CHRONIC LOW-GRADE INFLAMMATION

AND VISCERAL OBESITY
IN THE PATHOGENESIS OF VASCULAR AGING
AND CARDIOVASCULAR RISK

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Abstract

Chronic low-grade inflammation is regarded as a key pathogenetic mechanism linking visceral obesity with accelerated vascular aging and increased cardiovascular risk. Visceral adipose tissue functions as an active endocrine–inflammatory organ, producing pro-inflammatory cytokines, adipokines, and mediators that affect endothelial function, arterial stiffness, and microcirculation.

This article presents an integrative analysis of the role of chronic inflammation and visceral obesity in the development of vascular and cardiometabolic disorders. Pathophysiological mechanisms, clinical manifestations, diagnostic approaches, and preventive strategies aimed

at slowing vascular aging and reducing cardiovascular risk in patients with age-associated and metabolic disorders are discussed.

Keywords: chronic inflammation, visceral obesity, vascular aging, endothelial dysfunction, arterial stiffness, cardiovascular risk, inflammaging.

Introduction

Vascular aging is a multifactorial process that determines the development of cardiovascular diseases in older age. In addition to traditional risk factors such as arterial hypertension and dyslipidemia, increasing attention is being paid to the role of chronic systemic low-grade inflammation, often referred to as *inflammaging*.

Visceral obesity occupies a central position in the formation of the inflammatory background associated with metabolic disorders. Unlike subcutaneous adipose tissue, visceral fat is characterized by high metabolic and secretory activity, exerting a direct influence on the vascular wall and hemodynamic regulation. These processes are particularly significant in the context of age-associated changes, when compensatory mechanisms of the vascular system gradually become exhausted.

1. Visceral Adipose Tissue as a Source of Chronic Inflammation

Current concepts consider visceral adipose tissue as an active endocrine and immunomodulatory organ. Adipocytes and infiltrating immune cells produce a wide range of biologically active substances, including:

- pro-inflammatory cytokines (interleukin-6, tumor necrosis factor-α);
- chemokines that promote macrophage recruitment;
- adipokines with pro- and anti-inflammatory properties.

With an increase in visceral fat volume, the balance shifts toward pro-inflammatory mediators, leading to the development of chronic low-grade inflammation. This condition may persist for a long time without pronounced clinical manifestations; however, it exerts a significant impact on vascular function.

2. Chronic Inflammation and Endothelial Dysfunction

The vascular endothelium represents one of the primary targets of inflammatory mediators. Under the influence of pro-inflammatory cytokines, nitric oxide synthesis is impaired, expression of adhesion molecules is increased, and prothrombotic mechanisms are activated.

Chronic inflammation leads to reduced endothelium-dependent vasodilation and increased vascular tone. In combination with age-associated changes, this contributes to the

development of endothelial dysfunction—an early and potentially reversible stage of vascular aging.

3. Arterial Stiffness as an Integrative Marker of Vascular Aging

Arterial stiffness is one of the key phenotypic manifestations of vascular aging and is regarded as an independent predictor of cardiovascular morbidity and mortality. Unlike traditional risk factors that primarily reflect macrovessel status or systemic blood pressure levels, arterial stiffness integrates structural, functional, and inflammatory changes of the vascular wall that develop over prolonged periods.

3.1. Pathophysiological Mechanisms of Increased Arterial Stiffness in Chronic Inflammation

Chronic low-grade inflammation associated with visceral obesity exerts a direct effect on the vascular wall through several interrelated mechanisms:

1. Extracellular matrix remodeling
Pro-inflammatory cytokines stimulate activation of fibroblasts and vascular smooth muscle cells, leading to increased collagen synthesis and reduced elastin content. Disruption of the balance between elastic and collagen fibers results in loss of arterial wall elasticity and increased stiffness.

2. Oxidative stress and endothelial injury
In conditions of chronic inflammation, production of reactive oxygen species increases, reducing nitric oxide bioavailability and impairing endothelium-dependent vasodilation. This promotes functional arterial spasm and consolidation of structural changes in the vascular wall.

3. Immune cell infiltration of the vascular wall
Visceral obesity is accompanied by systemic immune activation. Macrophages and other inflammatory cells infiltrate the vascular wall, maintaining local inflammation and accelerating vascular remodeling processes.

Collectively, these mechanisms create conditions for accelerated increases in arterial stiffness that exceed physiological age-related vascular changes.

3.2. Hemodynamic Consequences of Increased Arterial Stiffness

Increased arterial stiffness alters pulse wave propagation. Loss of elastic properties of the aorta and large arteries leads to:

- increased pulse wave velocity;
- earlier reflection of the pulse wave from peripheral vessels;

- elevation of systolic and pulse pressure.

