

MRI assessment of the abdominal adipose tissue and the state of the abdominal aorta in patients with coronary artery disease: association with metabolic disorders

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ABSTRACT

Aim. To evaluate potential associations between quantitative features of visceral and subcutaneous adipose tissue (AT) and anthropometric characteristics of obesity, metabolic disorders, and the state of the abdominal aorta in patients with chronic coronary artery disease (CAD).

Materials and methods. The study included 55 patients (average age 61.2 ± 7.2 years) with chronic CAD. Magnetic resonance imaging (MRI) was performed on a 1.5 T MRI scanner using T2-weighted spin-echo modes. The area and volume of abdominal subcutaneous (SAT) and visceral adipose tissue (VAT) were calculated at the L4–L5 level; the total volumes of abdominal SAT and VAT were determined. Parameters of lipid and carbohydrate metabolism, as well as adipokine profile were studied in the blood serum.

Results. In the course of a multiple linear regression analysis, we detected the independent determinants, which described 95% of the total VAT volume variability and were represented by waist circumference (WC) and serum levels of high-density lipoprotein (HDL) cholesterol and adiponectin. The model was characterized by the significance level $p < 0.000001$, the residuals of the model were normal. We calculated the coefficients in the model: 1.39 for WC, -0.26 for HDL cholesterol, and -0.19 for adiponectin. We detected a positive correlation between the abdominal aorta (AA) diameter and SAT area at the L4–L5 level ($r_s = 0.48$; $p = 0.0014$), which does not depend on gender, and reverse correlations between the aorta diameter and glycated hemoglobin (HbA1c) level ($r_s = -0.40$; $p = 0.0359$) and postprandial glycemia ($r_s = -0.40$; $p = 0.0273$). The patients with a dilated aorta (group 2), when compared with the patients with a normal aorta diameter (group 1), did not differ in the AT accumulation, but demonstrated decreased levels of HbA1c and postprandial glycemia, which resulted in a smaller number of patients with type 2 diabetes mellitus.

Conclusion. We identified independent determinants of an increase in the total volume of abdominal visceral AT, such as an increase in WC and a decrease in serum adiponectin and HDL cholesterol levels. Results of the study indicate the presence of a link between the AA remodeling, accumulation of subcutaneous AT, and impaired glucose metabolism.

Key words: magnetic resonance imaging, abdominal adipose tissue, abdominal aorta, lipid and glucose metabolism disturbances, adiponectin.

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Conformity with the principles of ethics. All patients signed an informed consent to participate in the study and process the examination results. The study was approved by the Ethics Committee at Cardiology Research Institute, Tomsk NRMС (Protocol No. 146 of 16.06.2016).

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Магнитно-резонансная томографическая оценка абдоминальной жировой ткани и состояние брюшной аорты у пациентов с ишемической болезнью сердца: связь с нарушениями метаболизма

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РЕЗЮМЕ

Цель. Изучение потенциальных взаимосвязей количественных характеристик висцеральной и подкожной жировых тканей (ЖТ) с антропометрическими показателями ожирения, нарушениями метаболизма и состоянием брюшного отдела аорты у пациентов с хронической ишемической болезнью сердца (ИБС).

Материалы и методы. В исследовании приняли участие 55 пациентов (средний возраст $61,2 \pm 7,2$ лет) с хронической ИБС. Магнитно-резонансную томографию выполняли на 1,5 Т магнитно-резонансном томографе в T2-взвешенных спин-эхо режимах. Расчет площади и объема абдоминальных подкожной (ПЖТ) и висцеральной ЖТ (ВЖТ) проводился на уровне L4–L5, а также измерялся общий объем абдоминальных ПЖТ и ВЖТ. В сыворотке крови исследовали показатели липидного и углеводного метаболизма и состояние адипокинового профиля.

Результаты. В ходе множественного линейного регрессионного анализа установлены независимые детерминанты вариабельности общего объема абдоминальной ВЖТ, которые описывают 95% вариабельности этого показателя: окружность талии (ОТ), содержание в крови холестерина липопротеинов высокой плотности (ХС-ЛВП) и адипонектина. Уровень значимости модели составил $p < 0,000001$, остатки модели нормальны. Оценки коэффициентов в модели для: ОТ – 1,39; ХС-ЛВП – 0,26 и адипонектина – 0,19. Документированы корреляционные взаимосвязи диаметра абдоминальной аорты (АА): прямая – с площадью ПЖТ L4–L5 ($r_s = 0,48$; $p = 0,0014$), что не зависит от пола, и обратные – с уровнем гликированного гемоглобина (HbA1c) ($r_s = -0,40$; $p = 0,0359$) и постпрандиальной гликемией ($r_s = -0,40$; $p = 0,0273$). В сравнении с пациентами, имеющими нормальные значения диаметра АА (группа 1), у пациентов с расширенной АА (группа 2) не было значимых различий накопления ЖТ, но имел место более низкий уровень HbA1c и постпрандиальной гликемии, что определялось меньшим числом пациентов с сахарным диабетом типа 2.

Заключение. Установлены независимые детерминанты возрастания общего объема абдоминальной висцеральной ЖТ, которыми являются: увеличение окружности талии и сниженные значения содержания в крови адипонектина и ХС-ЛВП. Результаты исследования свидетельствуют о наличии взаимосвязи между процессами ремоделирования АА, накоплением подкожной абдоминальной ЖТ и нарушениями метаболизма глюкозы.

