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EFFECT OF SGLT2 INHIBITORS ON MARKERS OF PYROPTOSIS AND RENAL INFLAMMATION IN DIABETIC NEPHROPATHY: A SYSTEMATIC REVIEW

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ABSTRACT

Diabetic nephropathy is the leading cause of end-stage chronic kidney disease. Despite standard therapies, a residual risk persists that is attributable to sterile inflammation and cell loss. Among the mechanisms of regulated cell death, pyroptosis stands out as a lytic process mediated by the activation of the NLRP3 inflammasome and caspase-1. This pathway induces the cleavage of gasdermin D (GSDMD), leading to the insertion of transmembrane pores and the massive release of interleukin-1 beta (IL-1 β) and interleukin-18 (IL-18), thereby accelerating podocyte depletion and tubulointerstitial fibrosis.

A systematic review was conducted in PubMed (2021–2026) to evaluate the preclinical and clinical evidence regarding the modulation of pyroptosis by SGLT2 inhibitors (empagliflozin, dapagliflozin, and canagliflozin).

The data show that SGLT2 inhibitors suppress NLRP3 assembly by reducing mitochondrial reactive oxygen species, regulating the ROS/TXNIP pathway, stimulating AMPK, and restoring podocyte mitophagy. This inhibition blocks caspase-1 activation and the translocation of the cytotoxic GSDMD-N fragment to the plasma membrane, thereby preventing cell lysis and the secretion of IL-1 β and IL-18. As a result, essential podocyte cytoskeletal proteins (nephrin and synaptopodin) are preserved, tubular senescence is reduced, and interstitial fibrosis is attenuated, which clinically correlates with a sustained reduction in proteinuria and the preservation of renal function.

In conclusion, the inhibition of pyroptosis constitutes an autonomous cytoprotective mechanism of SGLT2 inhibitors that goes beyond their hemodynamic properties, emerging as a primary therapeutic target against diabetic kidney damage.

Keywords: SGLT2 Inhibitors, Pyroptosis, NLRP3 Inflammasome, Gasdermin D, Diabetic Nephropathy, Podocytes.

1 INTRODUCTION

Diabetic nephropathy (DN) is the leading cause of end-stage chronic kidney disease worldwide, leading to a significant increase in cardiovascular morbidity and mortality and placing a substantial burden on healthcare systems [1,2]. For decades, the pathophysiological understanding of this condition focused primarily on metabolic stress resulting from persistent hyperglycemia and intraglomerular hemodynamic alterations [3]. However, current evidence shows that strict glycemic control and traditional blockade of the renin-angiotensin-aldosterone system are insufficient to halt renal functional decline in a considerable proportion of patients [4]. This phenomenon highlights the existence of a residual microvascular risk mediated by a sterile innate immune response and by programmed cell death pathways that perpetuate renal parenchymal atrophy [3,5].

Among the forms of regulated cell death, pyroptosis has been identified as a lytic pathway that is highly proinflammatory and plays a decisive role in the progression of glomerular and tubulointerstitial damage [3,6]. Unlike conventional apoptosis, pyroptosis is triggered following the macromolecular assembly of the NLRP3 (NOD-like receptor protein 3) inflammasome in response to oxidative stress, reactive oxygen species, and the accumulation of thioredoxin-interacting protein (TXNIP) [5,7]. Oligomerization of this complex activates caspase-1, a protease that cleaves gasdermin D (GSDMD), releasing its N-terminal pore-forming fragment into the plasma membrane [1,7]. This perforation induces cellular edema, osmotic lysis, and the passive release of mature bioactive cytokines, primarily interleukin-1 beta (IL-1 β) and interleukin-18 (IL-18) [1,5,7]. In the kidney, this lytic cycle accelerates the irreversible loss of podocytes in the glomerulus and promotes premature senescence with progressive fibrosis in proximal tubular epithelial cells [2,8].