These changes increase left ventricular afterload and impair diastolic coronary perfusion, which is of particular importance in patients with age-associated and metabolic disorders.

Example (hemodynamic):
In a 62-year-old patient with abdominal obesity and moderately elevated arterial blood pressure, diastolic pressure may remain within normal limits, while pulse pressure is markedly increased. In such cases, arterial stiffness—rather than classical hypertension—becomes the leading factor of myocardial overload.

3.3. Relationship Between Visceral Obesity and Arterial Stiffness

Visceral adipose tissue enhances vascular aging not only through systemic inflammation but also via local metabolic effects. Elevated levels of free fatty acids, adipokines, and pro-inflammatory mediators contribute to impaired vascular reactivity and accelerate structural arterial changes.

Epidemiological and clinical studies demonstrate that waist circumference and indices of visceral obesity correlate with arterial stiffness parameters even in the absence of overt arterial hypertension.

Example (metabolic):
In a patient with a body mass index of 28–30 kg/m² and pronounced visceral obesity, office blood pressure values may remain within the normal range. However, instrumental assessment reveals increased arterial stiffness, reflecting early vascular changes not detected by standard examination methods.

3.4. Arterial Stiffness and Clinical Manifestations of Vascular Aging

Increased arterial stiffness may remain asymptomatic for a prolonged period; nevertheless, it has a substantial impact on the clinical course of cardiovascular diseases and overall functional status.

Clinical manifestations may include:

- reduced exercise tolerance;
- a tendency toward elevated systolic blood pressure during physical exertion;
- progression of diastolic dysfunction;
- increased risk of ischemic events.

Example (clinical):
An elderly patient with visceral obesity and chronic low-grade inflammation may report dyspnea during moderate physical activity while maintaining preserved ejection fraction. In

such cases, arterial stiffness and associated impairment of diastolic coronary perfusion may represent key pathogenetic mechanisms.

3.5. Arterial Stiffness as a Potentially Modifiable Risk Factor

Despite its close association with aging, arterial stiffness is not an entirely inevitable consequence of the aging process. Reduction of inflammatory activity, correction of visceral obesity, and improvement of endothelial function may slow or partially reverse vascular remodeling processes.

Thus, arterial stiffness may be considered not only a marker but also a potential therapeutic target within cardiovascular disease prevention strategies for patients with metabolic and age-associated disorders.

4. The Impact of Chronic Inflammation and Visceral Obesity

on Microcirculation and Tissue Perfusion

The microcirculatory network represents a key functional component of the vascular system, ensuring the delivery of oxygen, nutrients, and regulatory signals at the tissue level. Microcirculatory disturbances constitute one of the earliest and frequently underestimated manifestations of vascular aging, developing long before clinically overt macrovascular complications become apparent.

Chronic low-grade inflammation and visceral obesity exert a multilevel impact on microcirculation, affecting the endothelium, hemorheological properties of blood, the capillary network, and mechanisms of local blood flow regulation. These processes lead to a state of chronic low-grade tissue hypoperfusion, which may remain subclinical for prolonged periods but has a substantial impact on the function of target organs.

4.1. Endothelial Dysfunction of the Microcirculatory Bed

The endothelium of microcirculatory vessels plays a central role in regulating capillary blood flow and the distribution of perfusion in response to local metabolic demands. Under conditions of chronic inflammation, endothelial function is impaired at several levels:

- reduced synthesis and bioavailability of nitric oxide;
- increased expression of adhesion molecules;
- increased vascular wall permeability;
- activation of prothrombotic mechanisms.

Pro-inflammatory cytokines secreted by visceral adipose tissue impair the ability of the endothelium to adequately respond to metabolic signals, resulting in reduced endothelium-dependent vasodilation at the level of arterioles and precapillary sphincters.

Example (pathophysiological):
In a patient with visceral obesity and elevated C-reactive protein levels, the microcirculatory network may retain anatomical integrity but lose the capacity for adequate functional adaptation. Under such conditions, even with normal systemic arterial blood pressure, tissues experience a relative perfusion deficit during physical exertion.

4.2. Functional and Structural Capillary Rarefaction

One of the key manifestations of microcirculatory impairment in chronic inflammation is capillary rarefaction, defined as a reduction in the number of functioning capillaries. Two forms are distinguished:

- **structural rarefaction**, associated with the actual loss of capillaries;
- **functional rarefaction**, in which capillaries are anatomically preserved but do not participate in perfusion.

