Medical Science Journal for Advance Research

Vol. 6, No. 2, June 2025
e-ISSN: 2774-4892

Effects of Metformin on the Liver and Kidney in Diabetic Patients with Multiple Complications

Ahmed Ghdhban Al-Ziaydi [1], Mohammed Abbas Al-Silaykhee [2], and Ysra Abed Alhasan Aliwi [3]

[1] *Department of Medical Chemistry, College of Medicine, University of Al-Qadisiyah, Iraq.*

[2] *Department of Medical Chemistry, College of Medicine, University of Al-Qadisiyah, Iraq.*

[3] *Department of Agricultural Biotechnology, College of Biotechnology, University of Al-Qadisiyah, Iraq.*
ahmed.alziaydi@qu.edu.iq,mohammed.alsilaykhee@qu.edu.iq,yousra.alqargoli@qu.edu.iq

ABSTRACT

Background: *Diabetes mellitus (DM) is one of the most serious health concerns in the world due to its complicated nature with various health concerns, including liver and kidney damage. Metformin is a commonly prescribed medication for type 2 diabetes and is known for its effectiveness and safety; nonetheless, it does require scrutiny in the presence of liver and kidney diseases.* ***Objective***: *This study evaluates the concerns related to treatment risk versus benefits of metformin in managing multi-complicated diabetes with special focus on liver and kidney functions.* ***Methods***: *Metformin's impact on hepatic and renal parameters were evaluated to formulate key outcomes by measuring liver function tests, kidney functions, and complications like nonalcoholic fatty liver disease (NAFLD) and diabetic nephropathy.* ***Results***: *Reducing the progression of NAFLD, steatosis, and serum liver enzyme ALT/AST, metformin improves liver health which was supported by its action through AMPK-dependent pathways. In the kidney, micromolar concentrations of metformin appeared to protect renal function, stabilizing and reducing albuminuria in patients suffering from chronic kidney disease (CKD). Alongside these benefits, the risk of lactic acidosis in advanced CKD patients (eGFR < 30 mL/min/1.73m²) and vitamin B12 deficiency presented a need for caution. Longitudinal and meta-analysis studies confirmed that patients with mild to moderate CKD (eGFR ≥30 mL/min/1.73m²) could safely use the drug, provided there is some adjustment in dosage. Individualized dosing remains vital due to the potential harmful effects of gastrointestinal issues such as chronic diarrhea, and the rare occurrence of lactic acidosis. Newer studies underscored metformin's capability to reduce cardiovascular risks and its impact on personalized treatment, particularly for patients with β-thalassemia major and GDF-15, and ferritin biomarkers indicating relevant de-accumulation of iron overload and complication monitoring.* ***Conclusion***: *Metformin continues to be an effective medication for diabetes and has positive impacts on the health of the liver and kidneys. Its use is relatively safe in the early stages of CKD and NAFLD but should be used with caution in advanced hepatic-renal failure. A comprehensive approach, including genetic and biomarker methods is needed to individualize treatment strategies to maximize benefits. More studies are required to clarify the impact of metformin over an extended period of time, and how to best set criteria for patients with numerous coexisting diseases.*

Keywords: Diabetes Mellitus, Metformin, Liver, Kidney, Chronic Kidney Disease, Nonalcoholic Fatty Liver Disease, Complications.

Article Information
Received: April 19, 2025; Revised: May 24, 2025; Online: June, 2025.

https://doi.org/10.46966/msjar.v6i2.261

INTRODUCTION

Diabetes Mellitus is one of the major health concerns, and its incidence is rising in many regions, including South Korea. Diabetes Mellitus (DM) is a disease that was diagnosed in around 4,200 South Koreans as of 2018 on a daily basis (1). DM poses a serious threat to health, increasing the chances of having a stroke or myocardial infraction and elevating one's risk of metabolic syndrome along with both vascular and micro vascular complications (2,3). In South Korea, Metformin is the most commonly prescribed oral hypoglycemic agent for type-two diabetes patients has having a prevalence of around 48.5% as it is considered safe and effective (4,5). Molecular docking of Metformin and Metformin structure (Figure 1).

