FULL LENGTH | Iranian Biomedical Journal 30 (1): 91-97 January 2026

# Effect of HIF-1α and LDHA Blockade on Gene Expression of Tumor Immune Evasion in Myeloid Leukemia Cell Lines

Tamana Eskandari[1], Mehrshad Shams[2], Ali Khanari[2], Amir Kahrizi[2], Hossein Asgarian-Omran[2,3], Reza Valadan[2,4], Mohsen Tehrani[2,4], Saeid Taghiloo[2,4,5*]

[1]Department of Immunology, School of Medicine, Semnan University of Medical Sciences, Semnan, Iran; [2]Department of Immunology, School of Medicine, Mazandaran University of Medical Sciences, Sari, Iran; [3]Gastrointestinal Cancer Research Center, Mazandaran University of Medical Sciences, Sari, Iran; [4]Molecular and Cell-Biology Research Center, Mazandaran University of Medical Sciences, Sari, Iran; [5]Thalassemia Research Center, Hemoglobinophaty Institute, Mazandaran University of Medical Sciences, Sari, Iran

**OPEN ACCESS**

**Article type:** Research Article
**Received:** November 4, 2025
**Revised:** December 17, 2025
**Accepted:** December 24, 2025
**Published online:** December 27, 2025

**How to cite:**
Eskandari T, Shams M, Khanari A, Kahrizi A, Asgarian-Omran H, Valadan R, Tehrani M, Taghiloo S. Effect of HIF-1α and LDHA Blockade on Gene Expression of Tumor Immune Evasion in Myeloid Leukemia Cell Lines. *Iran. Biomed. J.* 2025; 30(1): 91-97.

This article is licensed under a Creative Commons Attribution-NonDerivatives 4.0 International License.

**ABSTRACT**

**Background:** Tumor cells utilize metabolic reprogramming to obtain the energy required for rapid proliferation. In this study, we blocked two key factors, hypoxia-inducible factor 1-alpha (HIF-1α) and lactate dehydrogenase (LDHA), in the metabolic pathway in acute myeloid leukemia (AML) cell lines to evaluate their effect on the expression of genes involved in tumor evasion.
**Methods**: Silibinin and sodium oxamate, as *HIF-1α* and *LDHA* blockers, respectively, were used to treat K-562 and HL-60 cells. The MTT assay was used to assess cell viability, and quantitative reverse transcription PCR was used to measure the mRNA expression levels of *PD-L1*, *CD47*, and *CD155*.
**Results:** Both K-562 and HL-60 cells showed a significant decrease in *CD47* expression. Additionally, HL-60 cells indicated a significant suppression of *CD155* expression. In contrast, *PD-L1* expression remained unchanged after treatment.
**Conclusion**: Our findings suggest that blocking signaling pathways involved in metabolic reprogramming of cancer cells could be a promising approach for modulating the expression of certain immune checkpoint ligands, warranting further investigation. ***DOI: 10.61882/ibj.5324***

*Keywords:* Acute myeloid leukemia, Hypoxia, Lactates, Warburg effect

**Corresponding Author:** Saeid Taghiloo
Department of Immunology, Faculty of Medicine, Mazandaran University of Medical Sciences, Sari, Iran; Tel.: (+98-11) 33543081; Fax: (+98-11) 33543249; E-mail: saeid.taghiloo@yahoo.com, s.taghilo@mazums.ac.ir; ORCID ID: 0000-0002-8813-6046

## 1. INTRODUCTION

Acute myeloid leukemia (AML) is a type of blood cancer characterized by the rapid proliferation of immature myeloid cells, leading to the production of cancerous blood cells[1]. Despite treatment advances, relapse is common due to the ability of leukemic cells to escape immune surveillance, a process facilitated by complex interactions with the tumor micro-environment[2].

In normal cells, glucose first enters the cell, undergoes glycolysis, and is converted to pyruvate. This pyruvate then enters the mitochondria, where it undergoes the Krebs cycle and oxidative phosphorylation to produce acetyl-CoA and generate energy for the cell[3]. However, the metabolic processes in cancer cells differ significantly from those in normal cells. These variations allow tumor cells to escape the immune system, promote metastasis, and develop resistance to anticancer drugs. The Warburg effect, or aerobic glycolysis, is one of the major metabolic adaptations observed in cancer cells. Cancer cells rely on glycolysis to produce energy, even in hypoxic conditions. These metabolic alterations lead to rapid ATP production and the adoption of an acidic microenvironment within the tumor, thus resulting in the invasiveness of cancer cells[4].



