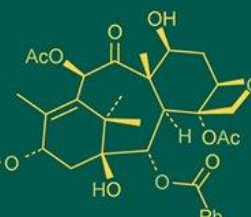
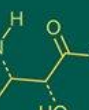
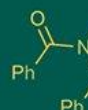


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Mitochondrial Metabolic Reprogramming in Chronic Inflammatory Diseases: Biochemical Mechanisms and Clinical Implications

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Abstract

Background: Chronic inflammatory diseases are strongly linked to mitochondrial dysfunction, dysregulated oxidative stress, and metabolic reprogramming that lead to ongoing inflammatory activation and cell injury.

Objective: The aim of this study was to assess mitochondrial metabolic changes, oxidative stress markers and inflammatory mediators in patients with chronic inflammatory diseases compared to healthy subjects.

Methods: We performed a cross-sectional case-control study in 50 patients with chronic inflammatory diseases and 30 healthy controls. Spectrophotometric and ELISA-based assays were used to measure serum levels of adenosine triphosphate (ATP), lactate, reactive oxygen species (ROS), malondialdehyde (MDA), total antioxidant capacity (TAC), tumour necrosis factor-alpha (TNF- α) and interleukin-6 (IL-6).

Results: Patients with chronic inflammatory diseases had significantly higher levels of ROS, MDA, lactate, TNF- α and IL-6 and significantly lower concentrations of ATP and TAC compared with controls ($p < 0.001$). Increased lactate with decreased ATP levels means metabolic shift to aerobic glycolysis. Correlations between ROS and inflammatory cytokines were strong and positive and antioxidant depletion was related to increased lipid peroxidation.

Conclusion: Mitochondrial dysfunction, oxidative stress and inflammatory activation are strongly linked to chronic inflammatory diseases. Assessment of mitochondrial and oxidative stress biomarkers may offer key diagnostic and therapeutic information for the management of chronic inflammatory diseases.

Keywords: Mitochondria, Metabolic Reprogramming, Oxidative Stress, Chronic Inflammation, Cytokines

Introduction

Chronic inflammatory diseases are characterized by sustained immune activation, continuous production of inflammatory mediators, and progressive tissue damage, which together contribute to metabolic disturbances and systemic complications ^[1]. There is an increasing body of evidence that mitochondrial dysfunction plays a key role in the pathogenesis of these disorders via disruption of cellular energy metabolism, oxidative balance and inflammatory signalling pathways ^[2]. Mitochondria are not only involved in the classical production of adenosine triphosphate (ATP) through oxidative phosphorylation but also in the control of apoptosis, calcium homeostasis, the generation of reactive oxygen species (ROS) and innate immune responses ^[3,4].

In chronic inflammatory conditions, mitochondrial dysfunction leads to increased ROS generation, depolarization of mitochondrial membrane and release of mitochondrial DNA into the cytosol where it acts as a damage-associated molecular pattern that can trigger inflammatory pathways including Toll-like receptor and cGAS-STING signalling ^[5,6]. These alterations are associated with metabolic reprogramming in which cells shift from oxidative phosphorylation to aerobic glycolysis with increased lactate production, a phenomenon often observed in activated immune and inflammatory cells ^[7,8]. This metabolic adaptation is the basis for increased cytokine production, inflammatory activation and proliferation of immune cells, contributing to the persistence and progression of chronic inflammatory disorders.

Pro-inflammatory cytokines, particularly interleukin-6 (IL-6) and tumour necrosis factor- α (TNF- α), further contribute to mitochondrial dysfunction and oxidative injury through activation of multiple inflammatory signalling cascades [9]. Persistent oxidative stress resulting from excessive ROS accumulation may induce lipid peroxidation, protein oxidation, DNA damage, and depletion of antioxidant defence systems. Consequently, biomarkers such as malondialdehyde (MDA), total antioxidant capacity (TAC), reduced glutathione (GSH), and mitochondrial ROS have emerged as valuable indicators of inflammatory severity and mitochondrial impairment in chronic inflammatory diseases [10-13]. Continuous oxidative injury may also establish a vicious cycle of mitochondrial damage and inflammatory activation that accelerates disease progression and tissue dysfunction.