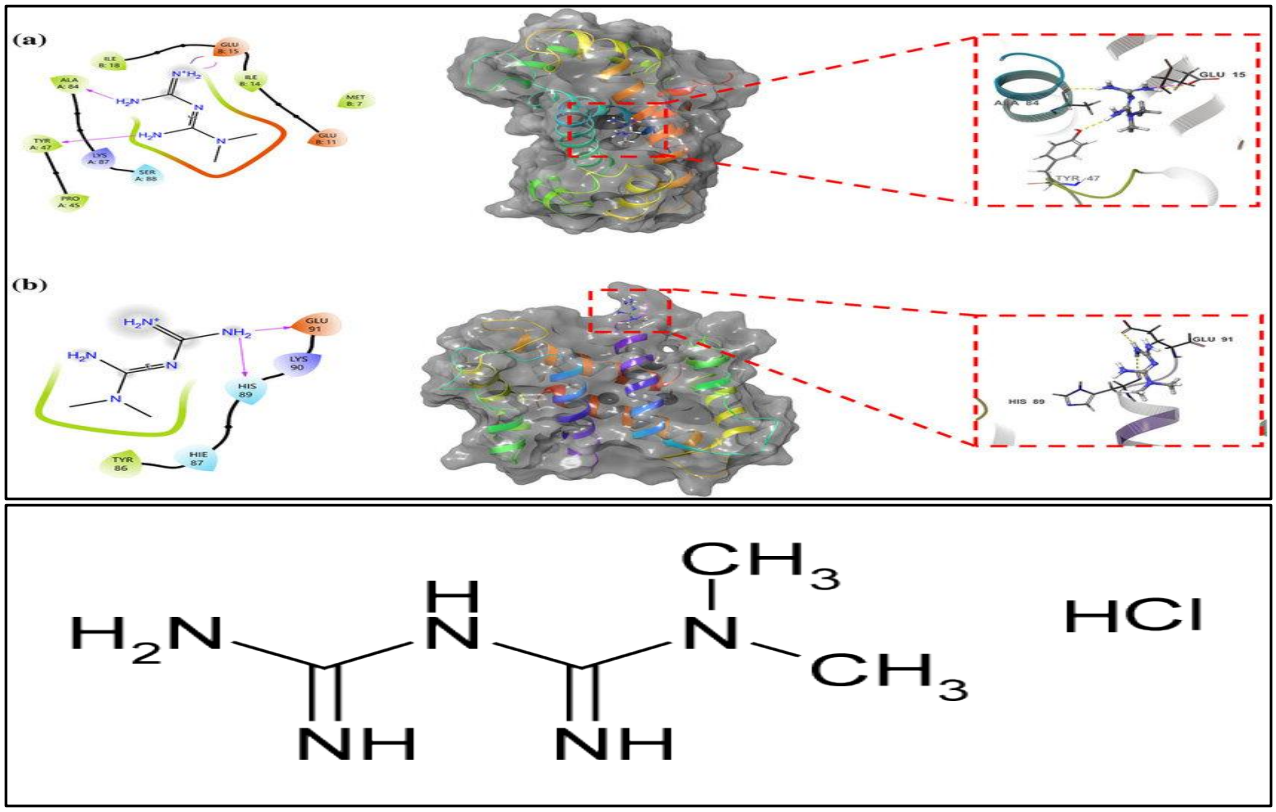

Figure 1: Molecular docking of Metformin and Metformin structure.

Overview of Diabetes Mellitus: Controlling the conditions of diabetes entail the use of medication alongside lifestyle changes. One of the main treatment procedures is Metformin, which helps in controlling blood sugar levels and the excess production of ketone bodies that can be detrimental to the liver and kidneys (6,7). Metformin is contraindicated for patients with renal failure or liver failure due to the chances of lactic acidosis (8).

Types of Diabetes: There exist three primary types of diabetes; type 1, type 2, and gestational. The former is a result of an autoimmune disorder that leads to the destruction of the beta cells in the pancreas, while the latter is usually associated with older humans who are insulin resistant but has been seen at an increasing rate in younger people (9,10). Whereas gestational diabetes happens during the period of pregnancy and tends to disappear after we give birth (11).

Diabetes Pathophysiology: In Diabetes Mellitus, there is an intricate interplay of systematized high blood sugar levels, which leads to a mixed dyslipidemia with kidney damage and chronic inflammation of liver tissues contributing to liver cirrhosis (12).

Furthermore, development of vascular damage along with complications such as nephropathy (13,14) occurs due to injurious processes sustained over time and chronic high glucose levels. There is Energy metabolism disruption or imbalance that induces inflammatory processes. (15).