Ключевые слова: магнитно-резонансная томография, абдоминальная жировая ткань, брюшная аорта, нарушения метаболизма липидов и глюкозы, адипонектин.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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Соответствие принципам этики. Все пациенты дали информированное согласие на участие и обработку результатов обследования. Исследование одобрено независимым этическим комитетом НИИ кардиологии, Томский НИМЦ (протокол № 146 от 16.06.2016).

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INTRODUCTION

A progressive increase in the prevalence of metabolic disorders and obesity is one of the most important features of modern society. According to the World Health Organization, more than 650 million people are obese and more than 1.9 billion are overweight. It is known that adipose tissue (AT) is the largest and the most active endocrine organ, participating in the regulation of energy balance, glucose and lipid homeostasis, as well as the functioning of the immune system in response to fluctuations in nutritional status, environment, lifestyle, and aging [1]. Numerous studies have shown a strong association between excessive accumulation of visceral adipose tissue (VAT) and the development of metabolic syndrome [2], type 2 diabetes mellitus (T2DM) [3], obstructive coronary artery disease, and myocardial infarction [4]. Adipose tissue is able to produce a wide spectrum of cytokines and adipokines, whereas the metabolic and functional properties of subcutaneous and visceral fat differ significantly [5], and the available data on the secretory potential of subcutaneous adipose tissue (SAT) are very contradictory.

Instrumental methods for assessing the degree of visceral obesity are important in the diagnosis and risk stratification of cardiovascular diseases [6]. Tomographic techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), are considered to be the golden standard [7]. According to some data, MRI may outperform CT in measurement accuracy [8]. MRI has high tissue differentiation, which makes it possible to quantify various fat depots while simultaneously evaluating adjacent organs and tissues. Approaches to quantitative analysis of AT are still an unanswered question, since there is no single protocol for measuring AT.

Only a few studies investigated a potential relationship between the quantitative characteristics of

abdominal AT and AA aneurysm, and the results of these studies are very controversial [9]. Since the majority of patients with abdominal aortic dilatation and aneurysm have pronounced atherosclerosis and CAD of various severity, it cannot be ruled out that this pathological relationship may be determined by common risk factors, including visceral obesity, which is confirmed by the results of some studies [10].

Since aortic dilatation is a complication in a number of pathologies with a high risk of adverse events, early detection of AA expansion signs will reduce mortality from conditions, such as aortic dissection and aneurysm ruptures. MRI has a class of evidence IC for diagnosing the aortic condition according to modern recommendations [11]. Tomographic methods are preferred for AA visualization, as this area is difficult to access for ultrasound examination. To date, no studies have been conducted on quantitative parameters of abdominal AT accumulation and parameters reflecting the nature of AA remodeling compared with the assessment of clinical characteristics of patients and the state of their metabolic and adipokine profiles. It is still unclear whether the presence of visceral abdominal obesity can modulate a relationship between abdominal fat accumulation and the degree of AA expansion, and what factors may be involved in this process.

The aim of the study was to evaluate potential associations between the quantitative features of visceral and subcutaneous adipose tissue and anthropometric characteristics of obesity, metabolic disorders, and the state of the abdominal aorta in patients with chronic coronary artery disease (CAD).

MATERIALS AND METHODS

The study included patients aged 48–78 years (60% of them were men) with verified CAD. All patients gave an informed consent to participate in the study and process the examination results. A single-stage

retrospective study was conducted in accordance with the standards of Good Clinical Practice and the principles of the Declaration of Helsinki. The study was approved by the local Ethics Committee at Cardiology Research Institute (Protocol No. 146 of 16.06.16).

The exclusion criteria included an acute complication of atherosclerosis less than 6 months ago; any inflammatory disease; T2DM with poor glycemic control and HbA1c > 10% or a daily glycemic level > 11 mmol / l; chronic kidney disease above C3b; left ventricular ejection fraction < 40%; and oncological, hematological, and immune diseases.

Table 1 presents the clinical characteristics of the recruited patients. The study included 55 men and women with verified chronic CAD at the age of 61.68 ± 6.7 years.

Table 1

Clinical characteristics of the patients recruited in the study (n = 55)	
Parameter	Value
Gender (male / female)	33 / 22
Age, years, $M \pm SM$	61.68 ± 6.7
Patients with myocardial infarction, n (%)	36 (65.5)
Duration of CAD, years*	3 (1; 8)
Patients with hypertension, n (%)	48 (87.3)
Duration of hypertension, years*	15 (10; 20)
Type 2 diabetes mellitus, n (%)	23 (41.8)
Duration of T2DM, years*	10 (1; 15)
Systolic blood pressure, mm Hg., $M \pm SM$	131.8 ± 15.2
Diastolic blood pressure, mm Hg., $M \pm SM$	75.9 ± 8.4
Smokers, n (%)	23 (41.8)
Patients with obesity, n (%):	45 (81.8)
– class I	23 (51.1)
– class II	14 (31.1)
– class III	8 (17.8)
Therapy with statins, n (%)	53 (96)

Metabolic syndrome was revealed in 78% of patients [12]. About half of the included patients had T2DM and were smokers. Anatomical stenosis in more than 70% of at least one of the main coronary arteries were established in 42 patients (76.4%), 2 (3.6%) patients had microvascular pathology, while changes in the coronary arteries were insignificant in other cases.