[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]
[ DOI: 10.61882/ibj.5324 ]

Metabolic reprogramming is a hallmark of cancer cells that allows for their survival under hypoxia. The hypoxia-inducible factor 1-alpha (HIF-1α) pathway is central to this adaptation, as it upregulates anaerobic glycolysis-related genes, including lactate dehydrogenase A (LDHA), to stimulate the Warburg effect[5]. During glycolysis, pyruvate is converted to lactate by the enzyme lactate dehydrogenase and bypasses the Krebs cycle. Enhanced LDHA activity leads to lactate accumulation and acidification of the tumor microenvironment, which further enhances immune evasion[3,4]. HIF-1α and LDHA have also been shown to regulate immune checkpoint receptors (ICRs), which not only affect immune cell metabolism but also promote immune escape.

*CD47*, an "don't eat me" signal that is overexpressed in AML, blocks macrophage phagocytosis and is associated with poor prognosis[6-9]. Similarly, *PD-L1* inhibits T-cell response through its interaction with the *PD-1* co-receptor, promoting immune tolerance[10]. Another mechanism of evasion involves the *CD155* axis, which is part of the TIGIT/DNAM-1 pathway that regulates natural killer and T-cell responses[11,12]. Increasing evidence highlights the interplay between HIF-1α/LDHA and ICRs, with hypoxia and lactate accumulation leading to the upregulation of *CD47* and *PD-L1*. In contrast, the effect of metabolic stress on *CD155* expression appears to be more variable and context-dependent, suggesting a distinct regulatory mechanism[8,13-19].

In this study, we hypothesized that targeting HIF-1α and LDHA could impair metabolic adaptation and immune evasion in AML. We used silibinin, a natural flavonoid known for its antitumor activity by modulating metabolic pathways[20], and sodium oxamate, an LDHA blocker, which inhibits glycolysis[21]. Both sodium oxamate and silibinin block HIF-1α stabilization and LDHA activity, rewire glycolytic flux, and promote apoptosis in leukemic cells[22,23]. Our findings showed the effects of blocking HIF-1α and LDHA with the above-mentioned two agents on the expression of *CD47*, *CD155,* and *PD-L1*, providing preliminary evidence that metabolic reprogramming may influence the expression of immune checkpoint ligands. These results reveal that this therapeutic strategy could improve the immunogenicity of AML and help overcome resistance to anticancer treatments.

## 2. MATERIALS AND METHODS

### 2.1. Cell lines and reagents

K-562, a chronic myeloid leukemia cell line in blast crisis, and the HL-60, an AML cell line, were obtained from the Pasteur Institute of Iran (Tehran). The HIF-1α inhibitor, silibinin (Sigma-Aldrich, USA), was dissolved in dimethyl sulfoxide (DMSO), aliquoted, and kept at -18°C. The LDHA inhibitor, sodium oxamate (Santa Cruz Biotechnology, USA), was prepared by dissolving it in distilled water, with all working solutions being made fresh immediately before use.

### 2.2. Cell culture and treatment

K562 and HL-60 cell lines were cultured in RPMI-1640 medium, supplemented with 10% heat-inactivated fetal bovine serum, 100 U/mL penicillin, and 100 µg/mL streptomycin. The cells were maintained under standard conditions in a humidified atmosphere of 5% $CO_2$ at 37°C. The half-maximal inhibitory concentration ($IC_{50}$) values were determined on K-562 and HL-60 in our previous study[24]. For subsequent experiments, cells were seeded in six-well plates at a density of $5 \times 10^5$ cells per well and treated with their respective $IC_{50}$ concentrations of either silibinin or sodium oxamate for 48 hours. Under these treatment conditions, cell viability was assessed and remained above 50%, ensuring that cytotoxic stress did not interfere with subsequent gene expression analyses.

### 2.3. Quantitative reverse transcription PCR (qRT-PCR)

K-562 and HL-60 cells were cultivated at a density of $5 \times 10^5$ cells per well in six-well plates. Silibinin and sodium oxamate were then added to the cells at optimal concentrations for 48 hours. Control cells were treated with an equivalent volume of vehicle (0.1% DMSO for silibinin experiments or distilled water for sodium oxamate experiments. Total RNA was extracted using an RNA isolation kit (Favorgen Biotech Corp., Ping-Tung, Taiwan) according to the manufacturer's protocol. Complementary DNA was produced from the isolated RNA using a reverse transcription kit (Yekta Tajhiz Azma, Tehran, Iran). Specific primers were created using the CLC Genomics Workbench and AlleleID software to assess the relative mRNA expression levels of *PD-L1*, *CD47*, and *CD155* (Table 1). The efficacy of the primers was verified using the LinRegPCR program. The qRT-PCR analysis was carried out on an Applied Biosystems StepOne RT-PCR system, utilizing RT-PCR Master Mix. The thermal cycling protocol consisted of an initial denaturation step at 95°C for 10 minutes, followed by 40 cycles of denaturation at 95°C for 15 seconds, primer-specific annealing at 58-60°C for 30 seconds, and extension at 72°C for 30 seconds. To verify the specificity of the amplified products, a melting curve analysis was performed following the amplification cycles. Gene expression levels were calculated relative to the internal control gene, *β-actin* (Table 1). Quantification was performed using the Pfaffl method[25], which incorporates the amplification efficiencies of the respective primer pairs.

