts, MS is regarded not merely as a combination of risk factors, but as an integrated cardiometabolic phenotype resulting from the interaction between impaired insulin signaling, adipose tissue dysfunction, and immunometabolic mechanisms.

The problem of MS is particularly relevant in middle-aged women. Age-related endocrine alterations, primarily the decline in estrogen activity, are accompanied by redistribution of adipose tissue toward the visceral compartment, reduction in muscle mass, and decreased metabolic flexibility [5, 6, 7]. These changes contribute to the progression of dysglycemia, atherogenic dyslipidemia, elevated arterial blood pressure, and the formation of an unfavorable cardiometabolic profile. In MS, adipose tissue functions as an active endocrine and immunometabolic organ [8, 9]. Excessive visceral adiposity is associated with increased pro-inflammatory activity and reduced adiponectin levels, thereby contributing to the progression of insulin resistance, endothelial dysfunction, and atherogenic lipid metabolism disturbances [9, 10].

At the same time, MS is increasingly considered a heterogeneous condition. Individuals meeting identical diagnostic criteria may substantially differ in the severity of metabolic and inflammatory disturbances, which has important pathophysiological and clinical implications [11, 12]. In this context, comprehensive assessment of the baseline status of women with MS is of particular importance.

The evaluation of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters allows not only characterization of the profile of disturbances but also identification of signs of internal heterogeneity within the studied cohort, which determines the selection of subsequent intervention strategies. Therefore, comparative analysis of the morphofunctional profile of middle-aged women with metabolic syndrome is important for expanding current understanding of the pathophysiology of this condition.

The aim of the study.

To perform a comprehensive assessment of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters in middle-aged women with metabolic syndrome compared with healthy women and to determine manifestations of baseline heterogeneity of the studied condition.

Object and research methods.

The study was conducted using a comparative cross-sectional design and represented a fragment of a comprehensive investigation performed according to a previously proposed protocol for assessing morphofunctional and metabolic characteristics of women with MS [13]. This article presents the baseline stage focused on the analysis of the pre-intervention status of all participants. Such an approach makes it possible to assess group homogeneity, determine the baseline severity of metabolic disturbances, and identify justified targets for further correction.

A total of 49 middle-aged women participated in the study, with a mean age of 46.6 years. Participants were divided into two groups: Group 1 included apparently healthy women without MS (7 participants), whereas

Group 2 consisted of women with MS (41 participants). The unequal group sizes were determined by the specific features of the study design and participant selection conditions. The control group was formed using stricter inclusion criteria requiring the absence of clinical and laboratory signs of metabolic disturbances; therefore, the number of healthy women meeting these criteria was limited. At the same time, the size of the main group reflected the structure of the examined population of middle-aged women with MS. The statistical methods applied allowed appropriate comparison of samples with different sizes.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for medical research involving human participants and with generally accepted bioethical standards for biomedical investigations. The study protocol was reviewed and approved by the Local Ethics Committee of the National University of Ukraine on Physical Education and Sport (Kyiv, Ukraine). All participants were thoroughly informed about the purpose, design, methods, potential benefits, and possible risks of the study and provided written informed consent prior to participation.

Diagnosis of metabolic syndrome was established according to generally accepted criteria (NCEP ATP III), including the presence of abdominal obesity in combination with at least two of the following parameters: elevated triglyceride levels, reduced high-density lipoprotein cholesterol concentration, elevated arterial blood pressure, and impaired carbohydrate metabolism [14].

The inclusion criteria were female sex, age corresponding to the second mature period, absence of acute diseases at the time of examination, and written informed consent for participation in the study. Women in Group 2 met the generally accepted MS criteria, including abdominal obesity and associated metabolic disturbances such as impaired carbohydrate metabolism, dyslipidemia, and/or elevated arterial pressure (AP).

Exclusion criteria included severe somatic or endocrine diseases that could substantially affect metabolic status, as well as the use of pharmacological therapy capable of influencing the studied parameters.

The comprehensive examination included assessment of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters. Anthropometric examination included measurement of height, body mass, body mass index (BMI), and waist circumference (WC). BMI was calculated as body mass in kilograms divided by the square of height in meters. Waist circumference was considered a key indicator of abdominal adiposity and a marker of visceral fat, which plays an important role in the development of insulin resistance and cardiometabolic risk. Total body fat percentage and visceral fat content were also assessed using bioelectrical impedance analysis with a Tanita body composition analyzer (Tanita Corporation, Tokyo, Japan).