The MRI study was carried out on a high-field MRI scanner with 1.5 T magnetic field strength (Titan Vantage, Toshiba Medical, 2010, Japan) in the supine position of the patient using built-in and external 4- and 8-channel quadrature coils for the whole body. The scanned area included the distance from the dome of the diaphragm to the entrance to the small pelvis. Measurements of the thickness of the anterior and posterior abdominal wall and the area of the ab-

dominal SAT and VAT were carried out at the level of the intervertebral L4–L5 discs. The AA diameter and wall thickness were measured at the L2–L3 level, 1–2 slices above the aortic bifurcation. The measurement of the total volume of the abdominal SAT and VAT was carried out taking into account all sections of the scanned area according to the method proposed by Fang et al. (2018).

Post-processing image analysis and measurements were performed using the eFilm 3.4 software package (MergeHealth, 2010) and 3D Slicer 4.9.0. The AT was automatically circled according to the specified intensity range of the MR signal corresponding to the AT, and, if necessary, adjustments were made. After that, the volume (cm³) and surface area (cm²) of all the selected voxels were calculated. Since no convincing data showing the compliance of single-slice measurements with the total amount of AT were published, it was decided to carry out the calculation as extensively as possible.

Samples of venous blood were obtained from patients in the morning in the fasted state. The serum levels of leptin (Mediagnost, Germany), adiponectin (Assaypro, USA), their ratio, and insulin (Accu-Bind, USA) were determined by solid-phase enzyme immunoassay. The content of total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C) was determined by the enzymatic colorimetric method (Diakon-DS kits, Russia). The glucose content in the blood serum was evaluated by the hexokinase method. The glucose and insulin levels were also evaluated 2 hours after the standard food intake (postprandial content).

Statistical analysis was conducted using the STATISTICA 10.0 software package for Windows. The normality of data distribution was defined by the Shapiro – Wilk test. Continuous variables with normal distribution were presented as $M \pm SD$, where M is the mean and SD is the standard deviation; with non-normal distribution – as the median and the interquartile range $Me (Q_{25\%}; Q_{75\%})$. Categorical variables were represented by the absolute and relative (%) frequencies. The nonparametric Mann – Whitney test was used to assess the statistical significance of differences, when the distribution of data was different from normal. The Spearman's rank correlation coefficient (r_s) was used to assess the relationships between the variables. A multiple linear regression model was constructed to assess the effect of biometric and laboratory parameters on the total volume of visceral fat. The differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

The average values of the abdominal AT and AA, calculated using MRI and 3D Slicer, are presented in Table 2.

Table 2

Average values of the abdominal AT depot, the diameter of the AA and its wall thickness in the overall sample		
Parameter	<i>M</i>	<i>SD</i>
Cross-sectional area of the vertebral body of L4–L5, cm ²	823.8	208.7
VAT area at L4–L5, cm ²	186.0	78.6
SAT area at L4–L5, cm ²	327.8	120.1
Total AT area at L4–L5, cm ²	513.8	161.7
SAT volume at L4–L5, cm ³	260.8	111.3
VAT volume at L4–L5, cm ³	140.4	53.8
Total AT volume at L4–L5, cm ³	404.3	141.5
Total VAT volume, cm ³	5,595.4	3,371.4
Total SAT volume, cm ³	4,217.7	1,363.9
Total volume of abdominal AT, cm ³	9,871.1	4,143.1
External diameter of AA, mm	20.5	4.4
Abdominal aorta wall thickness, mm	2.7	0.8

In cases of an increased diameter and, in particular, aneurysmal dilatation of the aorta, hyperintensive inclusions were visualized in the aortic wall on T2-weighted spin-echo images, indirectly reflecting hemorrhagic impregnation (pathological angiogenesis) in the wall thickness. The presence of hyperintensive foci in the arterial wall is a characteristic symptom of the pathological aortic dilatation, which, in response to LDL accumulation and local hypoxia, is accompanied by thickening of the intimal membrane and an increase in the amounts of extracellular matrix with development of an extensive network of microvessels (*vasa vasorum*). It is the small newly formed vessels that have a hyperintensive signal in the wall thickness in T2-weighted images. It is believed that neoangiogenesis can develop in the early stages of the atherosclerotic process and maintain local subclinical inflammation, so it is a good and fairly early marker of a high risk of aneurysm development in this area of the vessel wall [13].

Statistical processing of the data revealed that the existing gender characteristics of the accumulation and distribution of AT have a significant impact on a number of the studied parameters. Therefore, to eliminate this factor, the data were adjusted for gender, height, and body weight of patients.