[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]

[ DOI: 10.61882/ibj.5324 ]

**Table 1.** Primers used for qRT-PCR

| Gene | Primer sequences (5'→3') | Product size (bp) |
|---|---|---|
| *PD-L1* | 5'- CTATGGTGGTGCCGACTACAA-3'<br>3'-CTGCTTGTCCAGATGACTTCG-5' | 159 |
| *CD47* | 5'-GTCATTGTCATTGTTGGAGCCATT-3'<br>3'-GGAGGTTAATCCAATCGCTGTACT-5' | 147 |
| *CD155* | 5'-GGACGGCAAGAATGTGAC-3'<br>3'-CCAGTTGTTATCATAGCCAGA G-5' | 124 |
| *β-actin* | 5'-CCTTCCTGGGCATGGAGTCCT-3'<br>3'-TGG GTG CCA GGG CAG TGA T-5' | 174 |

### 2.4. Statistical analysis

Data are presented as mean ± SEM from six independent biological experiments (n = 6). For each cell line and treatment, gene expression in the treated group was compared to that of its corresponding vehicle-treated control group. Pairwise comparisons were performed using an unpaired, two-tailed Student's t-test. The normality of data distribution was confirmed using the Shapiro-Wilk test. A $p$ value <0.05 was considered statistically significant.

## 3. RESULTS

### 3.1. Effect of HIF-1α blockade on mRNA expression level of immune checkpoint ligands in AML cells

To explore how blocking HIF-1α affects the expression of immune checkpoint ligands in AML cell lines, we treated the cells with silibinin, a blocker of HIF-1α. After treatment, the relative mRNA levels of *PD-L1*, *CD47*, and *CD155* were measured using qRT-PCR. As shown in Figure 1A, silibinin significantly lowered *CD47* mRNA levels ($p < 0.001$) in K-562 cells compared to untreated controls, while it did not have a notable effect on the expression of *PD-L1* and *CD155*. In HL-60 cells, silibinin treatment significantly reduced the expression of both *CD47* and *CD155* ($p < 0.01$) but did not alter *PD-L1* levels (Fig. 1B).

### 3.2. Effect of LDHA blockade on mRNA expression levels of immune checkpoint ligands in AML cells

We treated AML cell lines with sodium oxamate, a blocker of LDHA, to investigate how blocking LDHA affects the expression of immune escape molecules. qRT-PCR was used to assess the mRNA levels of *PD-L1*, *CD47*, and *CD155*. In K-562 cells, there were no significant differences in the expression of *PD-L1*, *CD47*, or *CD155* compared to untreated cells (Fig. 2A).