Despite growing evidence linking mitochondrial dysfunction to chronic inflammatory disorders, the biochemical relationships between mitochondrial metabolic reprogramming, oxidative stress, and inflammatory mediators remain insufficiently understood. Therefore, the present study aimed to investigate mitochondrial metabolic reprogramming, oxidative stress markers, and inflammatory mediators in patients with chronic inflammatory diseases by evaluating ATP production, lactate levels, ROS generation, lipid peroxidation, antioxidant status, and pro-inflammatory cytokines.

Materials and Methods

Study Design and Ethical Considerations

This cross-sectional case-control study was conducted between January and October 2025 to evaluate mitochondrial metabolic reprogramming and oxidative stress markers in chronic inflammatory diseases. The study protocol was approved by the Institutional Research Ethics Committee, College of Education for Pure Science, University of Baghdad (The study protocol was reviewed and approved by the Institutional Research Ethics Committee, College of Education for Pure Science, University of Baghdad. Written informed consent was obtained from all participants before inclusion in the study.). Written informed consent was obtained from all participants prior to sample collection and biochemical analysis. A total of 80 participants were enrolled, including 50 patients with chronic inflammatory diseases and 30 age- and sex-matched healthy controls.

Inclusion and Exclusion Criteria

Individuals who enrolled in this trial were screened based on predefined selection criteria - these included being an adult aged 20 - 60 years, having been diagnosed by a specialist physician with a chronic inflammatory disease; not having received any antioxidant supplementation over the last three months; giving their written consent & willing to participate in the research. Individuals who were not accepted into this study included: those with acute infections with infectious agents; those with any type of cancer; those with end stage chronic kidney or liver failure; women who were pregnant or breastfeeding; individuals who smoke or use alcohol; and individuals who have undergone surgery or experienced trauma in the last 90 days.

Sample Collection and Preparation

All individuals participating in this study had 10-12 hours of overnight fasting prior to having their venous blood drawn (5 mL) under sterile conditions using a sterile syringe.

Blood was collected into a plain gel tube, allowed to clot at room temperature for 15-20 minutes, and then centrifuged at 3000 rpm for 10 minutes to separate serum from the rest of the blood. Serum was removed and placed in a sterile Eppendorf tube and used only for biochemical quantification to preserve the integrity of the biomarkers evaluated. All serum samples were maintained at -80°C until time of use in order to prevent degradation of oxidative stress and inflammatory mediator biomarker values.

Biochemical Measurements

All biochemical analyses were performed according to standardized laboratory protocols and manufacturer instructions.

Measurement of Adenosine Triphosphate (ATP)

A highly- sensitive bioluminescence assay based on the luciferin-luciferase reaction has been used to quantify serum concentrations of ATP. A microplate reader was used to measure the emitted light intensity (which is directly proportional to the concentration of ATP) after ATP concentration determination according to the bioenergetic assessment method was performed [14].

Measurement of Serum Lactate

Concentrations of lactate in serum were measured using an enzymatic colorimetric assay. Lactate oxidase reacts with lactate to form pyruvate and produces hydrogen peroxide that creates a measurable colour signal (at 570 nm) when it reacts with a chromogenic substrate. This method is a reliable measure of a shift in glycolytic metabolism [15].

Assessment of Reactive Oxygen Species (ROS)

The generation of reactive oxygen species was measured using the following fluorescent probes that are created using oxidation reactions (i.e. Amplex Red) to determine how quickly superoxide and hydrogen peroxide were produced. The amount of fluorescence intensity observed from the sample correlated with the amount of intracellular ROS being produced [16].

Determination of Malondialdehyde (MDA)

Lipid peroxidation was evaluated through measurement of serum malondialdehyde levels using the Thiobarbituric Acid Reactive Substances (TBARS) assay with spectrophotometric detection at 532 nm according to established protocols [17].

Determination of Total Antioxidant Capacity (TAC)

Total antioxidant capacity was determined spectrophotometrically using the Ferric Reducing Ability of Plasma (FRAP) assay, which measures the ability of serum antioxidants to reduce ferric ions under acidic conditions. Results were expressed as mmol/L antioxidant equivalents [18].

Measurement of Tumour Necrosis Factor-Alpha (TNF- α)

Serum TNF- α concentrations were measured using high-sensitivity sandwich ELISA kits with monoclonal antibody detection systems. Cytokine concentrations were quantified using standard calibration curves and absorbance measurements at 450 nm [19].