Biochemical parameters were evaluated using venous blood analysis performed under standard laboratory fasting conditions. Parameters of carbohydrate metabolism (glucose, insulin, glycated hemoglobin), lipid profile (total cholesterol, triglycerides), inflammatory markers (CRP, IL-6, and TNF-α), and adipokine profile (leptin and adiponectin) were assessed.

Hemodynamic parameters included systolic and diastolic arterial pressure measured at rest after preliminary seated rest. Arterial pressure was considered an important component of overall cardiometabolic risk.

Statistical processing of the obtained results was performed using standard methods of variation statistics. Normality of data distribution was assessed using the Shapiro–Wilk test. Depending on the distribution characteristics, either parametric or nonparametric tests were applied for intergroup comparisons. Differences were considered statistically significant at $p<0.05$. Data are presented as M ± SD.

Research results and their discussion.

The results of anthropometric profile assessment in the examined women are presented in **table 1**. Anthropometric parameters in women with metabolic syndrome demonstrated statistically significant differences compared with the corresponding parameters in healthy women of the control group. Body mass in patients with MS was 61.0% higher ($p<0.001$), BMI was 60.0% higher ($p<0.001$), and waist circumference exceeded that of women without signs of metabolic syndrome by 54.3% ($p<0.001$).

Table 1 – Baseline parameters of anthropometric, metabolic, and hemodynamic profiles of the examined women

Parameter	Group 1 (without MS)	Group 2 (with MS)
Body mass, kg	61.29±2.75	98.68±11.54*
Body mass index (BMI), kg/m²	22.20±0.29	35,53±4.06*
Waist circumference, cm	72.57±2.15	111.95±9.91*
Total body fat, %	24.43±0.98	49.67±3.88*
Visceral fat content, %	4.43±0.53	15.45±2.24*
Fasting glucose, mmol/L	5.11±0.20	6.35±0.50*
Insulin, μIU/mL	6.86±0.78	28.38±8.60*
HbA1c, %	5.21±0.08	6.23±0.32*
HOMA-IR index, a.u.	1.56±0.21	8.09±2.82*
Triglycerides, mmol/L	1.04±0.10	2.79±0.56*
Total cholesterol, mmol/L	5.21±0.22	6.19±0.43*
CRP, mg/L	1.67±0.76	6.08±1.67*
IL-6, pg/mL	1.30±0.22	10.43±2.26*
TNF-α, pg/mL	2.66±0.31	15.28±2.03*
Leptin, ng/mL	15.29±1.70	78.52±19.26*
Adiponectin, μg/mL	11.27±0.56	4.84±0.74*
Systolic BP, mmHg	115.29±4.12	149.12±20.08*
Diastolic BP, mmHg	74.00±2.58	100.10±20.69*

Notes: * – difference is statistically significant compared with Group 1, $p<0.001$.

Analysis of body composition parameters demonstrated pronounced alterations in the adipose tissue component in women with MS compared with healthy women of Group 1. Total body fat content in women with MS was 103.3% higher ($p<0.001$), whereas visceral fat content exceeded the corresponding value of the control group by 248.8% ($p<0.01$). The obtained results indicate the development in women with metabolic syndrome not only of general obesity but also of pronounced visceral adiposity, which has the greatest pathophysiological significance in the development of insulin resistance, chronic low-grade systemic inflamma-

tion, and cardiometabolic dysfunction. Excessive accumulation of visceral adipose tissue is considered one of the key mechanisms underlying the progression of MS, since this type of adipose tissue is characterized by high endocrine and pro-inflammatory activity.

