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INFLAMMATORY CYTOKINES PROFILE AND OXIDATIVE STRESS MARKERS IN THE SERUM OF ALBINO RATS INJECTED WITH MACROPHAGE MIGRATION INHIBITORY FACTOR

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Macrophage migration inhibitory factor (MIF) is a pleiotropic cytokine involved in the regulation of inflammation, immune responses, and redox homeostasis. However, its metabolic effects in experimental models remain insufficiently characterized. The aim of the work was to estimate the effect of recombinant MIF on cytokines profile, antioxidant defense markers and LPO indicators at different time points following its single intraperitoneal administration to albino rats. Animals were divided into a control group (n = 20) and three experimental groups (n = 10 each) assessed in 2, 3, and 14 days after MIF administration (10 μg/kg of b.w.), respectively. Serum samples were analyzed for IL-6, IL-10, TNF-α, IL-4, antioxidant markers and LPO products levels by ELISA and standard biochemical assays. It was shown that MIF administration induced time-dependent pro-inflammatory and pro-oxidant effects. Early compensatory anti-inflammatory responses were marked by increased IL-10 and decreased IL-6 levels. However, at the later stages (days 3 and 14), IL-6 and TNF-α elevation, along with IL-4 suppression, indicated a shift toward chronic inflammation. Antioxidant parameters progressively declined, with maximal suppression observed on day 14. Concurrently, a significant accumulation of LPO products confirmed sustained oxidative stress and membrane damage. These findings underscore the potential of MIF as a pharmacological target for the treatment of chronic inflammatory and metabolic disorders.

K e y w o r d s: macrophage migration inhibitory factor, interleukins, inflammation, antioxidant system, lipid peroxidation, albino rats.

Macrophage migration inhibitory factor (MIF) is a pleiotropic cytokine that plays a key role in regulating innate and adaptive immune responses, cellular metabolism, inflammation, and cell death mechanisms. Originally described as a factor that inhibits macrophage migration, MIF has since been recognized as a central mediator of immune regulation [1]. MIF is expressed by various cells – immune (macrophages, T lymphocytes), epithelial, endothelial, and even tumor cells – and can be actively secreted in response to infectious or stress stimuli. It modulates the production of pro-inflammatory cytokines, including TNF-α, IL-6, and γ-interferon, and acts as a glucocorticoid antagonist, maintaining inflammation even under high cortisol levels [1, 2]. Macrophage migration inhibitory factor (MIF) is a unique pleiotropic cytokine that, due to its particular synthesis, secretion, and ability to modulate the activity of anti-inflammatory hormones, plays a key role in regulating both innate and adaptive immune responses [3, 4]. Many inflammatory and autoimmune diseases are associated with dysregulation of MIF's pro-inflammatory functions. Neutralization of MIF may be an effective therapeutic approach for many diseases. MIF exerts its effects through multiple signaling pathways, including the activation of the MAPK/ERK, PI3K/Akt, and NF-κB pathways, which regulate cell proliferation, survival,

and inflammatory responses [5, 6]. Specifically, MIF binds to its receptor CD74, often in complex with co-receptors such as CXCR2 or CXCR4, initiating intracellular signaling cascades that drive immune and inflammatory responses [5]. The MAPK/ERK pathway, activated via MIF's interaction with CD74, promotes phosphorylation of ERK1/2, leading to enhanced transcription of pro-inflammatory cytokines like TNF-α and IL-6, which are critical in sustaining inflammatory processes. Similarly, the PI3K/Akt pathway, triggered by MIF, supports cell survival by inhibiting apoptosis and promoting proliferation, particularly in immune and tumor cells, through the activation of downstream targets like mTOR [6]. The NF-κB pathway, another key target of MIF, is activated through the degradation of IκB, allowing NF-κB translocation to the nucleus and subsequent upregulation of genes involved in inflammation, immune regulation, and cell survival. These pathways collectively amplify MIF's pro-inflammatory effects, enabling it to orchestrate robust immune responses while also contributing to pathological inflammation in diseases such as autoimmune disorders and cancer [5, 6]. Moreover, MIF's ability to modulate these signaling cascades under stress conditions, such as oxidative stress or infection, underscores its role as a pivotal regulator of cellular homeostasis and immune activation.