Metformin: Mechanism of Metformin Action: The most important action of Metformin is to reduce blood glucose levels by insulin secretion suppression, however, its sensitivity is increased (16). It controls energy homeostasis through AMP activated protein kinase (AMPK) which is important for catalyzed processes (17) (Figure 2, 3).

Insulin Sensitization: The increasing actions of Metformin further enhance blood glucose levels and from the liver, hepatic glucose secretion is lessened because of AMPK action (18,19). As a result, there is maintenance of blood sugar level, which is glucose in blood without hypoglycemia (20).

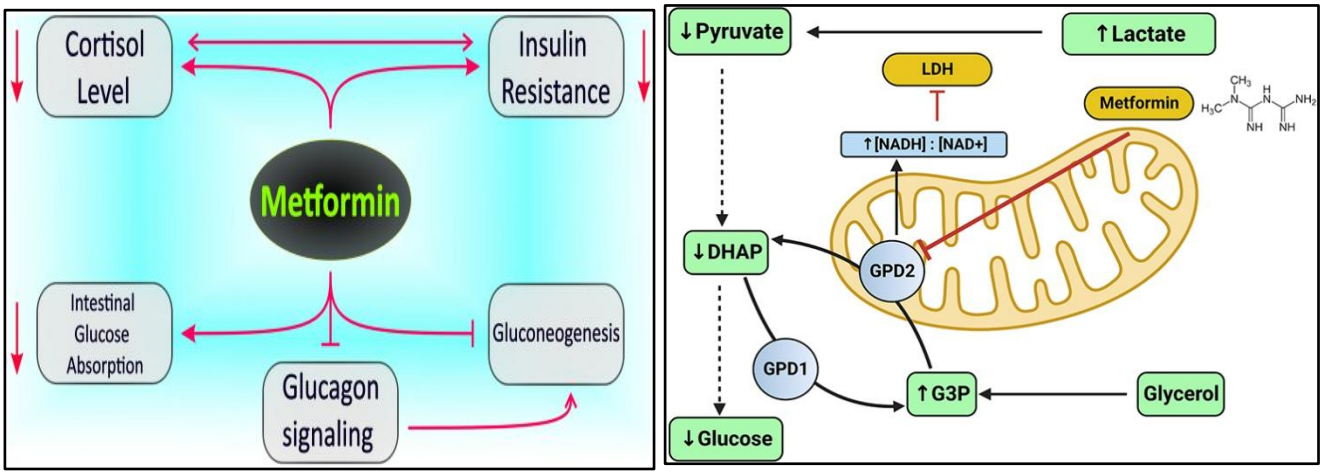

Figure 2: Mechanism of Metformin Action.