In the overall sample, after correction of statistically significant differences in the parameters, the correlations of the area and volume of the abdominal VAT and SAT with anthropometric parameters of

obesity and key biomarkers of lipid and carbohydrate metabolism were studied. The values of the total VAT showed significant positive correlations with WC ($r_s = 0.62$, $p = 0.00000$) and blood triglyceride levels ($r_s = 0.34$, $p = 0.0459$), leptin levels ($r_s = 0.64$, $p = 0.0020$), as well as negative correlations with HDL-C ($r_s = -0.49$, $p = 0.0028$) and adiponectin levels ($r_s = -0.37$, $p = 0.0486$). None of the quantitative parameters of SAT accumulation had associations with blood levels of adiponectin, triglycerides, and HDL-C, while the total volume of SAT showed positive correlations with WC ($r_s = 0.51$, $p = 0.0003$) and leptin levels ($r_s = 0.50$, $p = 0.0126$). There were no correlations between the values of the total SAT and VAT volumes and the content of glucose, HbA1c, and insulin.

It should be noted that the relationships between the quantitative characteristics of abdominal AT and the state of metabolism and adipokine profile have been analyzed in a very limited number of studies. [14]. Although adiponectin is known to be secreted by both subcutaneous and visceral AT [15], the results of studies on the contribution of various fat depots to determination of systemic adiponectin levels are contradictory and gender specific. Thus, a number of studies have shown that the development of local AT inflammation and insulin resistance negatively affects visceral production of adiponectin, while its synthesis in SAT remains unchanged, especially in women [16].

At the same time, there is evidence of a relationship between SAT area and the plasma level of adiponectin in men [17]. Leptin is an adiponectin antagonist which reflects the degree of AT hormonal activity and also a key marker of chronic subclinical inflammation in AT [18]. In the article by I.J. Neeland et al. (2013), the leptin content in the blood plasma was shown to be mainly associated with the SAT volume [14].

Our results on the presence of correlations between the content of serum leptin not only with the total volume of abdominal VAT, but also with the total volume of abdominal SAT confirm these data and question the idea of SAT as a metabolically inert fat depot.

Indeed, the existing data on the contribution of SAT to the formation of cardiovascular risk and metabolic imbalance, in comparison with VAT, are inconsistent [17]. The vast majority of studies present data on the VAT effect on the processes occurring in the aortic wall. It was shown that if VAT prevails, the aortic diameter [19] and calcification of the aortic wall decrease [20], its elastic properties change [21; 22], and intima-media thickness (IMT) increases [23]. In addition, a positive correlation between visceral obesity and the

development of atherosclerosis was proven [24–26]. At the same time, the role of SAT in changes in the aortic wall was not demonstrated. However, it is believed that SAT has a protective function in calcium deposition, thereby reducing the risk of atherosclerosis [20].

In the course of a multiple step-by-step linear regression analysis with an exception, conducted in the overall sample, we established the following independent determinants of the variability of the total VAT volume: waist circumference and blood levels of HDL-C and adiponectin. The significance level of the model was $p < 0.000001$, the coefficient of determination $R^2 = 0.949$, and the model residuals were normal. Estimates of the coefficients in the model: for WC –1.39, for HDL-C –0.26, and for adiponectin –0.19. It is known that obesity is associated not only with a decrease in the HDL-C content, but also with a change in their qualitative composition and a decrease in the ability to evacuate excess cholesterol from fat depots [27], and adiponectin has a direct effect on the HDL-C synthesis [28].

Next, we analyzed potential correlations of vascular remodeling parameters (values of AA diameter and wall thickness) with the content of serum biomarkers

and with all quantitative parameters of the abdominal SAT and VAT accumulation, including the total volume of abdominal AT. As it turned out, the only parameter of AT accumulation that had a correlation with AA diameter was the area of abdominal SAT at L4–L5 ($r_s = 0.48$, $p = 0.0014$) (Fig. 1). AA diameter also showed a negative correlation with the level of HbA1c ($r_s = -0.40$, $p = 0.0359$) and postprandial glycemia ($r_s = -0.40$, $p = 0.0273$).

To compare the clinical and anthropometric characteristics, the amount of abdominal AT and the levels of biomarkers depending on the AA diameter values, the overall sample of patients was divided into two groups – a group with normal values of the AA diameter ($n = 32$, group 1) and a group with its dilatation (outer diameter of more than 20 mm) ($n = 23$, group 2) [11]. Examples of MR images of the normal and dilated abdominal aorta with the corresponding typical variants of the SAT and VAT distribution are shown in Figures 2 and 3.

Table 3 shows the results of comparing the two groups after correction for gender differences of the studied parameters.