In addition to its classical immune functions, MIF is involved in the regulation of redox homeostasis. It has been shown to activate the transcription factor Nrf2 (nuclear factor erythroid 2-related factor 2), thereby regulating the expression of antioxidant response genes, including glutathione reductase, superoxide dismutase, and catalase [7]. MIF modulates oxidative stress by promoting the production of reactive oxygen species (ROS) through the macrophage activation, leading to intensified oxidative damage. It also alters the antioxidant enzyme activity, such as catalase and peroxidase [8, 9]. These features make MIF an important factor in the pathogenesis of inflammatory, autoimmune, cardiovascular, and oncological diseases [10, 11]. MIF induces autophagic degeneration of endothelial cells in the vascular wall, leading to vascular exudation. MIF exhibits a dual role in autophagy, acting both as an inducer of autophagy under stress conditions, promoting cell survival by facilitating the clearance of damaged organelles, and as a contributor to autophagic cell death in pathological states, such as chronic inflammation or endothelial dysfunction [12, 13]. In stress conditions, such as oxidative stress or nutrient deprivation, MIF promotes autophagy by upregulating key autophagic proteins like LC3-II and Beclin-1, facilitating the formation of autophagosomes that clear damaged mitochondria and other organelles, thereby enhancing cell survival [13]. This protective role is evident in glioblastoma, where MIF enhances autophagy via ROCK1 activity, supporting tumor cell survival and immune evasion. Conversely, in pathological contexts, such as chronic inflammation, MIF induces excessive autophagy in endothelial cells, leading to autophagic cell death and vascular leakage [12]. This process is mediated by MIF's activation of MAPK/ERK and PI3K/Akt pathways, which, under prolonged inflammatory stress, drive overactivation of autophagy, resulting in endothelial dysfunction and tissue damage. This dual functionality underscores MIF's complex role in balancing cellular homeostasis and exacerbating disease states, particularly in conditions involving chronic inflammation or vascular pathology [12, 13]. One of its key features is its ability to activate lipid peroxidation, resulting in the accumulation of metabolites such as hydrogen peroxide (H2O2), diene conjugates (DC), and malondialdehyde (MDA). These compounds destroy cell membranes, impairing their function and intensifying inflammation [15]. At the same time, MIF weakens antioxidant systems by reducing the levels of protein surface sulfhydryl groups (PSSH) and structurally masked protein sulfhydryl groups (MPSH), and total antioxidant activity (TAA), thereby disturbing the balance between oxidative and protective processes. This imbalance is especially critical in chronic inflammation, where MIF acts as a catalyst for pathological changes [7,15]. Recent data suggest that MIF may play a dual role, simultaneously inducing inflammation and activating protective antioxidant mechanisms. In models of liver fibrosis and stem cell damage, MIF demonstrated redox activity and the ability to reduce lipid peroxidation products (LPO) [16]. Emerging evidence also points to MIF's involvement in programmed cell death mechanisms, such as parthanatos. It can interact with apoptosis-inducing factors, facilitating their translocation to the nucleus and initiation of DNA degradation [17]. This highlights MIF's potential as a target for the treatment of chronic inflammatory, metabolic, and neurodegenerative diseases [18, 19]. Despite existing data on MIF's role in the regulation of individual components of inflammation and redox homeostasis, its systemic effects on the intercon-

nected processes of cytokine response, antioxidant defense, and lipid peroxidation under controlled experimental conditions remain insufficiently studied.

This study is the first to comprehensively assess the dynamics of pro-inflammatory (TNF-α, IL-6) and anti-inflammatory (IL-10, IL-4) cytokines, antioxidant enzyme activity, and lipid peroxidation markers (MDA, DC, H_2O_2) at different time points after recombinant MIF administration in white rats. The findings reveal previously undescribed metabolic effects of MIF and broaden the understanding of its role in oxidative stress and redox imbalance.