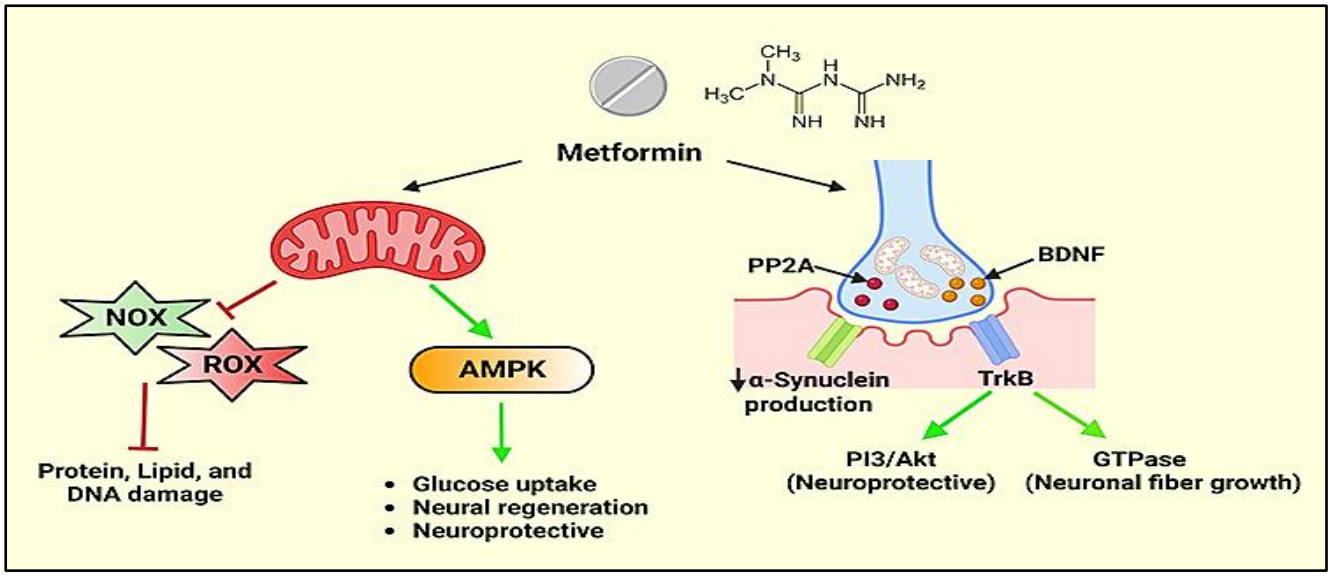

Figure 3: Neuroprotective role of metformin.

Impact on Gluconeogenesis: In regards to Metformin, gluconeogenesis is inhibited and mainly its action relies on transforming the liver, nevertheless, it does not occur only by hepatic ways (21). There is a change in mitochondria, which assists in decreasing the output of glucose from the liver (22).

Effects of Metformin on the Liver: There are other complications beyond controlling blood sugar that Metformin affects and do not include in Diabetes Mellitus (23). Improvement of the liver is done through insulin releasers called AMPK which close down glucogenesis while Metformin controls on purely dominating DM activity (24). The reduction of glucose caused by Metformin is brought about by independent or dependent mechanisms of AMPK (25). This activates glucose partitioning by enhancing insulin sensitivity and reducing hepatic glucose production, thus lowering plasma glucose levels (26).

Enzymatic activity of Liver: There are suggestions that Metformin may provide protection from some of the liver functional complications such as nonalcoholic fatty liver disease (NAFLD) and cirrhosis, with some data showing reduced hepatic decompensation risk (27,28). The drug has been cited with improvement of liver function tests among the diabetic patients (29).

Effects of Metformin on the Kidney: Beside its most common use in type 2 diabetes, metformin is of controversial use for chronic kidney disease (CKD) patients because of perceived dangers of lactic acidosis (30). However, some studies detected that under specific circumstances it may actually be safe (31).

Renal Function Parameters: As cladded in the research, Metformin doesn't greatly impair renal functions of well-controlled monitored patients with CKD (32,33). In fact, it could enhance nephroprotective effects through reduction of albuminuria (34).

Nephroprotective Effects: Though not well understood, Metformin does offer some reduction in the diabetic kidney disease progression (35). It is suggested to improve renal outcomes through inflammation and fibrosis modulation (36).

Impact on Diabetic Nephropathy: Metformin has been linked to a lower likelihood of developing microvascular issues, specifically nephropathy, even though study results are mixed (37,38). It is believed that long-term use may be associated with a lower risk of progression to end-stage renal disease (39).

Metformin and Multiple Complications: Its implications extend to the cardiovascular system, neuropathy, and retinopathy, showing Metformin's multifaceted association with the management of diabetic complications (40,41). Additionally, its potential for shielding patients from cardiovascular events is significant (42).

Clinical Studies and Evidence: Emerging research highlights the impact of Metformin on the liver and kidney health of diabetic patients. Meta-analyses alongside randomized control trials validate the medication's efficacy in blood glucose management and enhanced functioning of hepatic and renal systems (43,44).

Meta-analyses: Compared to other treatments, metformin was shown to improve liver function and its protective effects on the kidneys are, however, less defined (45,46). Despite this, the balance of benefits with harm is positive and incidences of adverse effects are minimal (47).

Longitudinal Studies and Randomized Control Trials: Observational studies suggest that patients on Metformin have a lower risk of kidney failure compared to patients on other therapies (48). Trials support the idea that unrestricted patients with mildly impaired renal function may preserve some degree of renal function (49).

Adverse Effects of Metformin: The most frequent adverse effects are gastrointestinal caused and, extremely rarely, might be lactic acidosis (50). There is a great need for close observation, particularly in those with renal dysfunction (51).

Gastrointestinal Issues: Gastrointestinal side

effects may cause some patients to discontinue treatment (52). Some measures to reduce these effects include slow dose increases (53).