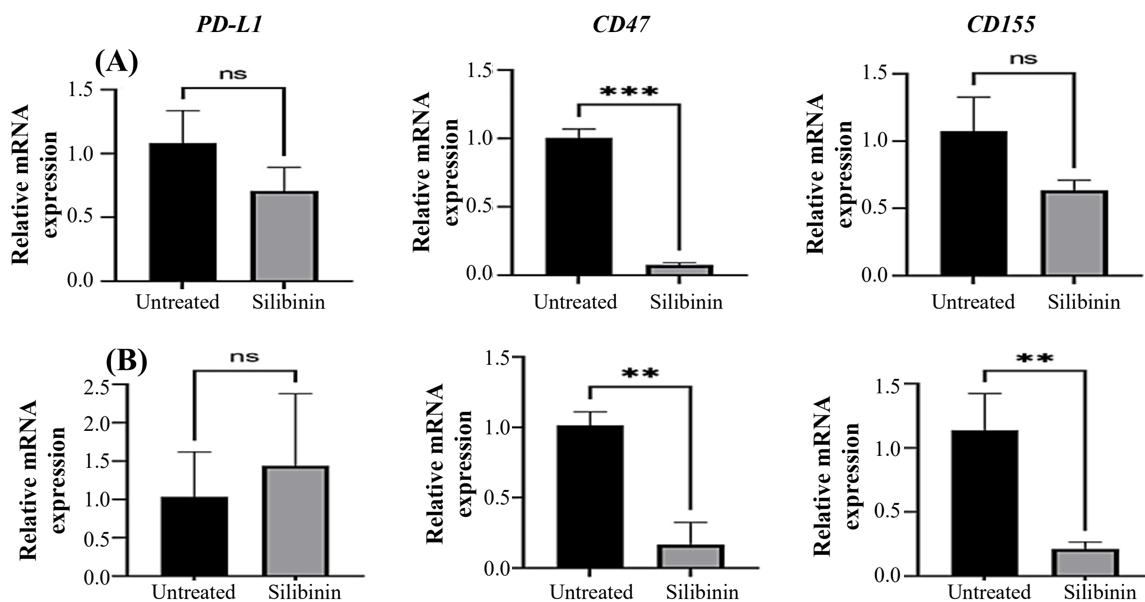


**Fig. 1.** Effects of silibinin on *PD-L1*, *CD47*, and *CD155* mRNA expression levels in treated AML cell lines. (A) K-562 and (B) HL-60 cells were treated with silibinin for 48 hours. Relative mRNA expression of *PD-L1*, *CD47*, and *CD155* were then measured using qRT-PCR. Treatments were performed in triplicate, and qRT-PCR analyses were conducted in duplicate (n = 6). Data are presented as mean ± SEM. Statistical significance was determined using an unpaired t-test ($^{**}p < 0.01$, $^{***}p < 0.001$); ns: not significant.

[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]
[ DOI: 10.61882/ibj.5324 ]

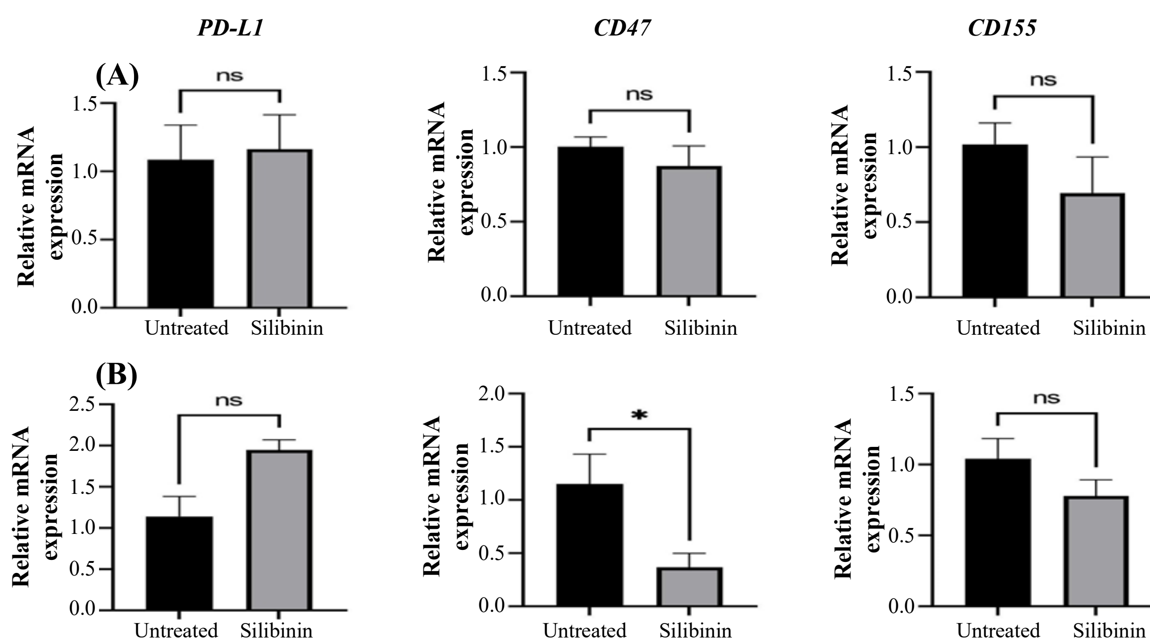


**Fig. 2.** Effects of sodium oxamate on *PD-L1, CD47,* and *CD155* mRNA expression levels in treated AML cell lines. (A) K-562 and (B) HL-60 cells were treated with sodium oxamate for 48 hours. Relative mRNA expression of *PD-L1, CD47,* and *CD155* was then measured using qRT-PCR. Treatments were performed in triplicate, and qRT-PCR analyses were conducted in duplicate (n = 6). Data are presented as mean ± SEM. Statistical significance was determined using an unpaired t-test ($^{*}p < 0.05$); ns: not significant.