The objective of this study is to investigate the systemic effects of MIF using an albino rat model, focusing on cytokine profiles, antioxidant system parameters, and lipid peroxidation indicators at various time points following a single administration of recombinant MIF. Importantly, this study is the first to comprehensively assess the systemic effects of recombinant MIF, highlighting its ability to induce pronounced metabolic and immune alterations.

Materials and Methods

The study was conducted on adult male outbred albino rats weighing 190–220 g, divided into a control group (Group I, $n = 20$) and three experimental groups (n = 10 each). Blood serum analyses were performed at 2 days (Group II), 3 days (Group III), and 14 days (Group IV) after MIF administration. The animals were housed in a vivarium under standard conditions at 22 ± 2.2°C, with food and water ad libitum. Experiments were conducted at the Research Center of the Azerbaijan Medical University.

The experimental groups received an intraperitoneal injection of 1 μg of recombinant MIF dissolved in 0.5 ml of physiological saline per 100 g of body weight. The control group received 0.5 mL of saline only. At 2, 3, and 14 days post-injection, blood samples were collected from each group to analyze interleukin levels (IL-6, IL-10, TNF-α, IL-4), antioxidant defense markers (PSSH, MPSH, peroxidase, catalase, TAA), and lipid peroxidation markers (H_2O_2, DC, MDA). The groups differed only in the timing of blood sampling (days 2, 3, and 14). Multiple blood collections from the same animals were not feasible because the volume required for analysis (3–4 ml) exceeded the allowable limit for repeated sampling without harm. Therefore, each animal was used once and euthanized after blood collection. Blood was collected from the abdominal aorta after euthanasia of the animals under light ether anesthesia. Each animal was used once. Euthanasia was performed following humane protocols, minimizing stress, by the approved experimental protocol.

Blood samples were analyzed using standard biochemical techniques. The concentrations of IL-6, IL-10, TNF-α, and IL-4 were determined by enzyme-linked immunosorbent assay (ELISA) using kits from Bender MedSystems (Austria) on a BioScreen MS-500 analyzer (USA). Oxidative stress in blood serum was evaluated by measuring H_2O_2 concentrations using the method of T. Asakawa and S. Matsushita [20], DC, according to I.D. Stalnaya and MDA using the method of V.P. Gavrilov et al. (1987). Antioxidant system evaluation included: catalase activity determined by M.A. Korolyuk's method (1988), the concentrations of protein surface sulfhydryl groups (PSSH) and structurally masked protein sulfhydryl groups (MPSH) were determined using Ellman's reagent [21], total antioxidant activity (TAA) assessed using the method of C. Rice-Evans et al [22], peroxidase activity determined according to the method of H.U. Bergmeyer [23].

Recombinant rat MIF (Cat. No. 228-20137, >95% purity, ProSpec) was used in all experiments and stored at −20°C as recommended by the manufacturer. The dose of recombinant MIF was selected based on data from preliminary preclinical studies demonstrating the range of its biological activity [8]. Days 2, 3, and 14 were chosen to assess the acute and delayed metabolic responses to MIF administration, as well as to identify the dynamics of its systemic effects.

All experiments were conducted in accordance with the recommendations of the European Commission on Bioethics (Strasbourg, 1986). The experimental protocol was approved by the Local Bioethics Committee of Azerbaijan Medical University (Protocol No. 239/21 AMU-BEC/2021-08) and adhered to international guidelines for the humane treatment of laboratory animals (EU Directive 2010/63/EU).

The statistical significance of the differences was calculated using Microsoft Office Excel. Both Student's *t*-test and the non-parametric Wilcoxon–Mann–Whitney U-test were applied according to modern methodological standards. A difference was considered statistically significant at $P < 0.05$ [24].

Results

The baseline levels of interleukins in the control group and their changes following MIF

administration are presented in Table 1. Significant alterations were observed post-injection.