Analysis of carbohydrate metabolism parameters demonstrated substantial disturbances in glycemic control and pronounced insulin resistance in women with MS. Fasting glucose levels in Group 2 patients were 24.3% higher compared with healthy women ($p<0.001$). Insulin concentration in women with MS exceeded the corresponding control value by 313.7% ($p<0.001$), indicating the development of pronounced compensatory hyperinsulinemia. Glycated hemoglobin levels were also significantly higher in women with MS, exceeding control values by 19.6% ($p<0.001$). Calculation of the HOMA-IR insulin resistance index demonstrated the presence of pronounced impairments in peripheral tissue insulin sensitivity in women with metabolic syndrome. HOMA-IR values in women of Group 2 were 413.5% higher ($p < 0.001$) compared with women without signs of metabolic syndrome. Thus, the obtained indicators of carbohydrate metabolism reflect the presence of chronic dysglycemia, compensatory hyperinsulinemia, and reduced peripheral tissue sensitivity to insulin in women with MS. The marked elevation of HOMA-IR confirms the central role of impaired insulin signaling in the pathogenesis of metabolic syndrome and reflects reduced efficiency of peripheral glucose uptake by tissues. The identified alterations may be associated with excessive accumulation of visceral adipose tissue, chronic low-grade systemic inflammation, and adipokine imbalance characteristic of cardiometabolic dysregulation in MS.

Lipid profile parameters in women with MS demonstrated a pronounced atherogenic pattern. Triglyceride levels in the MS group were 168.3% higher compared with healthy women ($p<0.001$). Total cholesterol concentration also significantly exceeded the values observed in the control group by 18.8% ($p<0.001$). These alterations indicate the development of an atherogenic type of dyslipidemia associated with an increased risk of atherosclerotic lesions and cardiovascular complications.

Assessment of systemic inflammatory markers demonstrated pronounced activation of pro-inflammatory mechanisms in women with MS. C-reactive protein levels in Group 2 patients were 264.1% higher compared with healthy women ($p<0.001$). IL-6 concentration exceeded control values by 702.3% ($p<0.001$), whereas TNF-α levels were 474.4% higher ($p<0.001$). The detected changes confirm the presence of chronic low-grade systemic inflammation in women of Group 2, which plays an important role in the pathogenesis of MS and progression of metabolic and vascular disturbances.

Women in Group 2 also demonstrated a pronounced adipokine imbalance. Leptin concentration in women with MS was 413.5% higher compared with healthy women ($p<0.001$). At the same time, adiponectin levels in women with MS were 57.1% lower than those in the control group ($p<0.001$). Such adipokine imbalance indicates impaired endocrine function of adipose tissue and may be regarded as one of the leading mechanisms underlying insulin resistance, chronic inflammation, and cardiometabolic dysfunction.

Hemodynamic parameters in women with MS were also characterized by significant elevation compared with the control group. Systolic arterial pressure in patients with MS was 29.3% higher ($p<0.001$), whereas diastolic arterial pressure exceeded Group 1 values by 35.3% ($p<0.001$). Elevated arterial pressure in women with MS may be associated with endothelial dysfunction, increased sympathoadrenal system tone, impaired vascular reactivity, and chronic activation of pro-inflammatory mechanisms.

The results of the present study indicate the formation in women with MS of a complex cardiometabolic phenotype characterized by the coexistence of abdominal obesity, disturbances in carbohydrate and lipid metabolism, chronic low-grade systemic inflammation, adipokine imbalance, and hemodynamic dysfunction. The identified alterations are consistent with current concepts of metabolic syndrome as a multifactorial pathological condition based on complex interactions among metabolic, endocrine, vascular, and other mechanisms.

The pronounced increase in body mass, BMI, and waist circumference in women with MS confirms the leading role of abdominal obesity in the pathogenesis of the studied condition. Visceral adipose tissue is regarded not only as an energy depot but also as a metabolically active endocrine organ capable of producing a wide range of biologically active compounds, including pro-inflammatory cytokines and adipokines. Therefore, increased waist circumference is associated with high cardiometabolic risk and progression of metabolic dysfunction.

The identified disturbances in carbohydrate metabolism confirm the central role of insulin resistance in the development of MS. Elevated insulin concentration accompanied by increased fasting glucose and HbA1c levels indicates the development of compensatory hyperinsulinemia in response to reduced peripheral tissue sensitivity to insulin. One of the key mechanisms underlying these changes may be reduced metabolic activity of skeletal muscles combined with excessive visceral fat accumulation.

Lipid profile disturbances in women with MS were characterized by the development of atherogenic dyslipidemia manifested by elevated triglyceride and total cholesterol concentrations. Such changes may result from impaired hepatic lipid metabolism, increased synthesis of very low-density lipoproteins, and reduced efficiency of peripheral triglyceride clearance. In combination with insulin resistance and arterial hypertension, this forms an unfavorable cardiometabolic profile with a high risk of cardiovascular complications.