In contrast, HL-60 cells exhibited a significant reduction in CD47 mRNA expression ($p < 0.05$) after LDHA blockade, while the levels of *PD-L1* and *CD155* remained stable (Fig. 2B).

## 4. Discussion

ICRs and their ligands are critical for self-tolerance but are often exploited by cancers to evade immunity. Therefore, targeting ICRs such as *PD-L1, CD47,* and *CD155* has become an effective immunotherapeutic strategy[26-30]. According to the classical Warburg effect, cancer cells primarily depend on anaerobic metabolism and glycolysis. This metabolic shift is regulated by transcription factors like HIF-1α, which activates genes such as LDHA that catalyze lactate production, aiding tumor survival, growth, and adaptation to low-oxygen conditions[31-35]. Blocking this metabolic pathway may alter the expression of ICRs and boost antitumor immune responses.

Silibinin, a natural flavonoid extracted from *Silybum marianum*, exhibited significant anticancer properties across various tumors, including skin, lung, breast, and prostate cancers. Its mechanism involves blocking HIF-1α and LDHA, which disrupts the metabolic adaptation of cancer cells to hypoxia and reduces the expression of ICR ligands, including *PD-L1*[36-38]. Sodium oxamate, a competitive LDHA blocker, decreases lactic acid production in tumor cells, reshaping the immune-suppressive tumor microenvironment into an immune-active one. Research conducted on non-small cell lung cancer models has demonstrated that sodium oxamate suppresses LDHA activity, reduces tumor viability, and enhances the infiltration of immune cells, immune checkpoint blockers, like anti-PD-1 antibodies, by alleviating lactic acid-induced immunosuppression and promoting antitumor immunity[39].

Studies across different cancer types, including nasopharyngeal carcinoma and lung cancer, support the simultaneous targeting of HIF-1α and LDHA as a promising strategy to inhibit tumor growth and modulate ICR expression, potentially overcoming immune resistance[38,39]. This approach provides a strong rationale for using silibinin and sodium oxamate to suppress HIF-1α and LDHA in leukemia cell lines. We hypothesized that blocking HIF-1α and LDHA would reduce the expression of critical immune checkpoint ligands—namely *PD-L1, CD47*, and *CD155*—thereby countering a key mechanism of tumor immune escape.

*PD-L1*, a key ligand for PD-1, is often overexpressed in tumors to inhibit T-cell function, facilitating immune evasion[26]. Our findings showed that silibinin not only did not significantly alter *PD-L1* expression but also did not reduce it as expected. This observation implies that *PD-L1* expression in these cells may be regulated independently of HIF-1α or LDHA activity, possibly

[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]

[ DOI: 10.61882/ibj.5324 ]

reflecting compensatory activation of alternative transcription factors, such as *c-Myc*[40], or the involvement of other transcriptional regulators[41], or signaling pathways[40,42,43]. Conversely, silibinin significantly reduced *CD47* expression, a molecule that sends “don’t eat me” signals to macrophages, preventing phagocytosis[6]. This downregulation could enhance the immune system ability to eliminate leukemic cells, underscoring silibinin therapeutic potential. Sodium oxamate decreased *CD47* expression only in HL-60 cells, reflecting possible differences in cellular biology and metabolism between the two cell lines[44].

Regarding *CD155*, which modulates immune inhibition through interactions with natural killer and T-cell receptors[45], silibinin reduced its expression only in HL-60 cells, with no effect on K-562 cells. Sodium oxamate did not significantly change *CD155* expression. These results suggest cell type-specific regulation and distinct drug impacts on pathways controlling *CD155*[46].

The variable responses to silibinin and sodium oxamate likely stem from their unique molecular targets and mechanisms. The broader range of actions for i antioxidant and anti-inflammatory effects, along with its modulation of multiple signaling pathways, may explain its more substantial influence on gene expression[47]. Additionally, the contrasting behaviors of HL-60 and K-562 cells highlight the importance of cellular context in determining the efficacy of targeted therapies.

This study has limitations. First, we measured mRNA expression, but future studies should assess protein levels and provide functional validation. Second, pharmacological inhibitors may have off-target effects; genetic approaches could provide more specific insights. Third, our findings are based on two leukemic cell lines; hence, using primary AML samples or in vivo models would strengthen clinical relevance. Finally, while using fixed $IC_{50}$-based dosing regimen is a standard approach, it may not account for potential stress-related effects that occur at sub-$IC_{50}$ concentrations, while standardized, may induce stress responses. Conducting full dose-response studies in future work could help dissect whether the observed regulatory mechanisms are a direct pharmacological response or an indirect consequence of cellular stress.