Lactic Acidosis: Although uncommon, lactic acidosis represents a significant risk, especially for people with renal insufficiency (54). Its prevalence is still low in patients with normal renal function (55).

Vitamin B12 Deficiency: A considerable number of metformin patients will develop vitamin B12 deficiency due to long-term use, which requires continuous assessment (56). The deficiency is likely to worsen neuropathy in patients with diabetes (57).

Patient Management Strategies: Diabetic patients with liver and kidney complications require combination treatment, careful surveillance, and lifestyle changes to achieve optimal control (58).

Monitoring the Function of the Kidneys: Renal functioning should be evaluated, and patients with raised levels of creatinine can be treated with metformin with caution (59). Metformin is now accepted in primary for certain stages of CKD (60).

Turning Down the Dosage of Metformin: When using combined therapy, physicians should account for the liver's glucose uptake and modify the metformin therapy relative to the hepatic function, if necessary (61). Effective individual treatment plans are crafted with enhanced safety and optimized effectiveness (62).

Diet and Exercise: These are fundamental in ameliorating the health of people with diabetes and averting complications (63). Patient education for encouraging active participation in lifestyle alterations achieves set objectives (64).

Focus of Further Direction: More works focusing on studying effects of metformin on the kidneys and liver of the diabetic patient, as well as developing tailored approach will be required (65).

Other Innovative Methods of Treatment: Metformin can be posited to act on the liver and kidney of diabetic patients simultaneously, thus the need for more research to ascertain its multitarget efficacy (66). The search for new combination therapies can yield very promising outcomes (67).

Personalized Medicine in Diabetes: Evaluated serum vitamin B12 levels in Iraqi type 2 diabetes mellitus patients on metformin showed a noteworthy prevalence of vitamin B12 deficiency. This marked deficiency (72) demonstrates an added burden through diabetes mismanagement. Such vitamin B12 deficiency is known to be a side effect of prolonged metformin treatment and is associated with the development of diabetic complicating factors such as neuropathy. These risks can be reduced through appropriate supplementation which must be coupled with routine monitoring of vitamin B12 levels. Collectively these results emphasize the need for tailoring strategies for managing chronic hyperglycemia through understanding patients' genetic makeup and biochemistry metabolic pathways.

CONCLUSION

Metformin remains at the forefront of type 2 diabetes management due to its protective features concerning the liver and kidney complications. In addition to glycemic control, the drug assists with the mitigation of nonalcoholic fatty liver disease (NAFLD) and improves the prognosis of chronic kidney disease (CKD) patients. Recent findings focus on the risks of lactic acidosis due to renal function impairment and suggest, with cautious oversight, that metformin can be used in some patients. His multifarious actions along metabolic pathways warrant the consideration of individualized care for every patient because

of the presence of comorbidities. More studies are needed to further understand how metformin protects the liver and kidneys, which, in turn, would help develop better treatment plans for these patients. Understanding these mechanisms would enhance caregiving and the life quality for diabetic patients with complex complications.