Table 3

Clinical characteristics, anthropometric parameters of obesity, quantitative parameters of abdominal AT, and laboratory data of patients depending on the AA diameter				
Parameter	Overall sample ($n = 55$)	Group 1 ($n = 32$)	Group 2 ($n = 23$)	p
Age, years, $M \pm SM$	61.7 $\pm$ 6.7	60.4 $\pm$ 7	61.1 $\pm$ 6.9	
Patients with T2DM, n (%)	23 (41.8)	17 (30.9)	6 (10.9)	0.04
Diameter of AA, mm, $Me (Q_{25\%}; Q_{75\%})$	20 (18; 21.5)	19 (18; 20)	22.5 (21.5; 24)	< 0.001
AA wall thickness, mm, $M \pm SM$	2.7 $\pm$ 0.8	2.4 $\pm$ 0.6	3.2 $\pm$ 0.9	
Body mass index, kg / m ²	29.6 (26.5; 34.5)	29.7 (26.5; 34.1)	31.8 (29.1; 37.7)	
Waist circumference, cm, $M \pm SM$	106.6 $\pm$ 13.9	103.2 $\pm$ 13.1	109.2 $\pm$ 14.1	
Hip circumference, cm, $M \pm SM$	108.8 $\pm$ 9.9	108.2 $\pm$ 9.1	109.2 $\pm$ 10.1	
Waist circumference / hip circumference ratio, $M \pm SM$	0.98 $\pm$ 0.08	0.95 $\pm$ 0.08	0.99 $\pm$ 0.07	0.02
VAT area, cm ² , $Me (Q_{25\%}; Q_{75\%})$	293 (240; 380)	140 (121; 251)	168 (133; 220)	
SAT area, cm ² , $Me (Q_{25\%}; Q_{75\%})$	164 (128; 220)	271 (237; 347)	309 (281; 419)	
Total AT area, cm ² , $Me (Q_{25\%}; Q_{75\%})$	487 (399.5; 599.5)	481 (411; 545)	503.3 (388; 623)	
Total VAT volume, cm ³ , $Me (Q_{25\%}; Q_{75\%})$	4,288 (3,146; 5,496)	4,220.5 (2,824; 5,181.5)	4,424 (3,516.5; 5,957.5)	
Total SAT area, cm ³ , $Me (Q_{25\%}; Q_{75\%})$	4,938 (3,634; 6,841)	4,766.5 (3,543; 6,667.5)	4,888 (3,653.5; 7,842)	
Total abdominal AT volume, cm ³ , $Me (Q_{25\%}; Q_{75\%})$	9,186.5 (7,233; 12,177.5)	9,344.5 (7,401; 11,816)	8,982.5 (7,065; 13,344)	
Glycemia, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	5.7 (4.4; 10.6)	6.0 (5.1; 10.4)	5.6 (4.4; 8.8)	0.038
Postprandial glycemia, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	7.5 (4.7; 14.96)	7.7 (5.6; 14.96)	7.1 (4.7; 12.7)	
HbA1c, %, $Me (Q_{25\%}; Q_{75\%})$	6.0 (5.5; 6.9)	6.5 (5.6; 7.2)	5.5 (5.5; 6.1)	0.003
Total cholesterol, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	3.9 (3.3; 4.7)	4.1 (3.4; 4.7)	3.7 (3.3; 5.1)	
LDL-C, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	2.1 (1.4; 2.9)	2.1 (1.6; 2.8)	1.9 (1.4; 3.3)	
HDL-C, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	1.1 (0.9; 1.4)	1.1 (0.9; 1.4)	1.07 (0.9; 1.3)	
Triglycerides, mmol / l, $Me (Q_{25\%}; Q_{75\%})$	1.5 (1.1; 1.9)	1.3 (0.9; 1.7)	1.49 (1.4; 1.9)	
Adiponectin, μ g / ml, $Me (Q_{25\%}; Q_{75\%})$	7.3 (2.5; 19.3)	7.6 (4.7; 11.9)	6.9 (6.2; 9.9)	
Leptin, ng / ml, $Me (Q_{25\%}; Q_{75\%})$	19.1 (9.3; 34.3)	14.1 (8.6; 34.1)	23.3 (11.2; 34.3)	

Note: the p values are given only for parameters for which statistically significant inter-group differences were revealed.

* in the overall sample, the parameters are given after correction for gender differences.

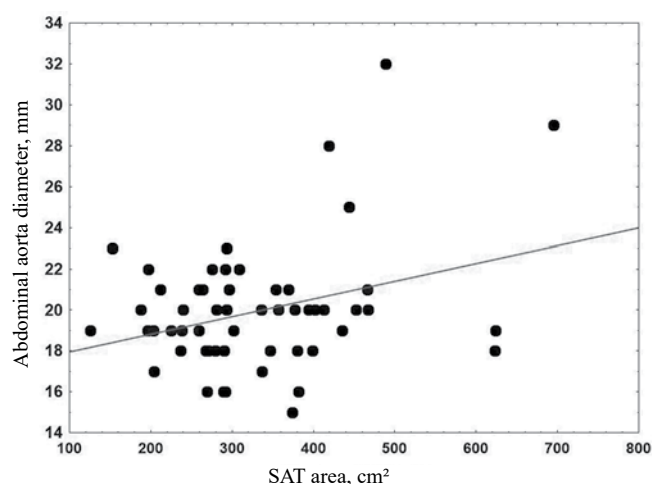


Fig. 1. Correlation between the SAT area at the L4–L5 level and the abdominal aorta diameter, $r_s = 0.48$, $p = 0.0014$

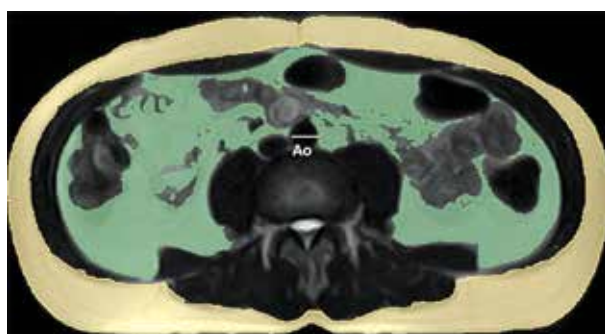


Fig. 2. MRI of the abdominal AT and aorta: male, 55 years old, BMI – 26, WC – 98 cm, postprandial glycaemia – 7.7 mmol / l, HbA1c – 5.7%; axial T2-weighted spin-echo slice; volume of abdominal subcutaneous adipose tissue (yellow) – 2,125 cm³, abdominal visceral adipose tissue (green) – 2,405 cm³, aorta diameter – 19 mm, the wall is smooth, without changes in the MR signal