In the context of visceral obesity and inflammation, functional rarefaction predominates at early stages, rendering the process potentially reversible with timely correction of risk factors.

Mechanisms contributing to capillary rarefaction include:

- impaired capillary recruitment;
- thickening of the basement membrane;
- pericyte dysfunction;
- microthrombus formation.

Example (clinical):
In a middle-aged patient with metabolic syndrome, signs of ischemic heart disease may be absent; however, early fatigue and reduced exercise tolerance may develop during physical activity. These symptoms may be attributable to insufficient capillary recruitment in skeletal muscle and myocardial tissue.

4.3. Hemorheological Abnormalities and Microcirculatory Blood Flow

Chronic inflammation affects not only the vascular wall but also the rheological properties of blood. In conditions of visceral obesity and systemic inflammation, the following changes are commonly observed:

- increased blood viscosity;

- reduced erythrocyte deformability;
- enhanced platelet aggregation;
- elevated fibrinogen levels.

These alterations hinder blood passage through narrow capillaries and exacerbate tissue hypoxia, particularly under conditions of reduced microcirculatory reserve.

Example (hemorheological):
Even a moderate increase in blood viscosity in a patient with chronic inflammation may result in a clinically significant deterioration of capillary blood flow, manifesting as cold extremities, delayed healing of micro-injuries, and reduced physical endurance.

4.4. Impairment of Microcirculatory Reserve and Tissue Hypoperfusion

Microcirculatory reserve reflects the ability of tissues to increase blood flow in response to elevated metabolic demand. Under conditions of chronic inflammation, this reserve is markedly reduced.

The principal mechanisms underlying the reduction of microcirculatory reserve include:

- endothelial dysfunction;
- functional capillary rarefaction;
- reduced vascular sensitivity to metabolic signals;
- neurohumoral alterations.

As a result, tissues enter a state of chronic low-grade hypoperfusion, which may not be accompanied by acute symptoms for extended periods but contributes to the progression of organ dysfunction.

Example (functional):
An elderly patient with visceral obesity may demonstrate normal macrohemodynamic parameters at rest; however, even minimal exertion may provoke pronounced dyspnea. One explanation for this phenomenon is a reduced microcirculatory reserve and the inability of tissues to adequately increase perfusion in response to increased demand.

4.5. Organ-Specific Features of Microcirculatory Disturbances

Microcirculatory disorders associated with chronic inflammation exhibit pronounced organ specificity:

- **Myocardium:** reduced coronary microcirculatory reserve, diastolic dysfunction.
- **Skeletal muscle:** early fatigue, decreased aerobic performance.

- **Brain:** impaired cognitive function, increased sensitivity to perfusion fluctuations.
- **Skin and peripheral tissues:** delayed wound healing, thermoregulatory disturbances.

Such organ specificity underscores the systemic nature of microcirculatory dysfunction and its contribution to clinical aging.

4.6. Clinical Significance of Microcirculatory Disorders

in the Context of Vascular Aging

Microcirculatory disturbances should be regarded as an early pathogenetic stage of vascular aging, preceding the development of pronounced macrovascular changes. Their presence explains the discrepancy between clinical symptoms and relatively "favorable" findings obtained by standard instrumental diagnostic methods.

Thus, microcirculation represents not a secondary, but a central link connecting chronic inflammation, visceral obesity, and the progression of cardiovascular risk.

4.7. Reversibility Potential of Microcirculatory Alterations

An important characteristic of microcirculatory disorders is their relative reversibility at early stages. Reduction of inflammatory activity, correction of visceral obesity, and improvement of endothelial function are capable of:

- enhancing capillary recruitment;
- improving tissue perfusion;
- slowing the progression of vascular aging.

This highlights the practical significance of early detection and a comprehensive preventive approach.

5. Diagnostic Approaches to the Assessment of Microcirculatory Disorders

in Chronic Inflammation and Visceral Obesity

The diagnosis of microcirculatory disorders represents one of the most challenging tasks in clinical endocrinology and cardiometabolic medicine. Unlike macrovascular pathology, alterations in microcirculation often remain inaccessible to standard imaging techniques and may not be accompanied by pronounced clinical symptoms for prolonged periods. At the same time, the microcirculatory bed constitutes an early target of chronic inflammation and visceral obesity, thereby forming a preclinical stage of vascular aging.

Contemporary diagnostic approaches are aimed at assessing the level of tissue perfusion, microcirculatory reactivity, and microcirculatory reserve, which allows functional abnormalities to be identified before irreversible structural changes develop.