REFERENCES

1. Kawanami D, Takashi Y, Tanabe M. Significance of Metformin Use in Diabetic Kidney Disease. 2020. ncbi.nlm.nih.gov
2. Nasri H, Rafieian-Kopaei M. Metformin: Current knowledge. 2014. ncbi.nlm.nih.gov
3. Yi Y, Kwon EJ, Yun G, Park S et al. Impact of metformin on cardiovascular and kidney outcome based on kidney function status in type 2 diabetic patients: a multicentric, retrospective cohort study. 2024. ncbi.nlm.nih.gov
4. Kleibert M, Zygmunciak P, Łakomska K, Mila K et al. Insight into the Molecular Mechanism of Diabetic Kidney Disease and the Role of Metformin in Its Pathogenesis. 2023. ncbi.nlm.nih.gov
5. Rena G, Grahame Hardie D, R. Pearson E. The mechanisms of action of metformin. 2017. ncbi.nlm.nih.gov
6. Ma S, Zheng Y, Xiao Y, Zhou P et al. Meta-analysis of studies using metformin as a reducer for liver cancer risk in diabetic patients. 2017. ncbi.nlm.nih.gov
7. Moonira T, S. Chachra S, E. Ford B, Marin S et al. Metformin lowers glucose 6-phosphate in hepatocytes by activation of glycolysis downstream of glucose phosphorylation. 2020. ncbi.nlm.nih.gov
8. Pinyopornpanish K, Leerapun A, Pinyopornpanish K, Chattipakorn N. Effects of Metformin on Hepatic Steatosis in Adults with Nonalcoholic Fatty Liver Disease and Diabetes: Insights from the Cellular to Patient Levels. 2021. ncbi.nlm.nih.gov
9. Munasinghe Dissanayake A, Christopher Wheldon M, Ahmed J, John Hood C. Extending Metformin Use in Diabetic Kidney Disease: A Pharmacokinetic Study in Stage 4 Diabetic Nephropathy. 2017. ncbi.nlm.nih.gov
10. Sree Boddepalli C, Dheeraj Gutlapalli S, Krishna Lavu V, Abdelwahab Mohamed Abdelwahab R et al. The Effectiveness and Safety of Metformin Compared to Sulfonylureas in Diabetic Nephropathy: A Systematic Review. 2022. ncbi.nlm.nih.gov
11. V. Wilkinson S, A. Tomlinson L, Iwagami M, A. Stirnadel-Farrant H et al. A systematic review comparing the evidence for kidney function outcomes between oral antidiabetic drugs for type 2 diabetes. 2018. ncbi.nlm.nih.gov
12. Chaudhary M, K Midha N, Sukhadiya P, Kumar D et al. Metformin-Induced Chronic Diarrhea Misdiagnosed as Irritable Bowel Syndrome for Years. 2024. ncbi.nlm.nih.gov
13. Fung Cheah Z, Chien Kuan Y. LBODP033 The Compliant Patient - When Adherence Hurts. 2022. ncbi.nlm.nih.gov
14. Khalifa M, Kantorovitch V. LBODP034 Metformin Associated Lactic Acidosis, Rare But Real. 2022. ncbi.nlm.nih.gov

15. Akinlade KS, Agbebaku SO, Rahamon SK, Balogun WO. Vitamin b(12) levels in patients with type 2 diabetes mellitus on metformin. 2015. ncbi.nlm.nih.gov

16. Ko SH, Ko SH, Ahn YB, Song KH et al. Association of Vitamin B(12) Deficiency and Metformin Use in Patients with Type 2 Diabetes. 2014. ncbi.nlm.nih.gov

17. Anand K, Jain S. Impact of Lifestyle Modification: An Intervention on Newly Diagnosed Diabetics of the Urban Slum of Meerut. 2024. ncbi.nlm.nih.gov

18. Stumvoll M, Goldstein BJ, Van Haeften TW. Type 2 diabetes: pathogenesis and treatment. Lancet. 2005;365(9465):1333-46.

19. Draznin B, Aroda V, Fradkin J, et al. Insulin Action and Insulin Resistance: A Scientific Statement from the American Heart Association. Circulation. 2016;133(12):1393-420.

20. DeFronzo RA. Insulin resistance: a key to the pathogenesis of type 2 diabetes. Diabetes. 1991;40(2):265-80.

21. Ferrannini E. The insulin resistance syndrome: a multisystem disorder. Diabetes Metab Rev. 1998;14(4):285-301.

22. Wu H, Ballantyne CM. Metabolic syndrome: a comprehensive perspective based on interactions between adipose tissue, skeletal muscle, and liver. Diabetes Care. 2010;33(1):242-7.

23. Rena G, Hardie DG, Pearson ER. The mechanisms of action of Metformin. Diabetologia. 2017;60(9):1577-85.

24. Bailey CJ. Metformin: historical overview. Diabetologia. 2017;60(9):1566-76.

25. Scheen AJ. Clinical pharmacokinetics of metformin. Clin Pharmacokinet. 1996;30(5):359-71.

26. Zhou G, Myers R, Li Y, et al. Role of AMP-activated protein kinase in metformin action. J Clin Invest. 2001;108(8):1167-74.

27. Viollet B, Guigas B, Garcia NS, et al. Cellular and molecular mechanisms of metformin: an overview. Clin Sci (Lond). 2012;122(6):253-70.

28. Inzucchi SE, Bergenstal RM, Buse JB, et al. Management of hyperglycemia in type 2 diabetes: a patient-centered approach. Diabetes Care. 2012;35(6):1364-79.

29. Musso G, Gambino R, Cassader M, Pagano G. Meta-analysis: natural history of non-alcoholic fatty liver disease (NAFLD) and diagnostic accuracy of non-invasive tests for liver disease severity. Ann Med. 2011;43(8):617-49.