At the early stage (day 2), IL-6 levels decreased by 2.4% ($P < 0.001$) compared to the control group, likely reflecting a compensatory suppression of inflammation. Concurrently, IL-10 levels increased by 8.03% ($P < 0.05$), indicating activation of anti-inflammatory mechanisms. By day 3, the concentrations of IL-6 and IL-10 rose by 1.2% ($P < 0.05$) and 12.7% ($P < 0.01$), respectively, compared to controls. By day 14, IL-6 showed a marked increase, suggesting the development of chronic inflammation, while IL-10 peaked, reflecting maximum anti-inflammatory activity.

The differences in IL-6 and IL-10 levels amounted to 25.8% ($P < 0.001$) and 35.2% ($P < 0.001$), respectively. IL-4 levels decreased by 7.6% on day 2, while TNF-α rose by 5.9%. On days 3 and 14, TNF-α levels continued to increase by 13.3% and 32.3%, respectively. IL-4 levels dropped by 16.5% ($P < 0.05$) and 29.9% ($P < 0.001$) on days 3 and 14, indicating a pro-inflammatory shift and macrophage activation in response to MIF.

Based on antioxidant defense markers measured in serum, MIF significantly suppressed antioxidant systems. On day 2, compared to the intact group, the average PSSH level decreased by 15.3% ($P < 0.001$), MPSH by 14.3% ($P < 0.01$), peroxidase activity by 22.3% ($P < 0.01$), catalase activity by 5.8% ($P < 0.05$), and TAA by 7.2% ($P < 0.05$) (Table 2).

By day 3, antioxidant capacity continued to decline: PSSH dropped by 21.2% ($P < 0.01$), MPSH by 20.6% ($P < 0.01$), peroxidase by 28.1% ($P < 0.01$), catalase by 12.8% ($P < 0.01$), and TAA by 16.1% ($P < 0.01$). By day 14, the depletion of antioxidant reserves became even more pronounced.

This progressive decrease across all antioxidant markers indicates an increasing level of oxidative stress induced by MIF. By day 14, antioxidant reserves were severely depleted, rendering the organism more vulnerable to oxidative damage. The drop in catalase and peroxidase activity impaired H_2O_2 neutralization, further exacerbating oxidative stress.

Lipid peroxidation markers in the serum showed a sharp increase compared to those in intact rats. On days 2, 3, and 14, average H_2O_2 concentrations were 120.9% ($P < 0.001$), 147.1% ($P < 0.001$), and 233.6% ($P < 0.001$), respectively, compared to the control. DC concentrations rose by 104.7%, 127.8%, and 279.8% ($P < 0.001$), and MDA levels by 119.3%, 197.6%, and 347.4% ($P < 0.001$), respectively.

The pronounced increase in lipid peroxidation markers indicates intense oxidative stress caused by MIF, with the highest values on day 14. H_2O_2 accu-

Table 1. Dynamics of serum interleukin levels in albino rats following MIF administration

Groups	Parameters, pg/ml			
	IL-6	IL-10	TNF-α	IL-4
I (Control)	121.97	49.96	20.12	22.43
II (Day 2)	89.76 ± 9.05***	53.97 ± 2.99*	21.32 ± 3.38	20.73 ± 2.30
III (Day 3)	123.38 ± 6,37*	56.28 ± 3.78**	22.79 ± 2.65	18.72 ± 2.85*
IV (Day 14)	153.41 ± 8.15***	67.56 ± 5.23***	26.63 ± 2.22	15.73 ± 2.79***

Note: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ compared to the control group

Table 2. Dynamics of antioxidant defense markers in albino rats serum after MIF administration

Groups	Parameters				TAA, %
	PSSH, nmol/mg	MSSH, nmol/mg	Peroxidase, mmol/l	Catalase, mmol/l	
I (Control)	30.9	21.24	11.27	248.8	39.64
II (Day 2)	26.17 ± 3.26***	18.21 ± 2.94**	8.74 ± 1.57**	234.50 ± 5.65	36.77 ± 3.04*
III (Day 3)	24.10 ± 1.71	16.87 ± 0.68	8.10 ± 0.51**	216.99 ± 6.81**	33.25 ± 4.22
IV (Day 14)	16.07 ± 2.02***	13.73 ± 2.30***	6.20 ± 1.33	183.70 ± 9.43***	28.26 ± 1.65***

