

Medical Science

To Cite:

Rusak-Sobolewska A, Krych G, Oklińska J, Skóra M, Jadczyk K, Kazimierski B, Gniado W, Mądry D. The latest reports about sodium-glucose cotransporter-2 inhibitors – a literature review. *Medical Science* 2026; 30: e60ms3839
doi: <https://doi.org/10.54905/dissci.v30i169.e60ms3839>

Authors' Affiliation:

¹The Nicolaus Copernicus Municipal Polyclinical Hospital in Olsztyn, ul. Niepodległości 44, 10-045 Olsztyn, Poland

²Provincial Complex Hospital named after Jędrzej Śniadecki in Białystok, ul. M. Curie-Skłodowskiej 26, 15-950 Białystok, Poland

³University Clinical Hospital in Białystok, ul. M. Curie-Skłodowskiej 26, 15-276 Białystok, Poland

*Corresponding author:

Aleksandra Rusak-Sobolewska,
The Nicolaus Copernicus Municipal Polyclinical Hospital in Olsztyn,
ul. Niepodległości 44, 10-045 Olsztyn, Poland,
ORCID: 0009-0006-7366-3368,
<https://orcid.org/0009-0006-7366-3368>,
E-mail: olarusak008@gmail.com,
Phone: +48-667-396-803.

ORCID List:

Aleksandra Rusak-Sobolewska	0009-0006-7366-3368
Gabriela Krych	0009-0005-6873-5358
Joanna Oklińska	0009-0001-5779-0539
Michał Skóra	0009-0001-5137-9490
Klaudia Jadczyk	0000-0002-2214-8319
Bartłomiej Kazimierski	0009-0007-4480-5440
Weronika Gniado	0009-0002-5676-3456
Dawid Mądry	0009-0003-5948-4548

Peer-Review History

Received: 09 September 2025

Reviewed & Revised: 21/September/2025 to 03/March/2026

Accepted: 16 March 2026

Published: 30 March 2026

Peer-review Method

External peer-review was done through double-blind method.

Medical Science

pISSN 2321-7359; eISSN 2321-7367



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The latest reports about sodium-glucose cotransporter-2 inhibitors – a literature review

Aleksandra Rusak-Sobolewska^{1*}, Gabriela Krych², Joanna Oklińska², Michał Skóra², Klaudia Jadczyk³, Bartłomiej Kazimierski², Weronika Gniado², Dawid Mądry²

ABSTRACT

Sodium-glucose cotransporter-2 (SGLT2) inhibitors are currently one of the most widely prescribed anti-hyperglycaemic drugs, and their popularity is rapidly increasing. As time has passed, it has turned out that these drugs are not only effective in treating diabetes mellitus 2, but also atherosclerotic cardiovascular disease, chronic kidney disease and heart failure, which are common DM2 comorbidities. Although flozins are associated with certain adverse effects, the latest research continues to identify subsequent potential therapeutic benefits. This article aimed to present the most recent studies from 2024 about these agents, including both positive and negative findings. A literature review was performed using following databases - the PubMed and Google Scholar. Applied terms were: “SGLT2 inhibitors and cancers,” “SGLT2 inhibitors and chronic diseases,” and “electrolytes and haemoglobin in type 2 diabetes mellitus.” Recent studies appear to be highly optimistic regarding SGLT2 inhibitors, demonstrating a reduced risk of hyperkalaemia, increased haemoglobin levels, a potential additional role in the management of atrial fibrillation, and possible anticancer effects. This article is a valid encouragement to continue studies about these agents, because with their multifunctional effects, they might turn out to be a universal drug for lifestyle diseases that more and more people suffer from.