30. Targher G, Byrne CD. Non-alcoholic fatty liver disease: an emerging driving force in chronic kidney disease. Nat Rev Nephrol. 2017;13(5):297-310.

31. Singh S, Allen AM, Wang Z, et al. Fibrosis progression in nonalcoholic fatty liver vs. nonalcoholic steatohepatitis: a systematic review and meta-analysis of paired-biopsy studies. Clin Gastroenterol Hepatol. 2015;13(4):643-54.

32. Inzucchi SE, Lipska KJ, Mayo H, et al. Metformin in patients with type 2 diabetes and kidney disease: a systematic review. JAMA. 2014;312(24):2668-75.

33. Lalau JD, Lacroix C. Metformin and lactic acidosis in diabetic humans.

Diabetes Obes Metab. 2003;5(3):190-201.

34. Roussel R, Travert F, Pasquet B, et al. Metformin use and mortality among patients with diabetes and atherothrombosis. Arch Intern Med. 2010;170(21):1892-9.

35. Hung SC, Kuo KL, Wu CC, et al. Metformin use and mortality in patients with advanced chronic kidney disease: national retrospective cohort study. BMJ. 2015;350:h1680.

36. Griffin SJ, Leaver JK, Irving GJ. Impact of metformin on cardiovascular disease: a meta-analysis of randomized trials among people with type 2 diabetes. Diabetologia. 2017;60(9):1620-9.

37. Holman RR, Paul SK, Bethel MA, et al. 10-year follow-up of intensive glucose control in type 2 diabetes. N Engl J Med. 2008;359(15):1577-89.

38. Evans JM, Ogston SA, Emslie-Smith A, et al. Risk of mortality and adverse cardiovascular outcomes in type 2 diabetes: a comparison of patients treated with sulfonylureas and metformin. Diabetologia. 2006;49(5):930-6.

39. Duan W, Ding Y, Yu X, et al. Metformin mitigates high-fat diet-induced metabolic inflammation in mice via inhibiting TLR4-mediated inflammatory pathway. Mediators Inflamm. 2017;2017:5828423.

40. He L, Wondisford FE. Metformin action: concentrations matter. Cell Metab. 2015;21(2):159-62.

41. Thomas MC, Cooper ME, Zimmet P. Changing epidemiology of type 2 diabetes mellitus and associated chronic kidney disease. Nat Rev Nephrol. 2016;12(2):73-81.

42. Gregg EW, Sattar N, Ali MK. The changing face of diabetes complications. Lancet Diabetes Endocrinol. 2016;4(6):537-47.

43. Rena G, Lang CC. Repurposing Metformin for cardiovascular disease. Circulation. 2018;137(5):422-4.

44. Zhou G, Myers R, Li Y, et al. Role of AMP-activated protein kinase in mechanism of Metformin action. J Clin Invest. 2001;108(8):1167-74.

45. Davis BJ, Xie Z, Viollet B, et al. Activation of the AMP-activated kinase by antidiabetes drug Metformin stimulates nitric oxide synthesis in vivo. Diabetes. 2006;55(2):496-505.

46. Cameron AR, Morrison VL, Levin D, et al. Anti-inflammatory effects of Metformin irrespective of diabetes status. Circ Res. 2016;119(5):652-65.

47. Preiss D, Lloyd SM, Ford I, et al. Metformin for non-diabetic patients with coronary heart disease (the CAMERA study). Eur Heart J. 2014;35(13):609-16.

48. Calvert JW, Gundewar S, Jha S, et al. Acute Metformin therapy confers cardioprotection against myocardial infarction via AMPK-eNOS-mediated signaling. Diabetes. 2008;57(3):696-705.

49. UK Prospective Diabetes Study Group. Effect of intensive blood-glucose control with Metformin on complications in overweight patients with T2DM. Lancet. 1998;352(9131):854-65.

50. Griffin SJ, Leaver JK, Irving GJ. Impact

of Metformin on cardiovascular disease: a meta-analysis of randomised trials. Am J Med. 2017;130(3):299-309.

51. Eurich DT, Weir DL, Majumdar SR, et al. Comparative safety and effectiveness of Metformin in patients with diabetes and heart failure. Circ Heart Fail. 2013;6(3):395-402. Doi

52. Eurich DT, Weir DL, Majumdar SR, et al. Comparative safety and effectiveness of Metformin in patients with diabetes and heart failure. Circ Heart Fail. 2013;6(3):395-402.