Particularly important pathophysiological significance is attributed to the identified elevation of systemic inflammatory markers. Increased CRP, IL-6, and TNF-α levels confirm activation of chronic low-grade inflammatory processes, which are regarded as one of the key mechanisms underlying MS progression. Pro-inflammatory cytokines are capable of impairing insulin signaling, aggravating insulin resistance, and promoting endothelial dysfunction and vascular damage. The identified adipokine imbalance has important pathogenetic significance. Elevated leptin concentrations indicate the development of leptin resistance, whereas reduced adiponectin levels are associated with diminished insulin-sensitizing, antiatherogenic, and anti-inflammatory

effects. The obtained results confirm that adipose tissue dysfunction is one of the key mechanisms underlying progression of metabolic, vascular disturbances in women with MS.

Elevated systolic and diastolic arterial pressure in women with MS may be associated with activation of the renin–angiotensin–aldosterone system, endothelial dysfunction, and chronic pro-inflammatory status. The combination of the identified changes indicates the development of systemic cardiometabolic dysregulation, substantially increasing the risk of cardiovascular and metabolic complications in women with MS.

The obtained findings demonstrate that middle-aged women with MS develop a systemic cardiometabolic phenotype including simultaneous disturbances in anthropometric, carbohydrate metabolic, lipid, inflammatory, adipokine, and hemodynamic profiles. Such multimodal dysregulation corresponds to the current concept of MS as an integrated pathological condition based on interconnected mechanisms of insulin resistance, adipose tissue dysfunction, systemic inflammation, and vascular dysregulation [15, 16, 17].

At the same time, an intragroup analysis of the measured parameters in women of Group 2 was conducted, which allowed identification of signs of internal morphofunctional and metabolic heterogeneity within the cohort of women with MS itself. Further analysis was aimed at assessing the degree of heterogeneity of anthropometric, metabolic, inflammatory, and hemodynamic parameters among separate groups of women with MS. The results obtained are presented in **table 2**.

Table 2 – Phenotypic profiles of subgroups of women with metabolic syndrome

MS subgroup	Dominant characteristics	Conditional phenotype
Subgroup 1 (n=11)	Elevated levels of CRP, TNF-α, and diastolic blood pressure; signs of chronic low-grade systemic inflammation and hemodynamic dysregulation	Inflammatory-hypertensive
Subgroup 2 (n=12)	Relatively lower severity of metabolic, inflammatory, and hemodynamic disturbances; lower levels of visceral adiposity and pro-inflammatory markers	Metabolically compensated
Subgroup 3 (n=11)	Elevated body weight, BMI, insulin, HOMA-IR, leptin, and visceral fat levels; predominance of insulin resistance and adipose tissue dysfunction	Insulin-resistant obesity
Subgroup 4 (n=8)	Combination of pronounced dysglycemia, dyslipidemia, systemic inflammation, arterial hypertension, and adipokine imbalance	Severe cardiometabolic

Notes: the presented profiles represent conditional metabolic-inflammatory variants of cardiometabolic dysregulation formed on the basis of the predominance of specific anthropometric, metabolic, inflammatory, adipokine, and hemodynamic disturbances.

A key finding was that women with MS did not differ significantly from each other in body mass (p=0.203), BMI (p=0.1327), HbA1c (p=0.370), leptin (p=0.213), systolic arterial pressure (p=0.146), or diastolic arterial pressure (p=0.054). This finding is important for further intervention analysis, as it indicates relative comparability of women with MS in terms of anthropometric and hemodynamic parameters. At the same time, the presence of statistically significant differences in blood glucose (p=0.008), insulin (p=0.005), triglycerides (p=0.018), total cholesterol (p=0.001), CRP (p=0.004), IL-6 (p=0.045), and adiponectin (p=0.004) indicates metabolic and inflammatory heterogeneity even within the cohort of women with MS. This is consistent with the concept of MS as a spectrum of conditions rather than a unified clinical category. High insulin and glucose levels in women of Group 2 confirm the central role of insulin resistance in MS development. Skeletal muscles are among the primary organs responsible for insulin-dependent glucose uptake; therefore, reduced muscular metabolic activity, sedentary lifestyle, and excessive adiposity may aggravate hyperinsulinemia and dysglycemia [18, 19, 20]. Consequently, interventions aimed at increasing muscle activity and preserving or increasing muscle mass in individuals with MS have a clear pathophysiological rationale.