5.1. Laser Doppler Flowmetry as a Method for Functional Assessment of Microcirculation

Laser Doppler flowmetry (LDF) is one of the most widely used non-invasive methods for evaluating microcirculatory blood flow in clinical and experimental studies. The method is based on the registration of the Doppler shift of laser radiation reflected from moving blood cellular elements, enabling the assessment of the relative level of tissue perfusion.

5.1.1. Baseline Microcirculatory Parameters

Analysis of baseline microcirculatory blood flow in patients with visceral obesity and chronic inflammation frequently reveals:

- a reduction in mean perfusion levels;
- pronounced variability of measurements;
- increased heterogeneity of blood flow.

These findings reflect functional instability of the microcirculatory bed and a reduction in its adaptive capacity.

Example (baseline LDF):
In a patient with metabolic syndrome, resting microcirculatory parameters may fall within a conventionally “normal” range; however, marked variability may be observed, indicating impaired regulatory mechanisms and instability of tissue perfusion.

5.1.2. Functional Tests and Microcirculatory Reserve

A key advantage of LDF is the ability to perform functional tests that allow assessment of microcirculatory reactivity, including:

- occlusion testing (reactive hyperemia);
- thermal stimulation;
- pharmacological interventions (in research protocols).

In patients with chronic inflammation and visceral obesity, the following patterns are commonly observed:

- reduced amplitude of reactive hyperemia;

- delayed recovery of perfusion following occlusion;
- diminished microcirculatory reserve.

Example (reactive hyperemia):
In a patient with abdominal obesity, occlusion testing reveals a weak and delayed hyperemic response, indicating endothelial dysfunction of the microcirculatory bed even in the absence of clinically overt vascular disease.

5.1.3. Clinical Significance of LDF Findings

LDF data make it possible to:

- identify early functional disturbances of microcirculation;
- assess the severity of endothelial dysfunction;
- monitor the dynamics of microcirculatory changes during correction of risk factors.

This method is particularly valuable for evaluating the effectiveness of non-pharmacological interventions aimed at reducing inflammatory activity and visceral obesity.

5.2. Videocapillaroscopy as a Method for Structural Assessment of Microcirculation

Videocapillaroscopy enables direct visualization of the capillary network, most commonly at the level of the nailfold. The method provides information on capillary density, morphology, and blood flow characteristics, making it a valuable tool for assessing structural aspects of microcirculatory disorders.

5.2.1. Morphological Capillary Changes in Inflammation and Obesity

In patients with chronic inflammation and visceral obesity, videocapillaroscopy may reveal:

- a reduced density of functioning capillaries;
- elongation and deformation of capillary loops;
- uneven blood flow distribution;
- areas of stasis or slowed flow.

These changes reflect both functional impairment and early structural remodeling of the microcirculatory bed.

Example (capillaroscopy):
In a patient with obesity and elevated inflammatory markers, nailfold videocapillaroscopy demonstrates reduced capillary density and marked blood flow heterogeneity despite the absence of clinical signs of peripheral vascular disease.

5.2.2. Differentiation Between Functional and Structural Abnormalities

One of the advantages of videocapillaroscopy is the ability to distinguish between:

- **functional capillary rarefaction**, which is potentially reversible;
- **structural rarefaction**, indicative of more advanced stages of vascular aging.

This distinction is important for selecting appropriate preventive strategies and for evaluating the reversibility of microcirculatory alterations.

5.3. Complementary Use of LDF and Videocapillaroscopy

The greatest diagnostic value is achieved through the combined application of functional and structural methods. The integration of LDF and videocapillaroscopy allows clinicians to:

- correlate perfusion data with capillary morphology;
- identify discrepancies between structural preservation and functional insufficiency of microcirculation;
- more accurately assess microcirculatory reserve.

Integrative example:
In a patient with visceral obesity, videocapillaroscopy may reveal a preserved capillary network, whereas LDF demonstrates a marked reduction in reactive hyperemia. This combination indicates functional microcirculatory dysfunction with a high potential for reversibility following timely intervention.

5.4. The Role of Microcirculatory Diagnostics in Clinical Practice

Despite certain limitations—including labor intensity, sensitivity to external conditions, and the need for standardization—methods for assessing microcirculation have important clinical value in:

- early diagnosis of vascular aging;
- stratification of cardiovascular risk in patients with metabolic disorders;
- monitoring the effectiveness of preventive interventions.

Incorporation of microcirculatory assessment into clinical reasoning shifts the focus from late-stage complications to early, potentially reversible phases of vascular dysfunction.