Note: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ compared to the control group

Table 3. Changes in serum lipid peroxidation markers in albino rats after MIF administration

Groups	Parameters		
	H_2O_2, c.u.	DC, D232/ml	MDA, nmol/mg
I (Control)	1.95	1.38	1.06
II (Day 2)	4.31±0.36***	2.83±0.57***	2.31±0.72***
III (Day 3)	4.82±0.96***	3.15±1.35***	3.14±0.37***
IV (Day 14)	6.5±1.39***	5.25±1.35***	4.72±0.71***

Note: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ compared to the control group

mulation was likely due to suppressed catalase and peroxidase activity, while rising DC and MDA levels reflect progressive membrane damage and intensified inflammation.

Discussion

The data obtained in this study demonstrate the multi-level effects of macrophage migration inhibitory factor (MIF) on cytokine regulation, the antioxidant defense system, and lipid peroxidation (LPO) processes in white rats. The nature of the changes recorded at various observation time points indicates a pronounced pro-inflammatory and pro-oxidant action of MIF.

On day 2, we observed a significant decrease in IL-6 and a simultaneous increase in IL-10, which may reflect an early compensatory anti-inflammatory response. This observation is consistent with data from models of acute inflammation and stress, where MIF exerts early modulatory effects on cytokine release to prevent excessive immune activation [4, 26]. However, by day 3, IL-6 and TNF-α levels rose markedly, accompanied by continued elevation of IL-10. The biphasic dynamics of IL-6 suggest complex regulation of inflammatory pathways, likely involving NF-κB and MAPK signaling pathways. This shift suggests a regulatory feedback loop between pro- and anti-inflammatory mediators. The pleiotropic nature of MIF, capable of both stimulating and suppressing immune pathways depending on the cellular context, has been described in several recent reviews [2, 4, 26], and our data support this dual functionality *in vivo*.

By day 14, a significant and sustained increase in IL-6 and TNF-α, accompanied by a marked decrease in IL-4 and a persistently high level of IL-10 were observed. This pattern may reflect a transition of inflammation to a chronic phase with a continuing pro-inflammatory background and compensatory anti-inflammatory activation. This pattern reflects a polarization towards a Th1-dominant immune response, in line with literature reports indicating that MIF promotes Th1 activation while suppressing Th2 cytokines such as IL-4 and IL-13 in chronic inflammation and autoimmunity [2,8]. Notably, the sustained elevation of IL-10 suggests that MIF may also exert anti-inflammatory effects by promoting macrophage polarization toward the M2 phenotype, which is characterized by increased IL-10 production and tissue repair functions [23]. MIF has been shown to modulate macrophage polarization by interacting with CD74 and CXCR4 receptors, enhancing the expression of M2 markers such as Arg1 and CD206, which contribute to the resolution of inflammation. Additionally, MIF supports the expansion and function of T regulatory (Treg) cells, which secrete IL-10 and TGF-β, further dampening inflammatory responses and promoting immune tolerance [25]. This dual action of MIF–driving pro-inflammatory responses while simultaneously fostering anti-inflammatory mechanisms via M2 macrophages and Treg cells–underscores its complex role in immune regulation.

The decrease in IL-4, characteristic of the Th2 response, highlights a shift of the immune response toward Th1-dominant inflammation induced by MIF, which is consistent with its known role as an activator of innate immunity and TNF-α production [6, 28].