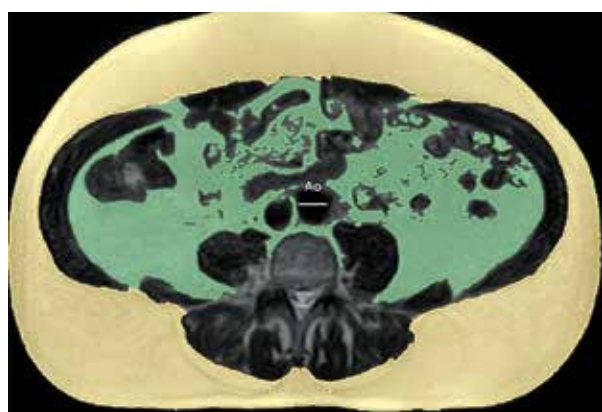


Fig. 3. MRI of the abdominal AT and aorta: male, 63 years old, BMI – 31, WC – 114 cm, postprandial glycaemia – 7.7 mmol / l, HbA1c – 6.2%; axial T2-weighted spin-echo slice; volume of abdominal subcutaneous adipose tissue (yellow) – 5,284 cm³, abdominal visceral adipose tissue (green) – 4,127 cm³, aorta diameter – 25 mm, the wall is smooth with small foci of the amplified MR signal

After the gender adjustment, the patients in group 2 showed higher values of the waist-to-hip circumference ratio, lower levels of HbA1c and basal glucose, as well as a tendency to lower values of postprandial glycemia, which was determined by a significantly lower number of patients with T2DM. In addition, in the patients from group 2, a tendency to a reduced level of adiponectin was observed, while there were no inter-group differences in body mass index and the area and volume of abdominal SAT and VAT.

Our results are consistent with the data of other research groups, which showed that patients with manifest disorders of carbohydrate metabolism tend to have a decrease in the aortic diameter, which may be mediated by a decline in the extracellular matrix degradation in hyperglycemia and an increase in the vascular wall stiffness [29].

Our data show a different nature of the relationships between subcutaneous and visceral abdominal fat depots and metabolic parameters. It is the volume of abdominal VAT that is closely related to the parameters of lipid metabolism and the level of adiponectin, while the lipid and adipokine profiles do not have an association with abdominal SAT accumulation. At the same time, the results of our study demonstrated for the first time that the abdominal SAT area was the only parameter associated with the AA diameter, and, apparently, the level of glycaemia can be considered a potential metabolic factor involved in the modulation of AA remodeling. The correlation of AA diameter with the SAT area at L4–L5 and the absence of an association between parameters of AA wall remodeling and the values of the abdominal AT volume require further studies. It is possible to assume that the total volume of abdominal AT, most fully reflecting its accumulation, is capable of correlating with the state of systemic metabolism. On the other hand, it is quite difficult to directly link the metabolic activity of such a large endocrine organ as abdominal AT only with the state of the abdominal aortic wall. In addition, it is known that SAT regresses more badly and is a source of a significant number of cellular mediators of inflammation and damage to the vascular wall. For these reasons, the demonstrated dependence of the abdominal aortic diameter on the SAT area at L4–L5 seems to most accurately reflect the negative impact of the abdominal AT on the processes of vascular remodeling.

In the future, it is of particular interest to study the potential relationships between abdominal aortic wall remodeling and quantitative parameters of perivascular aortic fat, as well as to conduct prospective studies

on the mechanisms linking quantitative characteristics of subcutaneous and visceral abdominal obesity with glucose (insulin) metabolism disorders.

CONCLUSION

According to the results of the study, independent determinants of an increase in the total volume of abdominal VAT were established, such as an increase in WC and a decrease in the adiponectin and HDL-C levels. Our data demonstrate the existence of a relationship between AA remodeling, abdominal AT accumulation, and impaired glucose metabolism. New data have been obtained suggesting a relationship between AA expansion and an increase in the abdominal SAT area, regardless of gender. There are negative correlations between the AA diameter values, on the one hand, and the HbA1c levels and postprandial glycaemia, on the other hand.

The limitations of the study are its single-stage design, small sample size, and a lack of a separate study of the quantitative characteristics of abdominal AT and its relationships in men, women, and patients with T2DM and obesity. Due to a lack of reference values for the total volume of abdominal VAT, it was not possible to create a predictive model for this parameter.