Keywords: SGLT2-inhibitors, flozins, dapagliflozin, canagliflozin, lifestyle diseases

1. INTRODUCTION

Sodium-glucose cotransporter-2 (SGLT2) inhibitors are the most widely prescribed antihyperglycaemic (blood sugar-lowering) medication classes for patients with type 2 diabetes mellitus (T2DM), prediabetes, or obesity, and the number of patients treated with them is rapidly increasing. The main reasons for this rise in treatment are that SGLT-2 inhibitors are very effective at reducing plasma glucose levels while also having a low risk of hypoglycaemia (low blood sugar). The low risk of hypoglycaemia associated with SGLT2 inhibitors is attributed to their insulin-independent mechanism of action. SGLT2 inhibitors work by selectively blocking SGLT2 in the proximal convoluted tubules of the nephrons (Nelinson et al., 2021).

Inhibition of these transporters reduces renal glucose reabsorption and induces glycosuria, as SGLT2 transporters account for approximately 90% of filtered glucose

reabsorption under physiological conditions (Hsia et al., 2017). The normal renal threshold for glucose reabsorption is about 180 mg/dL. SGLT 2 inhibitors increase the renal threshold for approximately 40–120 mg/dL glucose level, promoting urinary glucose excretion even when plasma glucose levels are normal or only slightly elevated. SGLT2 inhibitors may be safely combined with other glucose-lowering agents, resulting in additional reductions in glycated haemoglobin (HbA1c), fasting plasma glucose levels, and postprandial glucose concentrations. Moreover, their administration has been associated with beneficial effects on body weight and blood pressure, which may further enhance their therapeutic efficacy, particularly in patients with metabolic syndrome. (Nelinson et al., 2021). Relative to other oral antihyperglycemic drugs, SGLT2 inhibitors have shown long-term glucose-lowering efficacy. Compared with other oral antihyperglycaemic agents, SGLT2 inhibitors have demonstrated sustained long-term glucose-lowering efficacy. In a randomized, double-masked clinical trial involving 1,450 patients, treatment with an SGLT2 inhibitor resulted in a mean reduction in glycated haemoglobin (HbA1c) of approximately 0.55% after 104 weeks of therapy (Hsia et al., 2017). The role of these drugs is scientifically proven in atherosclerotic cardiovascular disease, heart failure, and chronic kidney disease. This is of immense importance, especially in type 2 diabetic patients, who commonly have these associated conditions, which form a significant cause of morbidity and mortality. Despite their overall favourable safety profile, the most commonly reported adverse effects associated with SGLT2 inhibitor therapy are genital infections, which are primarily attributed to glycosuria. Importantly, however, the risk of UTI does not appear to be significantly increased (Nelinson et al., 2021). Hyperglycaemia itself remains a more prominent risk factor for UTI in patients with T2DM.

Another coexisting problem is euglycemic ketoacidosis, but it appears rarely and genuinely in patients with multiple chronic conditions. Cumulatively, the relative benefits of SGLT2 inhibitors far outweigh their possible adverse effects, which is mainly why they have been so widely used in clinical settings. Due to their wide-ranging beneficial effects, SGLT2 inhibitors remain the focus of ongoing research studies aimed at further understanding their positive outcomes and possible adverse effects.