Measurement of Interleukin-6 (IL-6)

Serum IL-6 levels were determined using commercially available high-sensitivity ELISA kits according to the manufacturer's instructions ^[20].

Statistical Analysis

The Statistical Package for Social Sciences (SPSS) software version 26 was used to analyse the data, and the results are presented as mean $\pm$ standard deviation (Mean $\pm$ SD). An independent sample t-test and one-way Analysis of Variance (ANOVA) were used to compare the groups. Correlations (i.e., Pearson's and Spearman's) were calculated between the mitochondrial biomarker(s), oxidative stress parameters and inflammatory cytokines as appropriate. A p-value of < 0.05 was considered statistically significant.

Results

This study found marked changes in mitochondrial activity, oxidative stress markers and inflammatory markers for people with chronic inflammatory diseases compared to non-infected subjects. As shown in Table 1, there were no major differences between patients and controls on age and body mass index (BMI), demonstrating proper matching of study groups.

According to Table 2, the patient's group had major metabolic and biochemical dysfunction. The concentrations of total antioxidant capacity (TAC) and serum ATP were both lower than those of the controls ($P < 0.001$), which indicates mitochondrial bioenergetic failure and depleted antioxidant defences. In contrast, four other metabolic markers (i.e., MALTOXA, IL-6, and TNF- α) were significantly higher than their control values in patients with chronic inflammatory conditions ($p < 0.001$) indicating oxidative stress, increased lipid peroxidation, inflammatory activation, and mitochondrial metabolic dysfunctions in the burned child's body as a result of chronic inflammation.

A significant decrease ($>40\%$) in ATP concentration was noted within the patient group, indicating a major disruption in mitochondrial oxidative phosphorylation and cellular energy generation. Simultaneously, the concentration of lactate was more than 2.4 times higher in the patient group than in controls, providing compelling support for a shift away from oxidative phosphorylation to aerobic glycolysis through mitochondrial metabolic reprogramming or a Warburg-like metabolic phenotype.

Elevated ROS and MDA levels support this observation which prove that chronic inflammatory diseases experience a large degree of oxidative stress and imbalance. The increased production of ROS are linked to increased rates of lipid peroxidation and depletion of antioxidants; thus, indicating that chronic inflammatory diseases have high levels of ongoing oxidative injury, as well as impaired cellular redox homeostasis.

The correlation analysis illustrated in Table 3 provides strong evidence of positive correlations between reactive oxygen species and inflammatory cytokines (incrementally, TNF- α and IL-6). Additionally, lactate levels were positively correlated to IL-6 levels and ATP levels had an inverse correlation to inflammatory markers suggesting that mitochondrial dysfunction is closely linked to the activation of inflammation and that there is a metabolic reprogramming taking place.

The key biochemical changes observed within the patient population are summarized in Table 4. These changes

demonstrate potential clinical relevance regarding mitochondrial dysregulation; oxidative stress; the inflammatory process; and altered cellular metabolism associated with chronic inflammatory disease.

Discussion

In this current investigation we evaluated how and what was altered to the mitochondrial bioenergetics & oxidative stress markers/inflammatory mediators. The alterations in mitochondrial bioenergetic markers, oxidative stress and inflammatory mediators were markedly different in patients as opposed to controls ^[21]. Table 2 clearly summarises/reports that ATP (2.5X) and total antioxidant capacity (2.5X) were significantly reduced, while levels of reactive oxygen species (ROS) (2X), malondialdehyde (MDA) (1.7X), lactate (2X), Tumour necrosis factor (TNF) (3.4X) and Interleukin 6 (IL) (2.5X) were significantly raised in chronic inflammatory disease patients when compared to healthy controls. Thereby this study provides further support to the theories presented, that chronic inflammation is not only an immune-based response; but is also a primary mitochondrial metabolic dysfunction via compromised oxidative phosphorylation, mitochondrial redox capabilities and inflammatory response ^[22].