REFERENCES

1. Liu Z., Wu K.K.L., Jiang X., Xu A., Cheng K.K.Y. The role of adipose tissue senescence in obesity- and ageing-related metabolic disorders. *Clin. Sci. (Lond.)*. 2020; 134 (2): 315–330. DOI: 10.1042/CS20190966.
2. Wajchenberg B.L. Subcutaneous and visceral adipose tissue: their relation to the metabolic syndrome. *Endocr. Rev.* 2000; 21 (6):697–738. DOI: 10.1210/edrv.21.6.0415.
3. Freemantle N., Holmes J., Hockey A., Kumar S. How strong is the association between abdominal obesity and the incidence of type 2 diabetes? *Int. J. Clin. Pract.* 2008; 62 (9): 1391–1396. DOI: 10.1111/j.1742-1241.2008.01805.x.
4. Mandviwala T., Khalid U., Deswal A. Obesity and cardiovascular disease: a risk factor or a risk marker? *Curr. Atheroscler. Rep.* 2016;18 (5): 21. DOI: 10.1007/s11883-016-0575-4.
5. Lind L., Strand R., Kullberg J., Ahlström H. Cardiovascular-related proteins and the abdominal visceral to subcutaneous adipose tissue ratio. *Nutrition, Metabolism & Cardiovascular Diseases*. 2021; 31 (2): 532–539. DOI: 10.1016/j.numecd.2020.09.010.
6. Marzetti M., Brunton T., McCreight L., Pearson E., Docherty S., Gandy S.J. Quantitative MRI evaluation of whole abdomen adipose tissue volumes in healthy volunteers – validation of technique and implications for clinical studies. *BJR*. 2018; 91 (1087): 108720180025. DOI: 10.1259/bjr.20180025.
7. Klingensmith J.D., Elliott A.L., Givan A.H., Faszold Z.D., Mahan C.L., Doedtman A.M., Fernandez-Del-Valle M. Development and evaluation of a method for segmentation of cardiac, subcutaneous, and visceral adipose tissue from Dixon magnetic resonance images. *J. Med. Imaging (Bellingham)*. 2019; 6 (1):014004. DOI: 10.1117/1.JMI.6.1.014004.
8. Pescatori L.C., Savarino E., Mauri G., Silvestri E., Cariati M., Sardanelli F., Sconfienza L.M. Quantification of visceral adipose tissue by computed tomography and magnetic resonance imaging: reproducibility and accuracy. *Radiol. Bras.* 2019; 52 (1): 1–6. DOI: 10.1590/0100-3984.2017.0211.
9. Cronin O., Liu D., Bradshaw B., Iyer V., Buttner P., Cunningham M., Walker P.J., Golledge J. Visceral adiposity is not associated with abdominal aortic aneurysm presence and growth. *Vascular Medicine* 2014; 19 (4): 272–280. DOI: 10.1177/1358863X14537883.
10. Golledge J., Clancy P., Jamrozik K., Norman P.E. Obesity, adipokines, and abdominal aortic aneurysm: Health in Men study. *Circulation*. 2007; 116 (20): 2275–2279. DOI: 10.1161/CIRCULATIONAHA.107.717926.
11. Erbel R., Aboyans V., Boileau C., Bossone E., Bartolomeo R.D., Eggebrecht H., Evangelista A., Falk V., Frank H., Gaemperli O., Grabenwöger M., Haverich A., Jung B., Manolis A.J., Meijboom F., Nienaber C.A., Roffi M., Rousseau H., Sechtem U., Sirnes P.A., Allmen R.S., Vrints C.J.; ESC Committee for Practice Guidelines. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: Document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur. Heart J.* 2014; 35 (41): 2873–2926. DOI: 10.1093/eurheartj/ehu281.
12. Ahmedzhanov N.M., Butrova S.A., Dedov I.I., Zvenigorodskaya L.A., Kislyak O.A., Koshel'skaya O.A., Kuznetsova I.V., Kuharchuk V.V., Litvin A.YU., Medvedeva I.V., Mkrtumyan A.M., Mychka V.B., Nebieridze D.V., Nedogoda S.V., Oganov V.G., Ogarkov M.YU., Perepech N.B., Podzolkov V.I., Smetnik V.P., Susekov A.V., Titov V.N., Tyurina T.V., Fursov A.N., Hirmanov V.N., Chazova I.E., Chukaeva I.I., SHeStakova M.V., Shubina A.T. Russian experts' consensus on metabolic syndrome problem in the Russian Federation: definition, diagnostic criteria, primary prevention, and treatment. *Preventive medicine*. 2010; 13 (5): 27–32 (in Russ.).
13. Coolen B.F., Calcagno C., van Ooij P., Fayad Z.A., Strijkers G.J., Nederveen A.J. Vessel wall characterization using quantitative MRI: what's in a number? *MAGMA*. 2018; 31 (1): 201–222. DOI: 10.1007/s10334-017-0644-x.
14. Neeland I.J., Ayers C.R., Rohatgi A.K., Turer A.T., Berry J.D., Das S.R., Vega G.L., Khera A., McGuire D.K., Grundy S.M., de Lemos J.A. Associations of visceral and abdominal subcutaneous adipose tissue with markers of cardiac and metabolic risk in obese adults. *Obesity*. 2013; 21 (9): E439–E447. DOI: 10.1002/oby.20135.
15. Gruzdeva O.V., Borodkina D.A., Dyleva Y.A., Kuzmina A.A., Belik E.V., Brel N.K., Karetnikova V.N., Kashtalap V.V., Bychkova E.E., Barbarash O.L. The relationship of the epicardial fat and adipokines in myocardial infarction. *Russian Clinical Laboratory Diagnostics*. 2020; 65 (9): 533–540 (in Russ.).