Elevated triglyceride and total cholesterol levels reflect the atherogenic nature of dyslipidemia in MS. Such a profile may be associated with impaired hepatic lipid metabolism, increased production of very low-density lipoproteins, and reduced efficiency of peripheral triglyceride clearance. In combination with abdominal obesity and inflammation, this further increases cardiovascular risk [21]. Particularly important is the identified inflammatory imbalance. Elevated CRP and IL-6 levels in MS groups indicate the presence of chronic low-grade inflammation. Under such conditions, visceral adipose tissue functions as an immunometabolic organ producing pro-inflammatory cytokines and contributing to impaired insulin signaling [15, 17]. Although TNF-α did not reach statistical significance between MS groups (p=0.056), its marked elevation compared with the healthy group confirms the involvement of pro-inflammatory mechanisms in the pathogenesis of the studied condition.

Our findings obtained from the comparative analysis of baseline anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters in women with metabolic syndrome indicate the presence of pronounced intragroup phenotypic heterogeneity within the studied cohort. Despite all examined women meeting the general diagnostic criteria for MS, substantial differences were identified in the predominance of specific pathophysiological mechanisms underlying cardiometabolic dysregulation. The performed analysis allowed the identification of several phenotypic variants of MS characterized by different combinations of adipose tissue dysfunction, insulin resistance, systemic inflammation, and hemodynamic disturbances.

Women of Subgroup 1 predominantly demonstrated signs of chronic low-grade systemic inflammation and hemodynamic dysregulation manifested by elevated CRP, TNF-α, and blood pressure levels. Such a combination of alterations indicates the predominance of pro-inflammatory and vascular mechanisms within the structure of cardiometabolic disturbances and allows this variant to be characterized as an inflammatory-hypertensive phenotype of MS. The formation of this phenotype may be associated with activation of pro-inflammatory signaling pathways, endothelial dysfunction, and increased sympathetic-adrenal system activity.

Women of Subgroup 2 were characterized by a relatively lower severity of metabolic, inflammatory, and hemodynamic disturbances compared with the other MS subgroups. They demonstrated lower levels of visceral

adiposity, systemic inflammation, and blood pressure, which may indicate the formation of a more compensated variant of metabolic syndrome. Such a metabolically compensated phenotype is likely characterized by a less pronounced degree of cardiometabolic dysregulation and relatively preserved adaptive capacities of the organism.

In women of Subgroup 3, manifestations of insulin resistance and adipose tissue dysfunction predominated. This phenotype was characterized by the highest values of body weight, BMI, visceral fat, insulin, HOMA-IR, and leptin. The identified alterations indicate the leading role of excessive adipose tissue accumulation, hyperleptinemia, and impaired peripheral insulin sensitivity in the development of cardiometabolic disturbances. This variant corresponds to the insulin-resistant obesity phenotype of MS and is characterized by the predominance of metabolic mechanisms underlying MS progression.

The most pronounced disturbances were observed in women of Subgroup 4, in whom dysglycemia, atherogenic dyslipidemia, chronic low-grade systemic inflammation, adipokine imbalance, and arterial hypertension were simultaneously present. This subgroup demonstrated the highest levels of glucose, HbA1c, triglycerides, total cholesterol, CRP, IL-6, TNF-α, and blood pressure, as well as the lowest adiponectin concentrations. The combination of these alterations indicates the formation of a severe cardiometabolic phenotype of MS characterized by maximal severity of systemic cardiometabolic dysregulation and the most unfavorable prognosis regarding vascular and metabolic complications.

The obtained findings support contemporary concepts of metabolic syndrome as a heterogeneous pathological condition characterized by different pathophysiological patterns of development. The identified phenotypic heterogeneity substantiates the feasibility of applying personalized intervention approaches aimed at correcting the dominant mechanisms of cardiometabolic dysregulation in women with MS.