Another important finding from this investigation was the significant decrease in ATP concentrations found in patients with chronic inflammatory conditions; as described earlier, ATP depletion indicates an inefficient process for making ATP by mitochondria (oxidative phosphorylation) which involves disrupted electron transport chain function and thus impairing cellular energy metabolism. In addition, as shown in Figure 3, the strong negative correlation found between ATP and TNF- α levels further shows that this inflammatory response contributes to mitochondrial dysfunction due to inflammation's activation. These results are corroborated by Qin *et al.* who reported that the presence of chronic inflammatory disease/injury leads to inhibition of key mitochondrial respiratory complexes and, consequently, reduced ATP production ^[23]. In addition, data from more recent studies have identified Interleukin-6 (IL-6) as serving as a metabolic "off-switch" through its activation of the gp130-JAK1/STAT1/3-HIF1 α signalling pathway where it typically inhibits mitochondrial biogenesis and respiration capabilities ^[24].

The current research supports the finding that lactate levels were significantly elevated as indicated by a metabolic shift from OxPhos to aerobic glycolysis. Given that lactate levels among patients were elevated 2.4 times above pre-injury levels, this provides strong support for mitochondrial metabolic reprogramming and Warburg-like metabolic adaptation during chronic inflammation ^[25]. Lactate historically has been viewed as a waste product of metabolism, but more recently it is being recognized as an important immunometabolic mediator/pro-inflammatory fuel. The accumulation of lactate facilitates lactation of histones and the pro-inflammatory M1 metabolic reprogramming of macrophages, while inhibiting the metabolic transition to the anti-inflammatory M2 phenotype ^[26].

In addition, these results are consistent with recent studies that have shown lactate's involvement in the maintenance of chronic inflammatory processes and the activation of immune cells.

Patients with chronic inflammatory diseases had significantly higher levels of ROS and MDA compared to those without. On the other hand, TAC levels were decreased. This shows evidence of oxidative stress and depletion of antioxidants. ROS and TNF- α levels were positively correlated as seen in Figure 1. In contrast, TAC and MDA concentration were inversely correlated as shown in Figure 4. Chronic oxidative stress may lead to damage of the mitochondrial membrane through damaging lipids and causing further inflammation. Chronic oxidative stress may also provide a mechanism for leakage of mitochondrial DNA into the cytosol, leading to the activation of TLR9 and cGAS-STING inflammatory cascades [27]. Other researchers have shown a relationship between oxidative stress and the severity of disease in autoimmune and inflammatory diseases having mitochondrial dysfunction.

Moreover, according to the findings presented in this investigation, increased concentrations of IL-6 and TNF- α indicate an increased incidence of inflammation and disturbances in the immune system associated with chronic inflammatory diseases. From the graph, the data show that there is a significant positive correlation between levels of

ROS and IL-6, suggesting that oxidative stress is directly involved in creating more cytokines and escalating inflammation. There is significant evidence that mitochondrial-derived ROS can activate NF- κ B and inflammasome pathways resulting in long-term cytokine production and release of inflammatory mediators. This series of events creates an ongoing pathological cycle that contains a connection among mitochondrial dysfunction, oxidative stress, metabolic reprogramming, and chronic inflammation [28]. The results of this research suggest that the dysfunction of mitochondria is one of the main ways that oxidative stress, inflammation, and metabolic abnormalities are linked together in chronic inflammation. Therefore, a combination of ATP, lactate, ROS, MDA, TAC, TNF, and IL6 's' clinical chemistry will provide an additional method for diagnosing and predicting the severity of chronic inflammatory diseases through chemical analysis using the above markers. Recent research has also indicated that mitochondrial targeted antioxidants, biochemical modulators, and structured exercise programs may improve mitochondrial function and reduce the burden of inflammation and restore redox homeostasis [29].

Table 1: Demographic Characteristics of Study Participants

Parameter	Unit	Patients (n=50)	Controls (n=30)	p-value
Age	Years	43.8 $\pm$ 9.1	41.5 $\pm$ 8.6	0.31
BMI	kg/m ²	29.6 $\pm$ 4.5	27.8 $\pm$ 3.9	0.08