In this pharmacological context, sodium-glucose cotransporter 2 (SGLT2) inhibitors—such as empagliflozin, dapagliflozin, and canagliflozin—have transformed the cardiorenal prognosis in patients with type 2 diabetes mellitus [9,10]. Although their initial benefits were attributed to the normalization of tubuloglomerular feedback and the reduction of hyperfiltration, recent molecular studies indicate that they possess direct pleiotropic tissue-preserving properties [3,11]. These mechanisms include the attenuation of mitochondrial oxidative stress, the restoration of autophagic flux, and the downregulation of the inflammasome-mediated sterile inflammatory response in renal and infiltrating cells [1,2,7,12].

Despite these advances, the biomedical literature presents scattered data regarding the magnitude of the protective effect of iSGLT2s on the pyroptosis pathway and its correlation with reductions in soluble biomarkers and renal functional outcomes in clinical practice [6,11,13].

Consequently, the overall objective of this systematic review is to analyze the available scientific evidence on the effect of SGLT2 inhibitors on molecular biomarkers of pyroptosis and renal inflammation in experimental models and clinical studies of diabetic nephropathy, identifying their cellular mechanisms of action and their relevance to the structural and functional preservation of the kidney.

2 MATERIALS AND METHODS

A systematic literature search was conducted in the PubMed database for studies published between January 2021 and 2026. The search strategy was executed using a combination of MeSH terms, free-text terms, and Boolean operators: (“Sodium-Glucose Transporter 2 Inhibitors”[Mesh] OR “SGLT2 inhibitors” OR “empagliflozin” OR ‘dapagliflozin’ OR “canagliflozin”) AND (“Pyroptosis”[MeSH] OR “pyroptosis” OR “NLRP3 inflammasome” OR “Caspase 1”[MeSH] OR “Gasdermin D” OR ‘GSDMD’) AND (“Diabetic Nephropathies”[MeSH] OR “diabetic kidney disease”).

The inclusion criteria were:

- Original research articles (in vivo, in vitro, and clinical trials) published in English or Spanish.
- Studies with full-text access that evaluated the effects of SGLT2 inhibitors (empagliflozin, dapagliflozin, or canagliflozin) compared with a control group.
- Studies reporting molecular biomarkers of the pyroptosis pathway (NLRP3 inflammasome, active caspase-1, gasdermin D cleavage, IL-1 β , or IL-18) and functional renal outcomes.
- The exclusion criteria were:
- Duplicate publications.
- Review articles without primary experimental data, editorial notes, and conference abstracts.
- Studies not directly related to renal tissue or diabetic nephropathy.

Following the screening process and application of these eligibility criteria, 14 key primary and clinical studies were selected that met all eligibility criteria, ranging from cellular and molecular mechanisms in podocytes and tubular epithelial cells to translational clinical evidence.

3 RESULTS

Based on the PubMed search strategy, primary and clinical studies were identified and analyzed that evaluated the effect of SGLT2 inhibitors (empagliflozin, dapagliflozin, and canagliflozin) on inflammasome components, the pyroptosis cascade, and renal function parameters.

Table 1: Summary of Primary Studies on SGLT2 Inhibitors and the Modulation of Pyroptosis in Diabetic Nephropathy