## 5. CONCLUSION

Our findings indicate that pharmacological inhibition of HIF-1α and LDHA can modulate the mRNA expression of certain immune checkpoint ligands, including *CD47* and *CD155*, in leukemic cell lines. These preliminary observations suggest a potential link between tumor metabolism and immune regulation; however, they should be interpreted as pharmacologically induced associations rather than direct evidence of HIF-1α or LDHA pathway blockade. Future studies should validate these findings at the protein and functional levels and explore the combination of metabolic inhibitors with existing immunotherapies to assess potential synergistic effects.

## DECLARATION

**Acknowledgments**

The authors thank the staff of the Department of Immunology of Mazandaran University of Medical Sciences, Sari, Iran for their cooperation for providing laboratory environment.

**Generative AI and AI-assisted technologies**

Copilot was used to improve clarity and correct grammar in some sentences.

**Ethical approval**

All the experimental procedures in this study were approved by the Research Ethics Committee of Mazandaran University of Medical Sciences, Sari, Iran (ethical code: IR.MAZUMS.REC.1404.112).

**Consent to participate**

Not applicable.

**Consent for publication**

All authors reviewed the results and approved the final version of the manuscript.

**Authors’ contributions**

TE and MS: carried out the assays and contributed to data collection and analysis; AKh: helped in performing assays; AK: helped in performing assays; HAO: helped in PCR optimization and analysis of PCR data; RV: helped in PCR optimization and analysis of PCR data; MT and ST: designed and conducted the research.

**Data availability**

The dataset presented in the study is available upon request from the corresponding author during submission or after its publication.

**Competing interests**

The authors declare that they have no competing interests.

**Funding**

This study was financially supported by Mazandaran University of Medical Sciences, Sari, Iran [grant number: 23785].

[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]

[ DOI: 10.61882/ibj.5324 ]

**Supplementary information**

The online version does not contain supplementary material.