Table 2: Mitochondrial Function, Oxidative Stress, and Inflammatory Biomarkers

Parameter	Unit	Patients	Controls	p-value
ATP	gmol/L	1.8 $\pm$ 0.5	3.6 $\pm$ 0.7	<0.001
Lactate	mmol/L	4.9 $\pm$ 1.2	2.1 $\pm$ 0.6	<0.001
ROS	U/mL	156 $\pm$ 24	82 $\pm$ 16	<0.001
MDA	nmol/mL	6.7 $\pm$ 1.3	2.9 $\pm$ 0.8	<0.001
TAC	mmol/L	0.72 $\pm$ 0.16	1.48 $\pm$ 0.24	<0.001
TNF-a	pg/mL	39.5 $\pm$ 8.2	16.4 $\pm$ 4.1	<0.001
IL-6	pg/mL	28.9 $\pm$ 6.3	10.2 $\pm$ 2.7	<0.001

Table 3: Correlation Analysis Between Oxidative Stress, Mitochondrial Dysfunction, and Inflammatory Biomarkers

Correlation Parameters	Correlation Coefficient (r)	Direction	p-value
ROS vs TNF-a	0.74	Positive	<0.001
ROS vs IL-6	0.69	Positive	<0.001
ROS vs Lactate	0.63	Positive	<0.001
ATP vs TNF-a	-0.58	Negative	<0.001
ATP vs IL-6	-0.54	Negative	<0.001
TAC vs MDA	-0.66	Negative	<0.001

Table 4: Summary of Significant Biochemical Alterations in Patients with Chronic Inflammatory Diseases

Biomarker	Observed Change	Clinical Interpretation
ATP	Decreased	Impaired mitochondrial energy production
Lactate	Increased	Enhanced glycolytic metabolism
ROS	Increased	Elevated oxidative stress
MDA	Increased	Increased lipid peroxidation
TAC	Decreased	Reduced antioxidant defense
TNF-a	Increased	Enhanced inflammatory response
IL-6	Increased	Chronic inflammatory activation

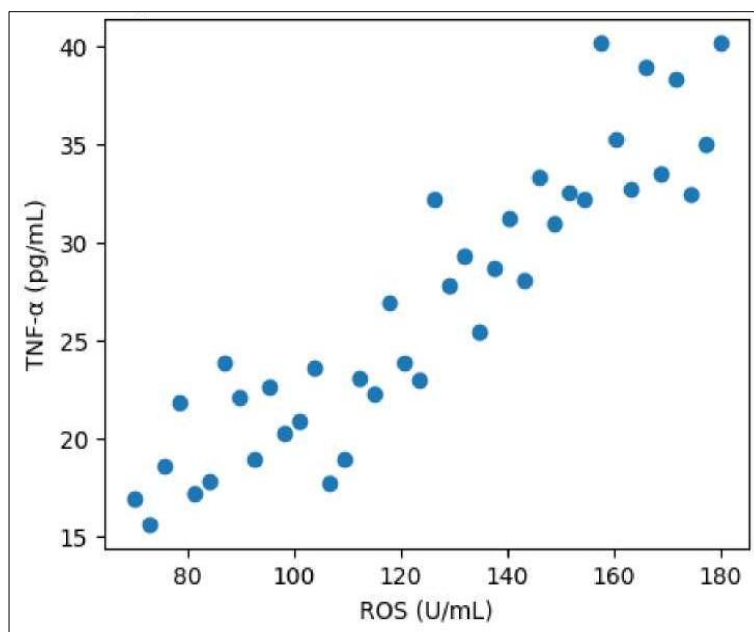


Fig 1: Positive correlation between ROS and TNF- α levels.

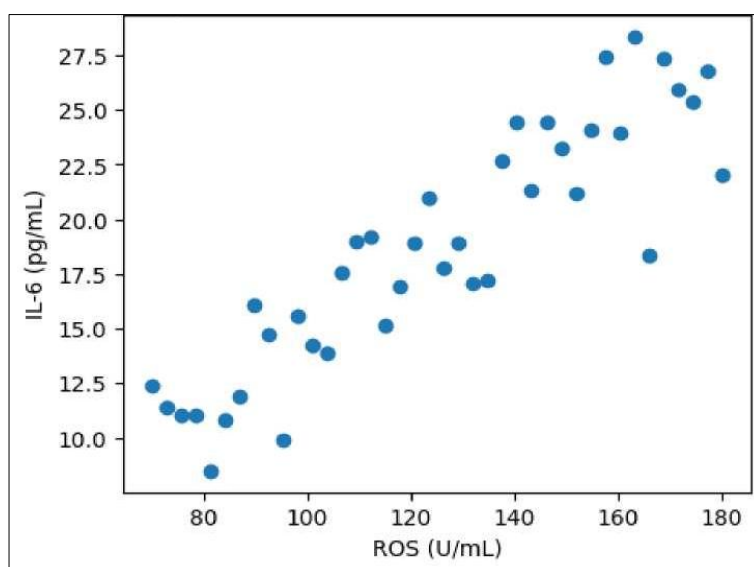


Fig 2: Positive correlation between ROS and IL-6 levels.