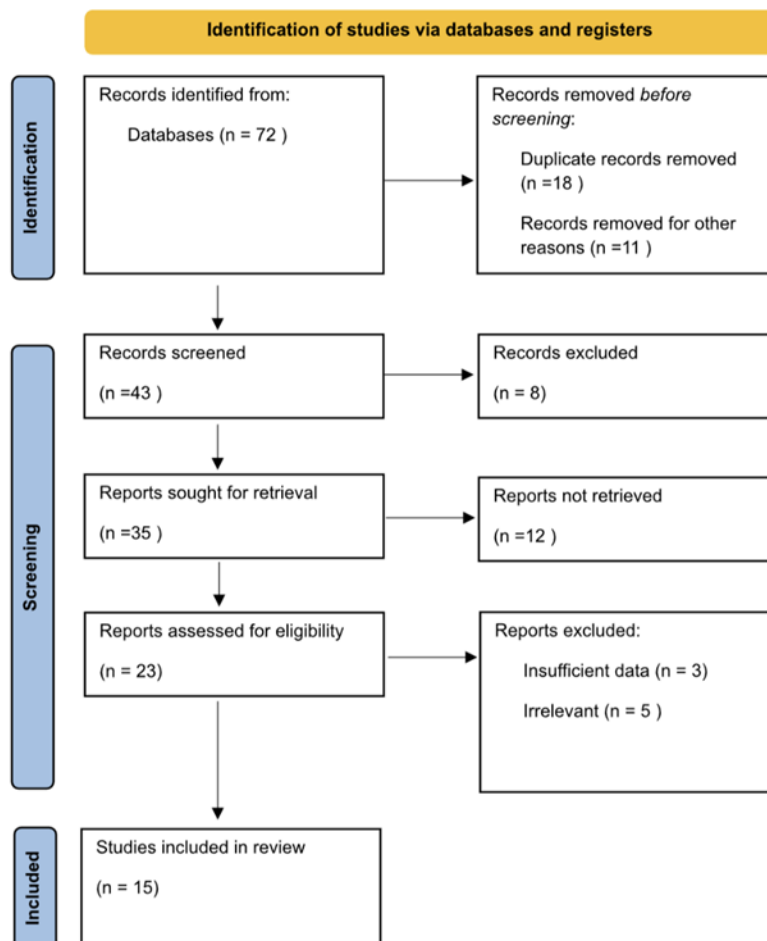


Figure 1. PRISMA CONSORT chart

2. REVIEW METHODS

This study was a narrative review of the existing literature on SGLT2 inhibitors and their clinical applications. The review paper was based on articles and pages available online, such as on PubMed, Google Scholar, and medical websites. Relevant publications were identified through targeted keyword searches related to SGLT2 inhibitors, antihyperglycaemic drugs, SGLT2 inhibitors and chronic diseases, and SGLT2 inhibitors and cancers.

Only English-language articles available online have been included, mainly those published after 2024 to provide up-to-date, clinically relevant information. Older articles were chosen to provide a brief historical background. The aim was to focus on potential new effects—the article research process followed by the PRISMA guidelines (Figure 1).

3. RESULTS & DISCUSSION

Effects on potassium

There is a question about the influence of SGLT2 inhibitors on potassium excretion, looking at the drug's physiological effects in the proximal tubule. Despite the drug's mechanism of action in the kidney tubules, potassium imbalances in plasma are rare (Palmer et al., 2024). However, a slight reduction in plasma potassium concentration occurs in patients with normal kidney function. When kidney function is reduced or when given with drugs that block the renin-angiotensin-aldosterone axis, flozins present a protective effect against hyperkalemia.

In a meta-analysis of individual patient data from six trials comprising >49,000 patients, SGLT2 reduces the risk of both serious (≥ 6.0 mmol/L) and mild (≥ 5.5 mmol/L) hyperkalemia without increasing the risk of hypokalemia, including among patients receiving diuretics (Hsia et al., 2017). The ability of SGLT2in to reduce the incidence of moderate to severe hyperkalemia is also present in heart failure patients receiving mineralocorticoid antagonists. What is essential is a balance between excretion and retention of K⁺. The kaliuretic effect is caused by an osmotic diuresis that leads to glycosuria, reducing plasma volume by about 7-9%. On the other hand, K⁺ secretion is decreasing by increasing the concentration of glucagon in the plasma. Also, flozins promote the excretion of electrolyte-free water, which is why the renin-angiotensin system is less activated. It all limits the kidney K⁺ excretion.

To sum up, the neutrality of SGLT2i therapy and the development of abnormalities in plasma K⁺ concentration were confirmed.

Effects on carcinogenesis

There was a suspicion of SGLT-2 inhibitors' influence on carcinogenesis, particularly because diabetes mellitus type 2 may be a risk factor for various cancers. Several mechanisms have been proposed to explain the potential anticancer effects of SGLT2 inhibitors. This includes inhibition of ATP production, suppression of glutamate dehydrogenase activity, inhibition of DNA and RNA synthesis, activation of AMP-activated protein kinase (AMPK) pathways, and induction of apoptosis and oxytosis. Nevertheless, further studies are required to prove the potential anticancer properties of these agents (Copur et al., 2024).