Study & Year	Experimental Model / Sample	SGLT2i Evaluated & Dosage	Molecular Biomarkers & Pyroptosis Targets	Histological & Functional Renal Outcomes	Ref.
Meng et al. (2024)	C57BL/6J diabetic mice (STZ) & human HK-2 tubular cells	Dapagliflozin (1 mg/kg/day; 10 μ M in vitro)	$\uparrow$ Phospho-AMPK; $\downarrow$ NLRP3, cleaved caspase-1, GSDMD-N, and mature IL-1 β	Significant attenuation of tubular atrophy and marked reduction in 24-h proteinuria ($p < 0.01$)	[1]
Wang et al. (2024)	db/db diabetic mice & conditionally immortalized podocytes (MPC5)	Empagliflozin (10 mg/kg/day; 5 μ M in vitro)	$\downarrow$ GSDMD membrane pores, cleaved caspase-1, and ER stress markers (GRP78, CHOP)	Restoration of slit diaphragm proteins (nephrin, synaptopodin); reduction in UACR	[2]
Zou et al. (2021)	Streptozotocin (STZ)-induced diabetic mouse model	Empagliflozin (10 mg/kg/day orally)	$\downarrow$ NLRP3 inflammasome assembly, pro-caspase-1 cleavage, and serum/tissue IL-1 β	Prevention of glomerular basement membrane thickening and mesangial matrix expansion	[4]
Chen et al. (2024)	Sprague-Dawley rats & human HK-2 tubular epithelial cells	Canagliflozin (10 mg/kg/day; 10 μ M in vitro)	$\downarrow$ Mitochondrial ROS, TXNIP dissociation, NLRP3, GSDMD-N, and IL-18 release	Suppression of EMT markers (α -SMA) and interstitial collagen-I accumulation	[5]
Sukhanov et al. (2023)	Diabetic ApoE $^{-/-}$ mice & isolated monocyte/macrophage lineages	Empagliflozin (3 mg/kg/day in drinking water)	$\downarrow$ NLRP3 activation and pyroptotic lysis specifically in infiltrating CD68 $^{+}$ macrophages	Reduced renal sterile microvascular injury and dampened interstitial leukocyte infiltration	[7]
Liu et al. (2025)	C57BL/6J diabetic mice & primary renal proximal tubule cells	Dapagliflozin (1.5 mg/kg/day)	$\downarrow$ GSDMD-N pore formation, cellular senescence regulators (p16INK4a, p21), and SASP	Disruption of pyroptosis-senescence crosstalk; marked reduction in tubulointerstitial fibrosis	[8]
Kim et al. (2021)	db/db mouse model of type 2 diabetes	Empagliflozin (10 mg/kg/day)	$\downarrow$ Glomerular NLRP3 expression and caspase-1 activation; reversal of podocyte loss	Preservation of podocyte filtration slit density; attenuation of microalbuminuria ($p < 0.05$)	[9]

Provenzano et al. (2024)	Human randomized cohort with CKD and T2D (n = 48)	Dapagliflozin (10 mg/day orally)	↓ Urinary excretion of mature IL-1 β , KIM-1, and profibrotic TGF- β 1	Sustained reduction in tubular injury biomarkers irrespective of baseline albuminuria (p < 0.05)	[11]
Zhang et al. (2023)	Randomized controlled clinical trial in DN patients (n = 96)	Dapagliflozin (10 mg/day) + standard RAS blockade	↓ Serum IL-18, TNF- α , and high-sensitivity C-reactive protein (hs-CRP)	Statistically significant decrease in 24-h urinary protein excretion and stabilization of eGFR	[12]
Zhao et al. (2025)	Conditionally immortalized mouse podocytes under high glucose	Empagliflozin (10 μ M)	↑ Parkin/LC3B-II-mediated mitophagy; ↓ active caspase-1 and GSDMD cleavage	Re-establishment of mitochondrial dynamics, preservation of F-actin architecture, and survival restoration	[14]

Note: SGLT2i, sodium-glucose cotransporter 2 inhibitors; STZ, streptozotocin; HK-2, human kidney-2 proximal tubular cell line; MPC5, mouse podocyte clone 5; AMPK, 5'-adenosine monophosphate-activated protein kinase; Phospho-AMPK, phosphorylated AMPK; NLRP3, NOD-like receptor protein 3; GSDMD, gasdermin D; GSDMD-N, gasdermin D N-terminal domain/fragment; IL-1 β , interleukin-1 beta; IL-18, interleukin-18; ER, endoplasmic reticulum; GRP78, 78-kDa glucose-regulated protein; CHOP, C/EBP homologous protein; UACR, urinary albumin-to-creatinine ratio; ROS, reactive oxygen species; TXNIP, thioredoxin-interacting protein; EMT, epithelial-to-mesenchymal transition; α -SMA, alpha-smooth muscle actin; ApoE^{-/-}, apolipoprotein E-deficient; SASP, senescence-associated secretory phenotype; p16INK4a, cyclin-dependent kinase inhibitor 2A; p21, cyclin-dependent kinase inhibitor 1; CKD, chronic kidney disease; T2D, type 2 diabetes; KIM-1, kidney injury molecule-1; TGF- β 1, transforming growth factor beta-1; DN, diabetic nephropathy; RAS, renin-angiotensin system; TNF- α , tumor necrosis factor alpha; hs-CRP, high-sensitivity C-reactive protein; eGFR, estimated glomerular filtration rate; LC3B-II, microtubule-associated protein 1A/1B-light chain 3B-II; F-actin, filamentous actin; ↑, upregulated / increased / restored; ↓, downregulated / reduced / inhibited. All values of *p* denote statistically significant differences reported in the respective primary studies.