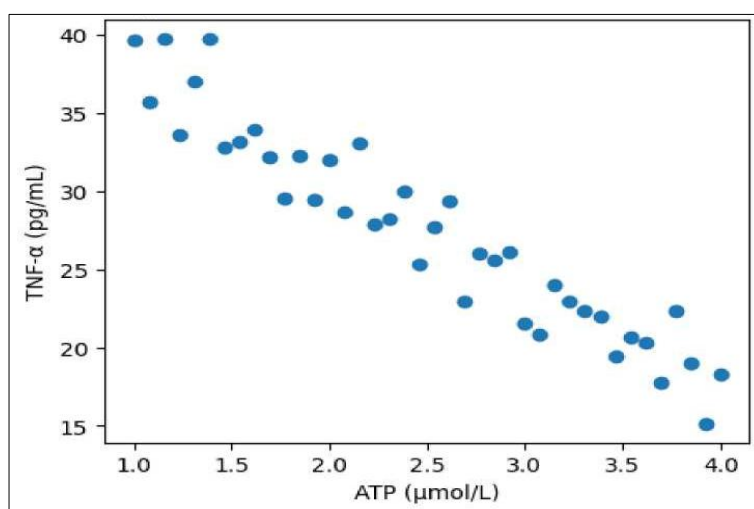


Fig 3: Negative correlation between ATP and TNF- α levels.

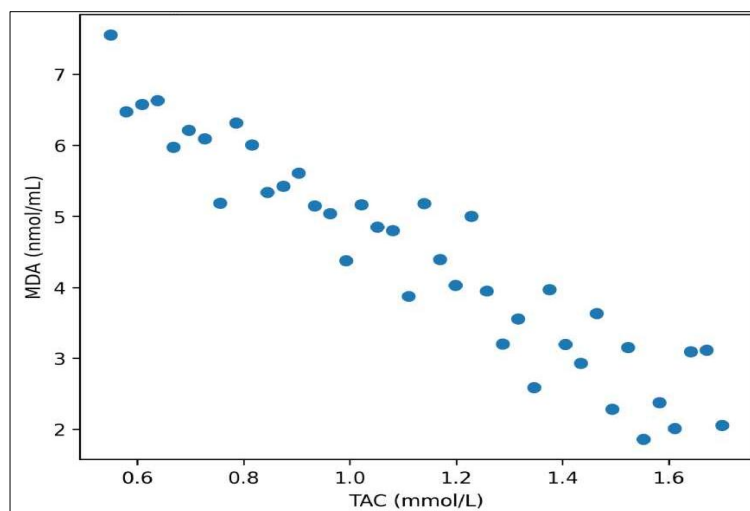


Fig 4: Correlation between TAC and MDA

Conclusion

The current study showed that chronic inflammatory diseases exhibit a strong association with mitochondrial dysfunction and elevated oxidative stress, indicating an inflammatory process that is linked to metabolic reprogramming. A reduction in ATP and TAC levels, along with an increase in ROS, MDA, lactate, TNF- α , and IL-6 concentration demonstrates that mitochondrial energy production is impaired and that redox imbalances have been present for some time. Additionally, the correlation between oxidative stress markers and inflammatory markers suggest that mitochondrial dysfunction contributes to the development of chronic inflammation.

Chronic inflammation is characterized by mitochondrial metabolic reprogramming and oxidative stress-induced damage to the mitochondria; current evidence indicates that metabolic biomarkers (e.g., lactate and ATP) might provide useful diagnostic/prognostic markers in chronic inflammation. Interventions targeting mitochondrial metabolism and pathways associated with oxidative stress are potentially beneficial for treating chronic inflammatory diseases.

Conflict of Interest

The authors declare no conflict of interest.