However, mouse studies revealed that using flozins could be associated with bladder cancer, especially when it comes to empagliflozin. Besides, meta-analyses showed no significant increase in overall malignancy incidence of any specific type. Also, including 58 publications comprising 113,909 participants with type 2 diabetes mellitus, chronic kidney disease, high cardiovascular risk, heart failure, or combined (SGLT2 inhibitor group, 63864; placebo group, 50045), it turned out that compared to the placebo, SGLT2 inhibitors did not significantly increase the overall incidence of cancer (Xu et al., 2024).

Moreover, anti-SGLT2 drugs could reduce heart damage associated with taking doxorubicin, which can allow for the use of higher doses of chemotherapy. A recent observational retrospective cohort study investigated the safety and effectiveness of SGLT2 inhibitors in patients with cancer and diabetes mellitus who were treated with anthracyclines. This trial of 32 case patients treated with SGLT2 inhibitors and anthracyclines and 96 control patients treated with anthracyclines without SGLT2 inhibitors. In a median follow-up of 1.5 years, SGLT2 inhibitors reduced the incidence of cardiac events (Dabour et al., 2024). There seems to be a requirement for additional research on the potential anticancer properties.

Effects on anaemia

Since the first studies on flozins were published, patients using them have been found to have higher haemoglobin and haematocrit levels than at the beginning. This issue is essential due to common anaemias in patients suffering from DM2, heart failure, and chronic kidney disease, because of the continuous inflammation process. Naturally, one of the reasons is the diuretic effect of these drugs and,

consequently, a decrease in plasma volume, leading to greater hemo concentration. However, it was noticed that other mechanisms could be involved in that process.

Studies have shown an increased level of erythropoietin in patients using anti-SGLT2 drugs. The probable reason is normalization of renal cortical oxygenation, which reduces metabolic stress and improves tubulointestinal function, thereby stimulating EPO production and, later, erythropoiesis. Also, flozins help increase iron availability. Chronic inflammation associated with the diseases mentioned above leads to increased hepcidin levels, which cause functional iron deficiency and, in turn, normocytic anaemia. Likewise, with EPO, anti-SGLT2 drugs reduce inflammation by activating hypoxia-inducible factor 2 (HIF-2), which is the main stimulus for the expression of genes involved in iron uptake and tissue distribution, including those in the bone marrow.

As a result, iron availability increases. Overall, treatment with SGLT2-i is associated with a 0.5–0.7 g/dL increase in hemoglobin levels and equivalent increase in hematocrit, which is another benefit for patients. At the American Society of Nephrology 2023 congress, meta-analyses on renal events were presented, confirming that the most protective changes in kidney function were an increase in hematocrit (35.5%) and a reduction in albuminuria (35.4%) (Cases et al., 2024). Additionally, haemoglobin and haematocrit levels rise regardless of co-occurring diabetes mellitus or heart failure (Locatelli and Del Vecchio, 2024).

A meta-analysis evaluating drug effects on anaemia indicated that canagliflozin at a dose of 100 mg was the most effective in increasing haematocrit levels, whereas a 200 mg dose produced the greatest increase in haemoglobin level (Luo et al., 2024).