53. Romero SP, Andrey JL, Garcia-Egido A, et al. Metformin therapy and prognosis of patients with heart failure and new-onset diabetes mellitus. Nutr Metab Cardiovasc Dis. 2015;25(2):166-74.

54. Aguilar D, Chan W, Bozkurt B, et al. Metformin use and mortality in ambulatory patients with diabetes and heart failure. Circ Heart Fail. 2011;4(1):53-8.

55. Targher G, Byrne CD, Lonardo A, et al. Non-alcoholic fatty liver disease and risk of incident cardiovascular disease: a meta-analysis. J Hepatol. 2016;65(3):589-600.

56. Hsu PF, Sung SH, Cheng HM, et al. Association of Metformin with lower atrial fibrillation risk in patients with type 2 diabetes mellitus. Europace. 2018;20(1):66-73. .

57. Lalau JD, Kajbaf F, Bennis Y, et al. Metformin treatment in patients with T2DM and chronic kidney disease: a review. Endocrinol Metab Clin North Am. 2018;47(3):599-613.

58. De Broe ME, Kajbaf F, Lalau JD. Renoprotective effects of Metformin. Nephron. 2018;138(4):261-74.

59. Inzucchi SE, Lipska KJ, Mayo H, et al. Metformin in patients with T2DM and kidney disease. N Engl J Med. 2018;380(10):977-9. doi:10.1056/NEJMc1812673.

60. Hou YC, Zheng CM, Yen TH, et al. Molecular mechanisms of Metformin for diabetes and cancer treatment. Front Physiol. 2018;9:1039. doi:10.3389/fphys.2018.01039.

61. FDA. Drug Safety Communication: Metformin and contrast-induced nephropathy. 2016. Available from: https://www.fda.gov.

62. Aroda VR, Edelstein SL, Goldberg RB, et al. Long-term Metformin use and vitamin B12 deficiency in the Diabetes Prevention Program Outcomes Study. J Clin Endocrinol Metab. 2016;101(4):1754-61.

63. Kibirige D, Mwebaze R. Vitamin B12 deficiency among patients with diabetes mellitus: is routine screening and supplementation justified? J Diabetes Metab Disord. 2013;12(1):17.

64. Salpeter SR, Greyber E, Pasternak GA. Risk of fatal and nonfatal lactic acidosis with Metformin use. Cochrane Database Syst Rev. 2010;(4):CD002967.

65. American Diabetes Association. Standards of Medical Care in Diabetes—2023. Diabetes Care. 2023;46(Suppl 1):S1-S200.

66. Cosentino F, Grant PJ, Aboyans V, et al. 2019 ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases. Eur Heart J. 2020;41(2):255-323. doi:10.1093/eurheartj/ehz486.

67. Zhou K, Bellenguez C, Spencer CC, et al. Common variants near ATM are associated with glycemic response to Metformin. Nat Genet. 2011;43(2):117-20.

68. Al-Ziaydi AG. Evaluation of D-Mannoheptulose and Doxorubicin as Potential Therapeutic Agents for Breast Cancer by Targeting Glycolysis and Inducing Apoptosis. Indian Journal of Clinical Biochemistry. 2024;1-0.

69. Kadooh QA, Al-Ziaydi AG, Hamza AJ. Evaluation of the influence of trastuzumab therapy on serum levels of HER-2 protein and breast cancer cell lines. Menopause Review. 2024;23(1).

70. Hamza HY, Al-Ziaydi AG, Alzamili AH. Exploring Growth Differentiation Factor-15 and H63D Gene Polymorphisms in β-thalassemia Major: Implications for Cardiovascular Risk and Iron Overload. Journal of Applied Hematology. 2024;15(1):55-61.

71. Salih MM, Al-Ziaydi AG, Alzamili AH. The Effect of Ferritin Level and Gene Expression of β-globin Promoter with β-thalassemia Patients in Al-Qadisiyah Governorate, Iraq. Journal of Applied Hematology. 2023;14(4):257-62.

72. Abed HH, Ali AM, Al-Ziaydi AG. Evaluation of serum vitamin B12 levels in Iraqi patients with type 2 diabetes mellitus using metformin. Pak J Pharm Sci. 2023;36(2):425-9.