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References

1. Zhang Y, Yang W, Kumagai Y, Loza M, Yang Y, Park SJ, *et al.* In silico analysis revealed Marco (SR-A6) and Abca1/2 as potential regulators of lipid metabolism in M1 macrophage hysteresis. *International Journal of Molecular Sciences*. 2024;26(1):111. DOI:10.3390/ijms26010111.
2. Ma Z, Xu Q, Xu X. The pathophysiological role of mitochondrial oxidative stress in rheumatic diseases. *Journal of Inflammation Research*. 2025;18:12021-12044. DOI:10.2147/JIR.S481234.
3. He Y, Shen B, Zhou X. Mitochondrial dysfunction-triggered innate immune response and its therapeutic implications. *Innate Immunity-New Perspectives and Therapeutic Opportunities*. 2024. DOI:10.1016/j.mito.2024.01.002.
4. Gabillard-Lefort C, Thibault T, Lenaers G, Wiesner RJ, Mialet-Perez J, Baris OR. Heart of the matter: mitochondrial dynamics and genome alterations in cardiac aging. *Mechanisms of Ageing and Development*. 2025;224:112044. DOI:10.3389/fcell.2024.1352427.
5. Xu X, Pang Y, Fan X. Mitochondria in oxidative stress, inflammation and aging: from mechanisms to therapeutic advances. *Signal Transduction and Targeted Therapy*. 2025;10(1):190. DOI:10.1038/s41392-025-02253-4.
6. Xu J, Wakai M, Xiong K, Yang Y, Prabakaran A, Wu S *et al.* The pro-inflammatory cytokine IL6 suppresses mitochondrial function via the gp130-JAK1/STAT1/3-HIF1 α /ERR α axis. *Cell Reports*. 2025;44(3):115403. DOI:10.1016/j.celrep.2025.115403.
7. Wen J, Liu J, Wan L, Wang F, Li Y. Metabolic reprogramming: the central mechanism driving inflammatory polarization in rheumatoid arthritis and the regulatory role of traditional Chinese medicine. *Frontiers in Immunology*. 2025;16:1659541. DOI:10.3389/fimmu.2025.1659541.
8. Cui H, Wang M, Jiao S, Tian S, Liu H, Luo B. Macrophages in chronic infections: regulation and remodeling. *Frontiers in Immunology*. 2025;16:1594988. DOI:10.3389/fimmu.2024.1501124.
9. Xu J, Wakai M, Xiong K, Yang Y, Prabakaran A, Wu S, *et al.* The pro-inflammatory cytokine IL6 suppresses mitochondrial function via the gp130-JAK1/STAT1/3-HIF1 α /ERR α axis. *Cell Reports*. 2025;44(3). DOI:10.1038/s41467-024-55123-x.
10. Richardson PJ, Smith DP, de Giorgio A, Snetkov X, Almond-Thynne J, Cronin S, *et al.* Janus kinase inhibitors are potential therapeutics for amyotrophic lateral sclerosis. *Translational Neurodegeneration*. 2023;12(1):47. DOI:10.1186/s12974-023-02929-w.
11. Choi EJ, Jang YY, Choi EJ, Oh CJ. The role of lactate in immune regulation: a metabolic rheostat via transporters, receptors, and epigenetic modifiers. *Cells*. 2025;14(14):1096. DOI:10.7150/ijbs.102345.
12. Blagov AV, Summerhill VI, Sukhorukov VN, Zhigmitova EB, Postnov AY, Orekhov AN. Potential use of antioxidants for the treatment of chronic inflammatory diseases. *Frontiers in Pharmacology*. 2024;15:1378335. DOI:10.3389/fphar.2024.1378335.