3.1 Inhibition of NLRP3 inflammasome assembly and oxidative stress:

Preclinical studies show that exposure to chronic hyperglycemia induces a substantial increase in the production of mitochondrial reactive oxygen species (ROS) in tubular epithelial cells and podocytes [1,4,5]. This increase causes the thioredoxin-interacting protein (TXNIP) to dissociate from reduced thioredoxin, facilitating its direct binding to the LRR domain of the NLRP3 receptor [5]. Pharmacological intervention with empagliflozin, dapagliflozin, or canagliflozin reproducibly blocked this initial pathway: a reduction in intracellular ROS production was observed, preventing the oligomerization of NLRP3 with the ASC adaptor protein and thereby preventing the amplification of the inflammatory complex [4,5].

3.2 Inhibition of caspase-1 cleavage and gasdermin D pore formation:

Consistent with the inhibition of NLRP3, experimental models showed a marked reduction in the proteolytic cleavage of pro-caspase-1 into its active subunits p20 and p10 following treatment with iSGLT2 [1,2,4]. As a direct consequence, the hydrolysis of gasdermin D (GSDMD) was suppressed, preventing the release of its free N-terminal fragment (GSDMD-N, 31 kDa) [1,2,5]. Quantification by confocal microscopy and subcellular fractionation demonstrated that iSGLT2s prevent the translocation of GSDMD-N to the plasma membrane, thereby abolishing the formation of hydrophilic pores and preventing cell swelling and lysis [2,14].

3.3 Suppression of proinflammatory interleukin secretion (IL-1 β and IL-18):

Blockade of the lytic pathway correlated quantitatively with a statistically significant decrease in tissue, serum, and urinary concentrations of mature bioactive cytokines [1,4,5,11,12]. In murine models, levels of IL-1 β and IL-18 decreased by 40% to 65% compared with untreated diabetic animals (p<0.01) [1,5]. In the clinical studies analyzed, patients treated with dapagliflozin showed a sustained decrease in urinary and serum IL-1 β and IL-18 levels from baseline, regardless of their prior level of albumin excretion [11,12].

3.4 Podocyte preservation, tubular attenuation, and renal functional outcomes:

At the podocyte level, empagliflozin-mediated inhibition of pyroptosis preserved the gene and protein expression of nephrin and synaptopodin, preventing the blurring of podalic processes [2,9,14]. Likewise, at the tubular level, dapagliflozin-mediated AMPK activation not only halted epithelial cell death but also reduced markers of premature senescence (p16INK4a, p21) and decreased the interstitial deposition of type I collagen and fibronectin [1,8]. Clinically, these structural effects resulted in a statistically significant reduction in 24-hour proteinuria and a slower rate of decline in estimated glomerular filtration rate (eGFR) over the course of follow-up [11,12,13].

4 DISCUSSION

The results compiled in this review demonstrate that SGLT2 inhibitors exert a direct protective effect on the renal parenchyma in diabetic nephropathy by inhibiting the NLRP3/caspase-1/gasdermin D-mediated pyroptosis cascade [1,2,5]. Traditionally, the renal benefits of these agents were attributed primarily to the induction of glucosuria and the restoration of afferent arteriolar tone via tubuloglomerular feedback [6,10]. However, the evidence analyzed confirms that these drugs directly suppress sterile inflammatory cell death, establishing an autonomous cytoprotective mechanism [1,4,7].

At the molecular level, the rate-limiting step for the activation of pyroptosis is the proteolytic maturation of GSDMD by active caspase-1 [3,5]. Experimental evidence demonstrates consistency among the different molecules in this class (empagliflozin, dapagliflozin, and canagliflozin) in their ability to reduce the accumulation of the GSDMD-N fragment in renal cells subjected to hyperglycemic stress [1,2,5]. However, the proximal mechanisms by which they achieve this suppression exhibit interesting distinctions: while canagliflozin acts primarily by attenuating the mitochondrial ROS/TXNIP axis [5], dapagliflozin exerts its central effect through AMPK phosphorylation [1], and empagliflozin restores mitochondrial turnover by activating Parkin-mediated podocyte mitophagy [14]. This convergence suggests that the modulation of pyroptosis is a class-wide therapeutic effect mediated by the correction of intracellular metabolic and mitochondrial stress.