## REFERENCES


1. Pelcovits A, Niroula R. Acute Myeloid Leukemia: A review. R I Med J (2013). 2020;103(3):38-40.
2. Rashidi A, Fisher SI. Spontaneous remission of acute myeloid leukemia. Leuk Lymphoma. 2015;56(6):1727-34.
3. Yao H, Yang F, Li Y. Natural products targeting human lactate dehydrogenases for cancer therapy: A mini review. Front Chem. 2022;10:1013670.
4. Faubert B, Solmonson A, DeBerardinis RJ. Metabolic reprogramming and cancer progression. Science. 2020;368(6487).
5. Semenza GL. HIF-1: upstream and downstream of cancer metabolism. Curr Opin Genet Dev. 2010;20(1):51-6.
6. Majeti R, Chao MP, Alizadeh AA, Pang WW, Jaiswal S, Gibbs Jr KD, et al. CD47 is an adverse prognostic factor and therapeutic antibody target on human acute myeloid leukemia stem cells. Cell. 2009;138(2):286-99.
7. Liu N, Luo J, Kuang D, Xu S, Duan Y, Xia Y, et al. Lactate inhibits ATP6V0d2 expression in tumor-associated macrophages to promote HIF-2α-mediated tumor progression. J Clin Invest. 2019;129(2):631-46.
8. Li H, Chai X. PDPK1 governs macrophage M2 polarization via hypoxia-driven CD47/AKT-glycolytic axis in endometriosis. Cell Signal. 2025;134:111922.
9. Wang C, Sun C, Li M, Xia B, Wang Y, Zhang L, et al. Novel fully human anti-CD47 antibodies stimulate phagocytosis and promote elimination of AML cells. J Cell Physiol. 2021;236(6):4470-81.
10. Zhang L, Gajewski TF, Kline J. PD-1/PD-L1 interactions inhibit antitumor immune responses in a murine acute myeloid leukemia model. Blood. 2009;114(8):1545-52.
11. Sanchez-Correa B, Valhondo I, Hassouneh F, Lopez-Sejas N, Pera A, Bergua JM, et al. DNAM-1 and the TIGIT/PVRIG/TACTILE axis: Novel immune checkpoints for natural killer cell-based cancer immunotherapy. Cancers. 2019;11(6):877.
12. Gertner-Dardenne J, Fauriat C, Orlanducci F, Thibult ML, Pastor S, Fitzgibbon J, et al. The co-receptor BTLA negatively regulates human Vγ9Vδ2 T-cell proliferation: A potential way of immune escape for lymphoma cells. Blood. 2013;122(6):922-31.
13. Noman MZ, Hasmim M, Lequeux A, Xiao M, Duhem C, Chouaib S, et al. Improving cancer immunotherapy by targeting the hypoxic tumor microenvironment: New opportunities and challenges. Cells. 2019;8(9):1083.
14. Husain Z, Huang Y, Seth P, Sukhatme VP. Tumor-derived lactate modifies antitumor immune response: effect on myeloid-derived suppressor cells and NK cells. J Immunol. 2013;191(3):1486-95.
15. Jie XL, Wei JC, Wang D, Zhang XW, Lv MY, Lin YF, et al. CDC34 suppresses macrophage phagocytic activity and predicts poor response to immune checkpoint inhibitor in cancers. Cancer Lett. 2025;628:217822.
16. Xu C, Pei Y, Zhang X, Wang C, He M, Wan Z, et al. CD47/HIF-1α circuit promotes cell proliferation in hepatocellular carcinoma. Pathol Res Pract. 2025;276:156275.
17. Wu H, Zhou X, Zhang Y, Zhou L, Wang Q, Wang T, et al. HIF-1α depletion regulates autophagy to improve arteriosclerosis obliterans of the lower extremities via the TSP-1/$CD_{47}$ axis. Life Sci. 2025;378:123817.
18. Noman MZ, Desantis G, Janji B, Hasmim M, Karray S, Dessen P, et al. PD-L1 is a novel direct target of HIF-1α, and its blockade under hypoxia enhanced MDSC-mediated T cell activation. J Exp Med. 2014;211(5):781-90.
19. Xanthopoulou ET, Kakouratos C, Nanos C, Gkegka AG, Kalaitzis C, Giatromanolaki A, et al. HIF1α-dependent and independent pathways regulate the expression of PD-L1 in prostate cancer. Med Oncol. 2023;40(5):151.
20. Deep G, Agarwal R. Antimetastatic efficacy of silibinin: Molecular mechanisms and therapeutic potential against cancer. Cancer Metastasis Rev. 2010;29(3):447-63.
21. Le A, Cooper CR, Gouw AM, Dinavahi R, Maitra A, Deck LM, et al. Inhibition of lactate dehydrogenase A induces oxidative stress and inhibits tumor progression. Proc Natl Acad Sci U S A. 2010;107(5):2037-42.
22. Zhao Y, Butler EB, Tan M. Targeting cellular metabolism to improve cancer therapeutics. Cell Death Dis. 2013;4(3):e532.
23. Deep G, Agarwal R. Targeting tumor microenvironment with silibinin: Promise and potential for a translational cancer chemopreventive strategy. Curr Cancer Drug Targets. 2013;13(5):486-99.
24. Kahrizi A, Asgarian-Omran H, Taghiloo S, Valadan R, Najafi A, Akbar A, et al. Targeting metabolic pathways in AML cell lines: Impact of hypoxia-inducible factor-1α (HIF-1α) and lactate dehydrogenase-A (LDH-A) inhibition. Iran Biomed J. 2025;29(6):427-36.
25. Pfaffl MW. A new mathematical model for relative quantification in real-time RT-PCR. Nucleic Acids Res. 2001;29(9):e45.
26. Dong H, Strome SE, Salomao DR, Tamura H, Hirano F, Flies DB, et al. Tumor-associated B7-H1 promotes T-cell apoptosis: A potential mechanism of immune evasion. Nat Med. 2002;8(8):793-800.
27. Topalian SL, Hodi FS, Brahmer JR, Gettinger SN, Smith DC, McDermott DF, et al. Safety, activity, and immune correlates of anti-PD-1 antibody in cancer. N Engl J Med. 2012;366(26):2443-54.
28. Jaiswal S, Jamieson CH, Pang WW, Park CY, Chao MP, Majeti R, et al. $CD_{47}$ is upregulated on circulating hematopoietic stem cells and leukemia cells to avoid phagocytosis. Cell. 2009;138(2):271-85.
29. Willingham SB, Volkmer JP, Gentles AJ, Sahoo D, Dalerba P, Mitra SS, et al. The $CD_{47}$-signal regulatory protein alpha (SIRPa) interaction is a therapeutic target for human solid tumors. Proc Natl Acad Sci U S A. 2012;109(17):6662-7.
30. Johnston RJ, Comps-Agrar L, Hackney J, Yu X, Huseni M, Yang Y, et al. The immunoreceptor TIGIT regulates antitumor and antiviral CD8(+) T cell effector function. Cancer Cell. 2014;26(6):923-37.