It is worth noting that following MIF administration, the concentration of TNF-α, a classical pro-inflammatory cytokine, demonstrated a consistent and progressive increase, confirming the activation of innate immune mechanisms and the intensification of inflammatory responses. Interestingly, another major pro-inflammatory cytokine, IL-6, exhibited a biphasic pattern: its level initially decreased significantly on day 2, then gradually increased, reaching a peak by day 14. Meanwhile, the anti-inflammatory cytokine IL-10 showed a stable

increase throughout the experiment, whereas IL-4 levels sharply decreased at later time points. This pattern was previously interpreted as a possible compensatory anti-inflammatory response; however, such an explanation is likely insufficient to fully characterize the observed immunological behavior. The early suppression of IL-6, despite the concurrent rise in TNF-α, may indicate selective modulation of signaling pathways, possibly involving differential activation of NF-κB or glucocorticoid-sensitive feedback mechanisms. The significant and sustained reduction in IL-4, associated with the Th2 response, suggests a shift toward a Th1-polarized immune response, one of the typical features of MIF's activity.

These observations suggest that MIF does not trigger a uniform pro-inflammatory reaction, but instead initiates a complex immune modulation characterized by early selective suppression of certain cytokines (particularly IL-6), possibly for fine-tuning the immune response, followed by sustained inflammatory activation, as reflected by elevated TNF-α and suppression of the antioxidant system. Further studies focused on early intracellular signaling events and cell-specific cytokine production are necessary to clarify this biphasic immune profile.

Biochemical data regarding oxidative stress are unequivocal: MIF administration leads to a significant reduction in antioxidant defense markers (PSH, BSSH, catalase, peroxidase, and total antioxidant activity) and a considerable increase in lipid peroxidation products (H_2O_2, DC, MDA). These findings indicate enhanced oxidative damage to lipids and disruption of redox homeostasis in the organism.

The results are important for understanding the role of MIF in the pathogenesis of inflammatory and oxidative diseases such as sepsis and atherosclerosis [9, 10]. Imbalances in cytokine levels, suppression of antioxidant defenses, and enhancement of LPO may exacerbate tissue damage during chronic inflammation. These data highlight the potential of MIF as a target for therapeutic interventions [16, 17].

The antioxidant status of animals after MIF administration showed sustained and progressive suppression of all investigated components. As early as day 2, statistically significant reductions in PSH and BSSH levels, catalase and peroxidase activity, and total antioxidant activity were observed. These impairments worsened by day 3 and reached their maximum by day 14, suggesting the development of chronic oxidative burden [16]. Against this background, a significant accumulation of LPO products – H_2O_2, diene conjugates, and malondialdehyde – was observed, indicating progressive damage to the lipid structures of cell membranes and an increase in oxidative stress. The particularly pronounced increase in MDA, a marker of the late stage of LPO and membrane destruction, is especially notable. The sharp rise in H_2O_2 levels correlates with the reduction in catalase and peroxidase activity, which are responsible for its neutralization, confirming the existence of an imbalance between reactive oxygen species (ROS) generation and elimination. These findings agree with earlier studies demonstrating that MIF promotes ROS production via mitochondrial and NADPH oxidase-dependent mechanisms, leading to cellular oxidative stress [29]. The marked elevation in MDA and suppression of catalase observed in our study closely resemble the profiles reported in models of MIF-induced tissue injury. While most of these studies focused on pathological conditions such as sepsis or autoimmune diseases, our data provide novel evidence that recombinant MIF alone, administered systemically, is sufficient to induce oxidative stress even in otherwise healthy rats [26, 29].

Thus, it can be concluded that at the early stage after MIF administration (day 2), an adaptive anti-inflammatory response occurs, involving IL-10 activation and IL-6 suppression; by day 3, the onset of an inflammatory shift and moderate inhibition of antioxidant mechanisms is observed. The late stage (day 14) can be characterized by the development of chronic inflammation, pronounced oxidative stress, membrane damage, and immune decompensation.

The obtained data are consistent with literature sources describing the ability of MIF to induce ROS production by activating macrophages and other cells of the innate immune system, as well as to inhibit antioxidant mechanisms through interactions with redox signaling pathways [14, 30]. Notably, the observed enhancement of LPO occurs in parallel with the intensification of the pro-inflammatory response, indicating the interconnected nature of MIF-induced inflammatory and oxidative processes. This combination of effects makes MIF a key target in chronic inflammatory conditions and pathological processes associated with impaired redox homeostasis.