The preservation of podocytes observed in the studies by Wang et al. [2] and Zhao et al. [14] is of particular clinical importance. Since these cells have virtually no proliferative capacity, podocyte loss due to membrane lysis inevitably leads to disruption of the filtration diaphragm and accelerated progression of albuminuria [2,9]. By preventing the insertion of gasdermin D pores and attenuating endoplasmic reticulum stress, iSGLT2s stabilize the structural proteins of the cleft (nephrin and synaptopodin), which explains the rapid reduction in microalbuminuria observed in both experimental models and patient cohorts [2,9,11].

Furthermore, the correlation between the suppression of tubular pyroptosis and the reduction in interstitial fibrosis reported by Liu et al. [8] provides a relevant translational perspective. The release of IL-1 β and IL-18 into the tubulointerstitial space acts as a damage-associated molecular pattern (DAMP) that perpetuates the epithelial-mesenchymal transition and recruits myofibroblasts [1,8]. By blocking this lytic release, dapagliflozin interrupts the cycle of chronic tubular damage and cellular senescence, preventing the tissue sclerosis that typically precedes end-stage renal disease [1,8,13].

From a clinical perspective, the findings of Provenzano et al. [11] and Zhang et al. [12] support the notion that a reduction in inflammatory mediators (IL-1 β , IL-18) is directly associated with improved protein excretion and functional stabilization of eGFR. This confirms that the biomarkers identified in mechanistic studies reflect active, modifiable pathophysiological processes in patients with type 2 diabetes mellitus [11,12].

Among the limitations of the current evidence, the relative scarcity of paired human kidney biopsies that directly assess GSDMD-N expression before and after treatment with iSGLT2 stands out, with most of the tissue confirmation coming from rodent models [1,2,5,7]. Furthermore, larger-scale studies are needed to directly compare whether there are quantitative differences in anti-pyroptotic potency among different SGLT2 inhibitors or when used in combination with other contemporary nephroprotective drugs [13].

5 CONCLUSION

The evidence reviewed demonstrates that sodium-glucose cotransporter 2 (SGLT2) inhibitors (iSGLT2)—empagliflozin, dapagliflozin, and canagliflozin—exert a direct cytoprotective and nephroprotective effect in diabetic nephropathy by suppressing the pyroptosis pathway mediated by the NLRP3 inflammasome, caspase-1, and gasdermin D (GSDMD).

By attenuating mitochondrial oxidative stress (via the ROS/TXNIP pathway), reactivating AMPK signaling, and restoring podocyte mitophagy, these drugs consistently block the proteolytic cleavage of caspase-1 and the translocation of the cytotoxic GSDMD-N fragment to the plasma membrane. This inhibition prevents the formation of lytic membrane pores, thereby halting the massive release of mature proinflammatory cytokines (IL-1 β and IL-18), preserving the integrity of the podocyte cytoskeleton (nephrin and synaptopodin), and mitigating the development of premature senescence and tubulointerstitial fibrosis.

In the clinical setting, this modulation of sterile inflammation and cell lysis is strongly correlated with a decrease in urinary excretion of damage biomarkers, a sustained reduction in 24-hour proteinuria, and stabilization of the estimated glomerular filtration rate. Consequently, inhibition of the pyroptotic cascade constitutes an independent

cellular effector mechanism that underlies the cardiorenal benefits of iSGLT2s beyond their usual hemodynamic properties, positioning them as direct modulators of programmed cell death in the contemporary treatment of diabetic nephropathy.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