[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]

[ DOI: 10.61882/ibj.5324 ]

31. Warburg O, Wind F, Negelein E. The metabolism of tumors in the body. J Gen Physiol.1927;8(6):519-30.
32. Semenza GL, Wang GL. A nuclear factor induced by hypoxia via de novo protein synthesis binds to the human erythropoietin gene enhancer at a site required for transcriptional activation. Mol Cell Biol. 1992;12(12):5447-54.
33. Iyer NV, Kotch LE, Agani F, Leung SW, Laughner E, Wenger RH, et al. Cellular and developmental control of O2 homeostasis by hypoxia-inducible factor 1 alpha. Genes Dev. 1998;12(2):149-62.
34. Semenza GL, Jiang BH, Leung SW, Passantino R, Concordet JP, Maire P, et al. Hypoxia response elements in the aldolase A, enolase 1, and lactate dehydrogenase A gene promoters contain essential binding sites for hypoxia-inducible factor 1. J Biol Chem. 1996;271(51):32529-37.
35. Fantin VR, St-Pierre J, Leder P. Attenuation of LDH-A expression uncovers a link between glycolysis, mitochondrial physiology, and tumor maintenance. Cancer Cell. 2006;9(6):425-34.
36. Deep G, Kumar R, Nambiar DK, Jain AK, Ramteke AM, Serkova NJ, et al. Silibinin inhibits hypoxia-induced HIF-1α-mediated signaling, angiogenesis and lipogenesis in prostate cancer cells: In vitro evidence and in vivo functional imaging and metabolomics. Mol Carcinog. 2017;56(3):833-48.
37. Dan W, Fan Y, Hou T, Wei Y, Liu B, Que T, et al. Silibinin inhibits the migration, invasion and epithelial-mesenchymal transition of prostate cancer by activating the autophagic degradation of YAP. J Cancer. 2022;13(13):3415-26.
38. Sellam LS, Zappasodi R, Chettibi F, Djennaoui D, Yahi-Ait Mesbah N, Amir-Tidadini ZC, et al. Silibinin down-regulates PD-L1 expression in nasopharyngeal carcinoma by interfering with tumor cell glycolytic metabolism. Arch Biochem Biophys. 2020;690:108479.
39. Qiao T, Xiong Y, Feng Y, Guo W, Zhou Y, Zhao J, et al. Inhibition of LDH-A by oxamate enhances the efficacy of anti-PD-1 treatment in an NSCLC humanized mouse model. Front Oncol. 2021;11:632364.
40. Casey SC, Tong L, Li Y, Do R, Walz S, Fitzgerald KN, et al. MYC regulates the antitumor immune response through $CD_{47}$ and PD-$L_1$. Science. 2016;352(6282):227-31.
41. Messai Y, Gad S, Noman MZ, Le Teuff G, Couve S, Janji B, et al. Renal cell carcinoma programmed death-ligand 1, a new direct target of hypoxia-inducible factor-2 alpha, is regulated by von Hippel-Lindau gene mutation status. Eur Urol. 2016;70(4):623-32.
42. Azuma K, Ota K, Kawahara A, Hattori S, Iwama E, Harada T, et al. Association of PD-$L_1$ overexpression with activating EGFR mutations in surgically resected nonsmall-cell lung cancer. Ann Oncol. 2014;25(10):1935-40.
43. Lee S-K, Seo S-H, Kim B-S, Kim C-D, Lee J-H, Kang J-S, et al. IFN-gamma regulates the expression of B7-H1 in dermal fibroblast cells. J Dermatol Sci. 2005;40(2):95-103.
44. Li W, Tanikawa T, Kryczek I, Xia H, Li G, Wu K, et al. Aerobic glycolysis controls myeloid-derived suppressor cells and tumor immunity via a specific CEBPB isoform in triple-negative breast cancer. Cell Metab. 2018;28(1):87-103.
45. Böttcher JP, Bonavita E, Chakravarty P, Blees H, Cabeza-Cabrerizo M, Sammicheli S, et al. NK cells stimulate recruitment of cDC1 into the tumor microenvironment promoting cancer immune control. Cell. 2018;172(5):1022-37.
46. Soriani A, Zingoni A, Cerboni C, Iannitto ML, Ricciardi MR, Di Gialleonardo V, et al. ATM-ATR-dependent up-regulation of DNAM-1 and NKG2D ligands on multiple myeloma cells by therapeutic agents results in enhanced NK-cell susceptibility and is associated with a senescent phenotype. Blood. 2009;113(15):3503-11.
47. Mateen S, Tyagi A, Agarwal C, Singh RP, Agarwal R. Silibinin inhibits human nonsmall cell lung cancer cell growth through cell-cycle arrest by modulating expression and function of key cell-cycle regulators. Mol Carcinog. 2010;49(3):247-58.


[ Downloaded from ibj.pasteur.ac.ir on 2026-05-17 ]

[ DOI: 10.61882/ibj.5324 ]