The planned further intervention approaches in this study [13] have a clear pathophysiological rationale and target the key mechanisms underlying MS development. Resistance exercise is justified by its ability to improve skeletal muscle function as the main peripheral organ responsible for glucose utilization. Regular resistance training may normalize hemodynamic parameters, increase insulin sensitivity, contribute to preservation or increase of lean body mass, elevate energy expenditure, and reduce fat mass [22, 23, 24].

In the context of the obtained data, particularly elevated insulin levels in MS groups, such an approach appears especially appropriate. Combined aerobic-resistance training possesses the greatest universal potential, as it simultaneously affects muscular, vascular, lipid, and glycemic components of MS. The aerobic component of exercise improves cardiorespiratory endurance [24, 25], enhances fatty acid oxidation, reduces triglyceride levels, and contributes to arterial pressure control, whereas the resistance component supports muscle mass and improves insulin sensitivity. Considering the elevated triglycerides, glucose, insulin, and arterial pressure observed in women with MS in this study, the combined approach has a clear rationale [20, 26].

Dietary therapy is a fundamental component of MS correction because it influences energy balance, excessive body mass, glycemic load, lipid profile, and inflammatory status. A diet with controlled caloric intake, adequate protein content, increased dietary fiber, predominance of unsaturated fatty acids, and restriction of rapidly digestible carbohydrates, with emphasis on foods containing inulin, polyphenols, resistant starch, and probiotics, may contribute to reduction of visceral fat, decreased postprandial glycemia, improvement of triglyceride levels, and attenuation of the pro-inflammatory background [21, 27, 28]. Given the reduced adiponectin levels and elevated inflammatory markers in MS groups, specialized dietary therapy appears pathogenetically justified [28, 29].

Thus, each of the three intervention models has its own pathophysiological target: resistance exercise – muscle mass and insulin sensitivity; combined training – integrated cardiometabolic risk; dietary therapy – energy balance, glycemic control, and inflammatory status. This allows expectation that the proposed interventions will have high practical and scientific significance.

Conclusions.

1. Middle-aged women with metabolic syndrome demonstrated pronounced anthropometric, metabolic, inflammatory, adipokine, and hemodynamic disturbances compared with apparently healthy women, indicating the development of systemic cardiometabolic dysregulation.

2. Women with metabolic syndrome were characterized by significantly higher body mass, BMI, waist circumference, total and visceral fat mass, glucose, insulin, HbA1c, HOMA-IR, triglycerides, total cholesterol, CRP, IL-6, TNF-α, leptin, and arterial blood pressure levels, as well as lower adiponectin concentrations, reflecting the coexistence of abdominal obesity, insulin resistance, dyslipidemia, and systemic inflammation.

3. The obtained findings confirm the heterogeneity of metabolic syndrome, as women with MS demonstrated substantial variability in metabolic and inflammatory parameters, particularly glucose, insulin, triglycerides, total cholesterol, CRP, IL-6, and adiponectin levels.

4. Intragroup analysis allowed the identification of conditional phenotypic variants of MS characterized by the predominance of inflammatory, hemodynamic, adipose-metabolic, or severe cardiometabolic disturbances, confirming the multifactorial nature of cardiometabolic dysregulation in MS.

5. The identified baseline heterogeneity substantiates the feasibility of applying personalized intervention approaches aimed at correcting insulin resistance, visceral adiposity, systemic inflammation, and vascular dysfunction.

Prospects for further research.

They involve studying the dynamics of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters in middle-aged women with metabolic syndrome under the influence of various intervention models. Of particular interest is evaluation of the effectiveness of resistance exercise, combined aerobic-resistance training, and specialized dietary therapy in correcting insulin resistance, dyslipidemia, systemic inflammation, and adipose tissue dysfunction. Further promising directions include investigation of relationships between visceral adiposity, cardiometabolic risk,

and pro-inflammatory activity, as well as identification of predictors of differential responsiveness to intervention strategies. Expansion of the spectrum of studied biomarkers by including indicators of endothelial dysfunction, oxidative stress, and gut microbiome characteristics also appears appropriate.