Effects on atrial fibrillation

SGLT2 inhibitors are commonly used in patients suffering from heart failure. Heart failure is a risk factor of atrial fibrillation, which increases mortality in the population. It was noticed that administration of these drugs lowers the risk of atrial arrhythmias and sudden cardiac death. Therefore, there appeared a suspicion whether flozins have an impact on atrial fibrillation treatment, also without comorbid heart failure. Dapagliflozin was used in human induced pluripotent stem cell-derived cardiomyocytes and human myocytes from 36 patients undergoing open-heart surgery. Moreover, the acute treatment with high-dose dapagliflozin resulted in a significant reduction in the inducibility, amplitude, and maximum upstroke velocity of action potentials. The inhibitory effects were much more pronounced in atrial cells than in ventricular cells (Paasche et al., 2024). In their quest for a physiological mechanism, researchers identified that dapagliflozin directly acts on the depolarization phase of atrial action potentials. More specifically, there was a significant decrease in peak sodium current densities, accompanied by a moderate inhibition of the transient outward potassium current. Experiments were repeated in a large-animal model, in that case, a pig, under anesthesia, and the acute effects of dapagliflozin were similar to those of class I antiarrhythmic agents. Conclusions are very promising - dapagliflozin could be effectively employed for cardioversion of acute AF episodes and rhythm control of persistent AF, which would be a novel mechanism of action for SGLT2 inhibitors. The results of this work suggest that a wide range of cardiac patients may benefit from the temporary use of higher-than-currently-approved doses of SGLT2 inhibitors, based on their acute antiarrhythmic effects.

Moreover, a meta-analysis of 33 placebo-controlled randomized clinical trials showed a significantly lower risk of AF, with the favorable effect of SGLT2 inhibitors appearing to be substantially greater in patients with HF_{rEF}, male gender, dapagliflozin, and longer follow-up (> 1 year) (Liao et al., 2024). When it comes to patients with a history of heart failure, there appears to be a borderline lower risk of sudden cardiac death while using SGLT2 inhibitors.

Effects on MAFLD

Metabolically associated fatty liver disease (MAFLD) is another condition in the spectrum of lifestyle diseases that can progress to death due to hepatic fibrosis, liver cirrhosis, and hepatocellular carcinoma.

Clinical trials conducted in patients with MAFLD previously treated with SGLT2 inhibitors have demonstrated that these drugs can improve liver steatosis and metabolic factors. The parameters assessed in these studies included serum transaminase activity, lipid profile, coagulation factors, and glycated haemoglobin levels. However, the present data are still limited and have to be confirmed by larger randomized trials. The parameters assessed in the study were the activity of serum transaminases, lipid profile, coagulation factors, and glycated hemoglobin. It was proven that nearly one year after the start of SGLT2 inhibitor therapy, a statistically significant decrease in aspartate aminotransferase (AST) and alanine aminotransferase (ALT) activity was found, together with a decrease in glycated haemoglobin levels and body mass index (BMI). In an observational study, there was a reduction in the risk of cardiovascular incidents and deaths in 10 years (Suki et al., 2025). The combination of SGLT2 inhibitors with glucagon-like peptide-1 receptor agonists is promising, owing to the possible synergistic effects of these medications on metabolism and the liver.

Effects on euglycemic ketoacidosis

Euglycemic diabetic ketoacidosis (euDKA) is a rare but very important complication of the use of sodium-glucose cotransporter 2 (SGLT2) inhibitors. By increasing the volume of glucose excreted by the kidneys, SGLT2 inhibitors lower plasma glucose levels; however, this also reduces insulin secretion and increases glucagon secretion. This hormonal change leads to increased lipolysis and, subsequently, increased ketone production, even when blood glucose is normal. In addition, pseudohyponatremia (low sodium in the blood) due to hyperglycemia is usually absent.

Patients who are at increased risk are those who have sepsis, those who are in the postoperative period, and those who are hospitalized with poor oral intake (Gao et al., 2025). If a patient presents with suspected metabolic acidosis, a quick urine ketone test is needed, regardless of their blood glucose level. Notably, comparable increases in ketone body concentrations have been observed following a single dose of an SGLT2 inhibitor and during chronic therapy (Lee et al., 2025). Importantly, the presence of euglycemic diabetic ketoacidosis was not associated with increased hospital stay, mortality, or a higher rate of transfer to the ICU.

Effects on urogenital infections

Regarding their mechanism of action, which involves inducing glycosuria, sodium-glucose cotransporter-2 inhibitors have been associated with a theoretical increased risk of genitourinary tract infections. Furthermore, glycosuria may also affect the pH levels in the area, affecting the microbiome of the urinary tract. With the increasing use of flozins, there has been an increase in the number of patients with UTI symptoms. In most of these cases, the symptoms were not laboratory confirmed (Confederat et al., 2025). Such complaints were reported among patients aged 65 years or older, with reduced estimated glomerular filtration rate (eGFR) and concomitant proteinuria.