6. Prevention and Correction Strategies

for Chronic Inflammation, Visceral Obesity,
and Microcirculatory Disorders
in the Context of Vascular Aging

Prevention and correction of vascular aging associated with chronic low-grade inflammation and visceral obesity require a comprehensive, multilevel approach. Unlike macrovascular pathology, microcirculatory and inflammatory disturbances develop gradually and often remain subclinical, thereby creating a window of opportunity for early and potentially reversible intervention.

The key principle is targeting not isolated symptoms or individual parameters, but a **unified pathogenetic continuum** that includes visceral adipose tissue, systemic inflammation, endothelial dysfunction, arterial stiffness, and microcirculatory reserve.

6.1. Non-Pharmacological Strategies

6.1.1. Correction of Visceral Obesity as a Fundamental Intervention

Reduction of visceral adipose tissue volume represents one of the most effective strategies for decreasing inflammatory activity and improving microcirculatory function. Even moderate weight reduction is associated with:

- decreased production of pro-inflammatory cytokines;
- improvement of endothelium-dependent vasodilation;
- enhanced capillary recruitment;
- reduction in arterial stiffness.

Importantly, clinically meaningful benefits may be observed **before normalization of body mass index**, underscoring the significance of qualitative redistribution of adipose tissue rather than absolute weight loss alone.

6.1.2. Physical Activity and Microcirculatory Adaptation

Regular aerobic physical activity exerts a multilevel beneficial effect on the vascular system by:

- stimulating endothelium-dependent nitric oxide production;
- increasing microcirculatory reserve;
- promoting capillary recruitment;
- reducing systemic inflammatory activity.

Notably, improvements in microcirculation may occur **earlier** than changes in macrohemodynamic parameters or lipid profiles, making physical activity a cornerstone of vascular aging prevention.

6.1.3. Dietary Approaches and Anti-Inflammatory Potential of Nutrition

Dietary patterns significantly influence systemic inflammation and vascular function. Anti-inflammatory dietary strategies include:

- reducing intake of saturated fats and ultra-processed foods;
- increasing dietary fiber consumption;
- incorporating sources of polyunsaturated fatty acids and antioxidants.

Such approaches contribute to lowering inflammatory markers and improving endothelial function, with favorable effects on microcirculation and arterial stiffness.

6.2. Pharmacological Approaches within an Integrative Framework

Pharmacological therapy in the context of chronic inflammation and vascular aging should be regarded as part of an **integrative cardiometabolic strategy**, rather than an isolated intervention.

Medications targeting arterial blood pressure, lipid metabolism, and insulin resistance may exert pleiotropic effects on the endothelium and microcirculation. Their clinical value lies not only in achieving target levels of traditional risk factors, but also in reducing inflammatory activity and slowing vascular remodeling.

However, pharmacological intervention alone, without concomitant lifestyle modification, is generally insufficient to fully restore microcirculatory reserve.

6.3. The Role of Microcirculatory Monitoring in Prevention

Advances in diagnostic techniques, including laser Doppler flowmetry and videocapillaroscopy, enable **personalized preventive strategies**. Dynamic assessment of microcirculation allows clinicians to:

- detect early functional abnormalities;
- evaluate the effectiveness of preventive interventions;
- adjust management strategies before irreversible vascular changes occur.

Thus, microcirculation becomes not only a subject of pathogenetic analysis but also a practical tool for clinical monitoring of vascular aging.

Conclusion

Chronic low-grade inflammation and visceral obesity constitute a central pathogenetic link connecting metabolic disturbances with accelerated vascular aging and increased cardiovascular risk. These processes operate through a complex network of interrelated mechanisms, including endothelial dysfunction, increased arterial stiffness, and multilevel microcirculatory impairment.

The expanded analysis demonstrates that the microcirculatory bed represents one of the earliest and most sensitive targets of inflammatory and metabolic stress. Reduction of microcirculatory reserve and functional capillary rarefaction may remain subclinical for prolonged periods; however, they play a critical role in decreased exercise tolerance, progression of diastolic dysfunction, and increased vulnerability of target organs.

Integration of data on visceral obesity, inflammatory markers, arterial stiffness, and microcirculatory function supports the concept of vascular aging as a dynamic and potentially modifiable process. This perspective highlights the importance of early diagnosis and comprehensive prevention aimed at addressing primary pathogenetic mechanisms rather than late-stage clinical manifestations.

Incorporating microcirculatory assessment into the clinical reasoning of endocrinologists and cardiologists enables more accurate cardiovascular risk stratification and the development of personalized preventive strategies, thereby contributing to the slowing of vascular aging and reduction of long-term cardiovascular complications.

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