The dual nature of MIF's action – pro-inflammatory and antioxidant-stabilizing – underscores its pathophysiological significance. Although some models describe a potential redox-regulating or even

protective role of MIF [31], in the context of this experiment, its action was associated with enhanced systemic inflammation and oxidative stress. The suppression of the antioxidant system in the context of elevated cytokine response creates a favorable environment for the chronification of inflammation and tissue damage, emphasizing the potential of MIF as a pharmacological target.

Administration of MIF induces significant metabolic changes, including shifts in interleukin profiles, suppression of antioxidant defense, and enhancement of lipid peroxidation. The results emphasize the role of MIF in the development of a pro-inflammatory and oxidative state, which is crucial for understanding its contribution to pathological processes. The data obtained confirm the involvement of MIF in disrupting redox homeostasis and promoting systemic inflammatory responses. The simultaneous suppression of protective antioxidant mechanisms and activation of lipid peroxidation suggest that MIF may act as a catalyst of metabolic imbalance, exacerbating inflammation-induced tissue damage.

Conclusion. The results demonstrate that systemic administration of MIF plays a key role in disrupting redox homeostasis, enhancing inflammation and lipid peroxidation, and suppressing antioxidant defense in rats. These findings confirm its involvement in the pathogenesis of oxidative-inflammatory conditions and indicate the potential of MIF as a therapeutic target in chronic inflammatory and metabolic diseases. Further research is needed to explore the underlying molecular mechanisms and develop strategies for modulating MIF activity.

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ПРОФІЛЬ ЗАПАЛЬНИХ ЦИТОКІНІВ ТА МАРКЕРИ ОКИСНОГО СТРЕСУ В СИРОВАТЦІ КРОВІ ЩУРІВ-АЛЬБІНОСІВ ЗА ВВЕДЕННЯ ФАКТОРУ ІНГІБУВАННЯ МІГРАЦІЇ МАКРОФАГІВ

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Фактор інгібування міграції макрофагів (MIF) це плейотропний цитокін, який бере участь у регуляції запалення, імунних реакцій та окисно-відновного гомеостазу. Однак його метаболічні ефекти в експериментальних моделях залишаються недостатньо вивченими. Метою роботи було оцінити вплив рекомбінантного MIF на профіль цитокінів, маркери антиоксидантного захисту та показники ПОЛ у різні періоди часу після його одноразового внутрішньочеревного введення щурам-альбіносам. Тварин було поділено на контрольну групу (n = 20) та три експериментальні групи (n = 10 у кожній), які оцінювали після введення MIF (10 мкг/кг маси тіла) через 2, 3 та 14 днів, відповідно. У зразках сироватки визначали рівні IL-6, IL-10, TNF-α, IL-4, антиоксидантних маркерів та продуктів ПОЛ за допомогою ELISA та стандартних біохімічних методів. Показано, що введення MIF індукувало прозапальні та прооксидантні ефекти залежно від часу. Ранні компенсаторні протизапальні відповіді характеризувалися підвищенням рівня IL-10 та зниженням рівня IL-6. Однак на пізніших стадіях (3 та 14 день) підвищення рівня IL-6 та TNF-α,

а також пригнічення IL-4 вказували на перехід до хронічного запалення. Антиоксидантні параметри поступово знижувалися, з максимальним пригніченням, що спостерігалося на 14-й день. Разом з тим, значне накопичення продуктів ПОЛ підтвердило тривалий оксидативний стрес і пошкодження мембран. Ці результати свідчать про потенціал MIF як фармакологічної мішені для лікування хронічних запальних і метаболічних порушень.

Ключові слова: фактор інгібування міграції макрофагів, інтерлейкіни, запалення, антиоксидантна система, перекисне окислення ліпідів, щури-альбіноси.

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