The incidence of infections was higher in patients with diabetes compared with those receiving flozins for renal or cardiovascular indications; however, this observation may be confounded by the fact that diabetes is an independent risk factor for UTI. Nevertheless, the potential clinical benefits of SGLT2 inhibitor therapy outweigh the risk of infection and should not represent a barrier to treatment initiation.

In the end, SGLT-2 inhibitors are extremely versatile therapeutic products with a large and ever-increasing clinical base. They were launched as glucose-reducing medications for T2DM. However, they have also demonstrated significant benefit in treating conditions like chronic renal failure and heart disease, independent of the antihyperglycemic effects of these medications.

Current evidence indicates that the clinical benefits of SGLT-2 inhibitors far outweigh the potential risks, given their high tolerability in patients. That said, some adverse events associated with SGLT-2 inhibitors must be considered in practice. Of these, the most important would be euglycemic diabetic ketoacidosis, a rare but potentially serious metabolic complication characterized by high-anion-gap metabolic acidosis, increased ketone production, and venous glucose concentrations that are either normal or only slightly elevated. Although this condition does not occur frequently, clinicians should be vigilant for it, especially when there are potential precipitating factors such as extended periods of fasting, acute illness, stress/fractured bones/treatments associated with surgery, or excessive alcohol consumption. There are concerns about the potential risk of genitourinary infections related to SGLT2 inhibitor-induced glycosuria. Although genital infections were reported more commonly, available evidence does not indicate a significant increase in the risk of UTI (Table 1). It is similar to that seen in patients with diabetes mellitus not receiving flozins.

Table 1. Summary of the mechanisms of action

CATEGORY	EFFECT	OUTCOME
ADVANTAGES	Cardioprotective effect	Reduced risk of atrial fibrillation and cardiac events
ADVANTAGES	Increased haemoglobin and hematocrit	Higher erythropoietin and improved iron availability
ADVANTAGES	MAFLD improvement	Reduced liver enzymes, steatosis, HbA1c and BMI
ADVANTAGES	Potassium neutrality	Maintains potassium balance
ADVANTAGES	Potential anticancer effect	Inhibition of ATP production, AMPK activation, apoptosis induction

DISADVANTAGESs	Euglycemic ketoacidosis	Increased ketone production despite normal glucose
DISADVANTAGES	Urinary tract infections	Glucosuria promotes genitourinary infections

4. CONCLUSION

In conclusion, as scientists have become interested in flozins, some experimental studies have examined both the established and potential benefits of these medications. In this review, we have considered the latest advances in what is now known as the 'less-explored' pleiotropic effects of SGLT2 inhibitors, including their ability to lower the incidence of hyperkalaemia; their anticarcinogenic potential; potential increases in haemoglobin; and indications for reducing both new-onset and recurrent atrial fibrillation through prevention of atrial fibrillation. This new understanding of the pleiotropic effects of SGLT2 inhibitors has major implications for how we manage related lifestyle diseases as we advance.

Acknowledgments

We would like to express my sincere gratitude to all those who supported me throughout the course of this work.

Authors' Contributions

Conceptualization, supervision, and project administration: Aleksandra Rusak-Sobolewska, Gabriela Krych, Joanna Oklińska

Methodology: Michał Skóra, Klaudia Jadczyk

Software, validation, formal analysis, investigation, resources, writing original draft preparation: Weronika Gniado, Bartłomiej Kazimierski, Dawid Mądry.

Writing review, editing, and visualization: Aleksandra Rusak-Sobolewska, Gabriela Krych.

All authors have read and agreed with the published version of the manuscript.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Funding

This research did not receive any external funding like specific grant from funding agencies in the public, commercial, or nonprofit sectors.

Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

All data associated with this work are present in the paper.

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