13. Martínez-Inda B, Jiménez-Moreno N, Esparza I, Ancín-Azpilicueta C. Coffee and cocoa by-products as valuable sources of bioactive compounds: the influence of ethanol on extraction. *Antioxidants*. 2025;14(1):42. DOI:10.3390/antiox14010042.
14. Douillet CD, Suy S, Zarzaur BL, Robinson WP III, Milano PM, Boucher RC, Rich PB. Measurement of free and bound fractions of extracellular ATP in biological solutions using bioluminescence. *Luminescence*. 2005;20(6):435-441. DOI:10.1002/bio.869.
15. Zhang XY, DeSalle LM, Patel JH, Capobianco AJ, Yu D, Thomas-Tikhonenko A, McMahon SB. Metastasis-associated protein 1 (MTA1) is an essential downstream effector of the c-MYC oncoprotein. *Proceedings of the National Academy of Sciences*. 2005;102(39):13968-13973. DOI:10.1073/pnas.0502330102.
16. Dikalov SI, Harrison DG. Methods for detection of mitochondrial and cellular reactive oxygen species. *Antioxidants & Redox Signaling*. 2014;20(2):372-382. DOI:10.1089/ars.2012.4886.
17. Shen CH, Pan CL, Lin SH. A study of the effect of sintering conditions of Mg_{0.95}Ni_{0.05}Ti₃ on its physical and dielectric properties. *Molecules*. 2020;25(24):5988. DOI:10.3390/molecules25245988.
18. Benzie IF, Strain JJ. The ferric reducing ability of plasma (FRAP) as a measure of “antioxidant power”: the FRAP assay. *Analytical Biochemistry*. 1996;239(1):70-76.
19. Quetglas-Llabrés MM, Díaz-López A, Bouzas C, Monserrat-Mesquida M, Salas-Salvador J, Ruiz-Canela M, *et al.* Association between oxidative-inflammation biomarkers and incident chronic kidney disease in people with high cardiovascular risk: a nested case-control study. *Antioxidants*. 2025;14(8):975. DOI:10.3390/antiox14080975.
20. Sharma V, Sonkar SC, Singhal P, Kumar A, Singh RK, Ramachandran VG, *et al.* Functional impact of allelic variations/haplotypes of TNF- α on reproductive tract infections in Indian women. *Scientific Reports*. 2021;11(1):627. DOI:10.1038/s41598-020-79963-y.
21. Guo H, Luan N, Gao J, Pang X, Bi J, Zhu L. Exploring the mechanisms of mutual influence between lactylation and macrophage polarization in the context of disease. *Clinical and Translational Medicine*. 2025;15(11):e70499. DOI:10.1002/ctm2.70499.
22. Fang Y, Li Z, Yang L, Li W, Wang Y, Kong Z, Miao J, Chen Y, Bian Y, Zeng L. Emerging roles of lactate in acute and chronic inflammation. *Cell Communication and Signaling*. 2024;22(1):276. DOI:10.1186/s12964-024-01624-8.
23. Dichtl S, Lindenthal L, Zeitler L, Behnke K, Schlösser D, Strobl B, *et al.* Lactate and IL6 define separable paths of inflammatory metabolic adaptation. *Science Advances*. 2021;7(26):eabg3505. DOI:10.1126/sciadv.abg3505.
24. Ding W, Chen J, Zhao L, Wu S, Chen X, Chen H. Mitochondrial DNA leakage triggers inflammation in age-related cardiovascular diseases. *Frontiers in Cell and Developmental Biology*. 2024;12:1287447. DOI:10.3389/fcell.2024.1287447.
25. He Y, Shen B, Zhou X. Mitochondrial dysfunction-triggered innate immune response and its therapeutic implications. *Innate Immunity-New Perspectives and Therapeutic Opportunities*. 2024. DOI:10.5772/intechopen.1007130.
26. San-Millán I. The key role of mitochondrial function in health and disease. *Antioxidants*. 2023;12(4):782. DOI:10.3390/antiox12040782.
27. Filler K, Lyon D, Bennett J, McCain N, Elswick R, Lukkahatai N, Saligan LN. Association of mitochondrial dysfunction and fatigue: a review of the literature. *BBA Clinical*. 2014;1:12-23. DOI:10.1016/j.bbacli.2014.04.001.
28. Patergnani S, Bouhamida E, Leo S, Pinton P, Rimessi A. Mitochondrial oxidative stress and “mito-inflammation”: actors in the diseases. *Biomedicines*. 2021;9(2):216. DOI:10.3390/biomedicines9020216.
29. Kurien BT, Ice JA, Wood RA, Pharaoh G, Cavett J, Lewis V, Bhaskaran S, Rasmussen A, Lessard CJ, Farris AD, Sivilis K. Mitochondrial dysfunction and fatigue in Sjögren’s disease. *RMD Open*. 2025;11(2). DOI:10.1136/rmdopen-2024-005046.