16. Reneau J., Goldblatt M., Gould J., Kindel T., Kastenmeier A., Higgins R., Rengel L.R., Schoyer K., James R., Obi B., Moosreiner A., Nicholson K., Sahoo D., Kidambi S. Effect of adiposity on tissue-specific adiponectin secretion. *PLoS One*. 2018; 13 (6): e0198889. DOI: 10.1371/journal.pone.0198889.
17. Frederiksen L., Nielsen T.L., Wraae K., Hagen C., Frystyk J., Flyvbjerg A., Brixen K., Andersen M. Subcutaneous rather than visceral adipose tissue is associated with adiponectin levels and insulin resistance in young men. *J. Clin. Endocrinol. Metab.* 2009; 94 (10): 4010-5. DOI: 10.1210/jc.2009-0980.
18. Beshpalova I.D., Ryazantseva N.V., Kalyuzhin V.V., Dzyuman A.N., Osikhov I.A., Medyantsev Y.A., Klinovitskiy I.Y., Murashev B.Y., Afanasyeva D.S., Bychkov V.A. Clinicomorphological parallels in abdominal obesity. *Bulletin of the Siberian Branch of the Russian Academy of Medical Sciences*. 2014; 34 (4): 51–58 (in Russ.).
19. Apoloni R.C., Zerati A.E., Wolosker N., Saes G.F., Wolosker M., Curado T., Puech-Leão P., De Luccia N. Analysis of the Correlation Between Central Obesity and Abdominal Aortic Diseases. *Ann. Vasc. Surg.* 2019; 54: 176–184. DOI: 10.1016/j.avsg.2018.06.016.
20. Goldenberg L., Saliba W., Hayeq H., Hasadia R., Zeina A.R. The impact of abdominal fat on abdominal aorta calcification measured on non-enhanced CT. *Medicine (Baltimore)*. 2018; 97 (49): e13233. DOI: 10.1097/MD.00000000000013233.
21. Muenkaew M., Boonyasirinant T., Kritayaphong R. Correlation between aortic stiffness and visceral fat determined by magnetic resonance imaging. *J. Med. Assoc. Thai.* 2012; 95 (2): S117–S126.
22. Sutton-Tyrrell K., Newman A., Simonsick E.M., Havlik R., Pahor M., Lakatta E., Spurgeon H., Vaitkevicius P. Aortic stiffness is associated with visceral adiposity in older adults enrolled in the study of health, aging, and body composition. *Hypertension*. 2001; 38 (3): 429–433. DOI: 10.1161/01.hyp.38.3.429.
23. Mzayek F., Wang L.E., Relyea G., Yu X., Terry J.G., Carr J., Hundley G.W., Hall M.E., Correa A. Impact of abdominal Obesity on Proximal and Distal Aorta Wall Thickness in African Americans: The Jackson Heart Study. *Obesity (Silver Spring)*. 2019; 27 (9): 1527–1532. DOI: 10.1002/oby.22563.
24. Polat T.B., Urganci N., Caliskan K.C., Akyildiz B. Correlation of abdominal fat accumulation and stiffness of the abdominal aorta in obese children. *J. Pediatr. Endocrinol. Metab.* 2008; 21 (11): 1031–1040. DOI: 10.1515/jpem.2008.21.11.1031.
25. Efe D., Aygün F., Acar T., Yildiz M., Gemici K. Investigation of relation between visceral and subcutaneous abdominal fat volumes and calcified aortic plaques via multislice computed tomography. *Vascular*. 2015; 23 (4): 396–402. DOI: 10.1177/1708538114552012.
26. Reijrink M., de Boer S.A., Spoor D.S., Lefrandt J.D., Lambers Heerspink H.J., Boellaard R., Greuter M.J., Borra R.J.H., Hillebrands J.L., Slart R.H.J.A., Mulder D.J. Visceral adipose tissue volume is associated with premature atherosclerosis in early type 2 diabetes mellitus independent of traditional risk factors. *Atherosclerosis*. 2019; 290: 87–93. DOI: 10.1016/j.atherosclerosis.2019.09.016.
27. Wang H., Peng D.Q. New insights into the mechanism of low high-density lipoprotein cholesterol in obesity. *Lipids Health Dis.* 2011; 10: 176. DOI: 10.1186/1476-511X-10-176.
28. Yanai H., Yoshida H. Beneficial effects of adiponectin on glucose and lipid metabolism and atherosclerotic progression: mechanisms and perspectives. *International Journal of Molecular Sciences*. 2019; 20 (5): 1190. DOI: 10.3390/ijms20051190.
29. Dereziński T., Zozulińska-Ziółkiewicz D., Uruska A., Dąbrowski M. Abdominal aorta diameter as a novel marker of diabetes incidence risk in elderly women. *Sci. Rep.* 2020; 10 (1): 13734. DOI: 10.1038/s41598-020-70736-1.

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Ryumshina N.I. – analysis and interpretation of data, critical revision of the manuscript for important intellectual content, drafting of the manuscript. Koshelskaya O.A. – conception and design, critical revision of the manuscript for important intellectual content, final approval of the manuscript for publication. Kologrivova I.V. – analysis and interpretation of data, critical revision of the manuscript for important intellectual content. Kharitonova O.A. – analysis and interpretation of data. Nasekina K.A. – analysis and interpretation of data. Ussov V.Yu. – conception and design, final approval of the manuscript for publication.

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