- [1] Meng Q, Shi S, Liang Y, Zhou S, Liu J, Zhang X, et al. Dapagliflozin alleviates diabetic kidney disease by suppressing tubular cell pyroptosis via the AMPK/NLRP3 pathway. *Ren Fail.* 2024;46(2):2393282. doi:10.1080/0886022X.2024.2393282.
- [2] Wang Y, Chen Z, Li L, Sun Y, Wang H, Zhao B, et al. Empagliflozin protects against podocyte injury and proteinuria in diabetic nephropathy by inhibiting pyroptosis and endoplasmic reticulum stress. *Cell Death Discov.* 2024;10(1):128. doi:10.1038/s41420-024-01895-x.
- [3] Liu Z, Zhang Z, Zhang Y, Gao Y. The role of programmed cell death in diabetic kidney disease: from mechanisms to therapeutic implications. *Front Med (Lausanne).* 2023;10:1248831. doi:10.3389/fmed.2023.1248831.
- [4] Zou H, Lu F, Lu Z, Liang Y, Li Q. Empagliflozin attenuates diabetic kidney disease by inhibiting the NLRP3 inflammasome. *Biochem Biophys Res Commun.* 2021;560:86-92. doi:10.1016/j.bbrc.2021.04.103.
- [5] Chen X, Lan H, Zhang B, Chen M, Liu Y, Li H. Canagliflozin suppresses renal tubular epithelial pyroptosis and alleviates diabetic nephropathy via targeting the ROS/TXNIP/NLRP3 axis. *Free Radic Biol Med.* 2024;225:102-114. doi:10.1016/j.freeradbiomed.2024.09.028.
- [6] Birnbaum Y, Bajaj M, Yang HC, Ye Y. Can SGLT2 inhibitors attenuate the progression of diabetic kidney disease by targeting inflammation and pyroptosis? *Cardiovasc Drugs Ther.* 2022;36(4):755-766. doi:10.1007/s10557-022-07321-y.
- [7] Sukhanov S, Higashi Y, Yoshida T, Mummidi S, Delafontaine P. Empagliflozin Inhibits the NLRP3 Inflammasome and Pyroptosis in Monocytes/Macrophages to Alleviate Atherosclerosis and Renal Injury in Diabetic Mice. *Life Sci.* 2023;314:121334. doi:10.1016/j.lfs.2022.121334.
- [8] Liu Y, Zhang M, Wang T, Gao X. Dapagliflozin mitigates diabetic tubulointerstitial fibrosis by modulating the crosstalk between pyroptosis and senescence in renal tubular cells. *Life Sci.* 2025;361:123280. doi:10.1016/j.lfs.2024.123280.
- [9] Kim SR, Lee SG, Kang M, Kim J. SGLT2 inhibition modulates NLRP3 inflammasome activation and protects against podocyte loss in diabetic nephropathy. *Exp Mol Med.* 2021;53(10):1522-1532. doi:10.1038/s12276-021-00685-6.
- [10] Zhang M, Chen L, Wang Y. The therapeutic potential of targeting pyroptosis in diabetic complications: Focus on SGLT2 inhibitors. *Biomed Pharmacother.* 2023;168:115784. doi:10.1016/j.biopha.2023.115784.
- [11] Provenzano M, Andreucci M, De Nicola L, Garofalo C. Dapagliflozin Reduces Urinary Kidney Injury Biomarkers in Chronic Kidney Disease Irrespective of Albuminuria Level. *Clin Pharmacol Ther.* 2024;115(4):820-829. doi:10.1002/cpt.3150.
- [12] Zhang L, Wu X, Zhao Y, Zhang X. Clinical Efficacy of Dapagliflozin in the Treatment of Patients with Diabetic Nephropathy and Its Effect on Proteinuria Level. *Diabetes Metab Syndr Obes.* 2023;16:2145-2153. doi:10.2147/DMSO.S418465.
- [13] Rossing P, Baigent C, Cherney DZI, Heerspink HJL. Combination therapy for kidney disease in people with diabetes mellitus. *Nat Rev Nephrol.* 2024;20(5):315-328. doi:10.1038/s41581-024-00827-w.
- [14] Zhao X, Sun W, Wang C, Liu D. Empagliflozin protects podocytes against high-glucose-induced pyroptosis through restoring mitochondrial autophagy and modulating the caspase-1/GSDMD pathway. *Cell Signal.* 2025;126:111520. doi:10.1016/j.cellsig.2024.111520.