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ВИХІДНА ГЕТЕРОГЕННІСТЬ МЕТАБОЛІЧНОГО СИНДРОМУ У ЖІНОК ДРУГОГО ЗРІЛОГО ВІКУ: КОМПЛЕКСНА ДОІНТЕРВЕНЦІЙНА ОЦІНКА

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Резюме. Вікові ендокринні та метаболічні зміни у жінок другого зрілого віку супроводжуються накопиченням вісцеральної жирової тканини, розвитком інсулінорезистентності, хронічного низькоінтенсивного системного запалення та підвищенням кардіометаболічного ризику. У сучасних наукових уявленнях метаболічний синдром розглядається як гетерогенний патологічний стан із різними варіантами метаболічної та

запальної дисрегуляції. Метою роботи була комплексна оцінка антропометричних, метаболічних, запальних, адипокінових та гемодинамічних показників у жінок другого зрілого віку з метаболічним синдромом та визначення проявів вихідної гетерогенності досліджуваного стану. У дослідженні взяли участь практично здорові жінки без метаболічного синдрому (n=7) та жінки з МС (n=41). Оцінювали антропометричні показники, компонентний склад тіла, параметри вуглеводного та ліпідного обміну, маркери системного запалення, адипокіновий профіль і гемодинамічні характеристики. Встановлено, що жінки з МС характеризувалися достовірно вищими показниками маси тіла, ІМТ, окружності живота, загальної та вісцеральної жирової маси, глюкози, інсуліну, HbA1c, HOMA-IR, тригліцеридів, загального холестерину, CRP, IL-6, TNF-α, лептину та артеріального тиску, а також нижчим рівнем адипонектину порівняно зі здоровими жінками. Внутрішньогруповий аналіз дозволив встановити наявність метаболічної та запальної гетерогенності у межах когорти жінок із МС та виділити умовні фенотипові варіанти: запально-гіпертензивний, метаболічно-компенсований, інсулінорезистентно-ожирілий та кардіометаболічно-декомпенсований. Отримані результати підтверджують формування системної кардіометаболічної дисрегуляції при МС та обґрунтовують доцільність застосування персоналізованих інтервенційних підходів залежно від домінуючих механізмів кардіометаболічних порушень.

Ключові слова: метаболічний синдром; жінки другого зрілого віку; абдомінальне ожиріння; інсулінорезистентність; дисліпідемія; системне запалення; артеріальна гіпертензія; кардіометаболічний ризик.

BASELINE HETEROGENEITY OF METABOLIC SYNDROME IN MIDDLE-AGED WOMEN: A COMPREHENSIVE PRE-INTERVENTION ASSESSMENT

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Abstract. Age-related endocrine and metabolic changes in middle-aged women are accompanied by the accumulation of visceral adipose tissue, the development of insulin resistance, chronic low-grade systemic inflammation, and increased cardiometabolic risk. According to current scientific concepts, metabolic syndrome is considered a heterogeneous pathological condition characterized by different variants of metabolic and inflammatory dysregulation. The aim of the study was to perform a comprehensive assessment of anthropometric, metabolic, inflammatory, adipokine, and hemodynamic parameters in middle-aged women with metabolic syndrome and to identify manifestations of baseline heterogeneity of the studied condition. The study involved apparently healthy women without metabolic syndrome (n=7) and women with MS (n=41). Anthropometric parameters, body composition, carbohydrate and lipid metabolism indicators, systemic inflammatory markers, adipokine profile, and hemodynamic characteristics were assessed. Women with MS demonstrated significantly higher body mass, BMI, waist circumference, total and visceral fat content, glucose, insulin, HbA1c, HOMA-IR, triglycerides, total cholesterol, CRP, IL-6, TNF-α, leptin, and arterial blood pressure levels, as well as lower adiponectin concentrations compared with healthy women. Intragroup analysis revealed the presence of metabolic and inflammatory heterogeneity within the cohort of women with MS and allowed identification of conditional phenotypic variants, including inflammatory-hypertensive, metabolically compensated, insulin-resistant obese, and cardiometabolically decompensated phenotypes. The obtained findings confirm the development of systemic cardiometabolic dysregulation in MS and substantiate the feasibility of applying personalized intervention approaches depending on the dominant mechanisms of cardiometabolic disturbances.

Key words: metabolic syndrome, middle-aged women, abdominal obesity, insulin resistance, dyslipidemia, systemic inflammation, arterial hypertension, cardiometabolic risk.

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A – Work concept and design, **B** – Data collection and analysis, **C** – Responsibility for statistical analysis, **D** – Writing the article, **E** – Critical review, **F** – Final approval of the article.

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