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The Role of Diabetes Mellitus in the Development of Chronic Kidney Disease: A Review

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ABSTRACT

Chronic kidney disease (CKD) is a prevalent and severe complication of diabetes mellitus (DM), significantly impacting morbidity and mortality globally. In individuals with diabetes, CKD arises from a confluence of mechanisms, including persistent hyperglycemia, glomerular hyperfiltration, oxidative stress, and the activation of profibrotic pathways, culminating in progressive kidney injury. Several factors, such as poor glycemic control, hypertension, obesity, and genetic predisposition, further accelerate the decline in kidney function. In the early stages of CKD, there are usually no symptoms. Albuminuria or small drops in the estimated glomerular filtration rate (eGFR) are usually the first signs that the kidneys are affected. Treatment combines renoprotective medications like ACE inhibitors, ARBs, SGLT2 inhibitors, and GLP-1 receptor agonists with patient education and regular checkups to slow the disease's progress. A proactive, multifaceted approach is essential to reduce the burden of CKD in individuals with diabetes and to improve long-term kidney and cardiovascular outcomes. Doctors and researchers need to know how diabetic CKD starts, what causes it, how it shows up in patients, and how to treat it so that they can come up with better ways to help patients.

Keywords: chronic kidney disease; diabetes mellitus; manifestation; risk factor, prevention

INTRODUCTION

Chronic kidney disease (CKD) is defined by lasting kidney damage or a reduced estimated glomerular filtration rate (eGFR) below 60 mL/min/1.73 m^2 for at least three months. The condition reflects a gradual decline in kidney function, which can eventually require interventions like dialysis or kidney transplantation [9].

Chronic Kidney Disease (CKD) has emerged as a major cause of death around the world, and it is one of the few non-communicable diseases with a steadily increasing death rate over the past two decades [11]. Based on the global studies assessing the prevalence of CKD, it is estimated that approximately 843.6 million people suffer from CKD stage 1-5 [8].

Among the many risk factors that can lead to CKD, diabetes mellitus (DM) has emerged as the major contributor, particularly in developed countries [9]. The global prevalence of DM continues to rise gradually, affecting hundreds of millions of people worldwide, and is expected to increase further [18]. The continued rise of DM will contribute significantly to the increasing burden of CKD. Most of the increase is expected to occur in the Asian region [13]. Therefore, this review focuses on the role of DM in the development of CKD, starting with pathogenesis, risk factors, clinical manifestation, assessment of kidney function, prevention, and management.

METHODS

This study was a focused narrative literature review that aimed to bring together the most recent research about how diabetes mellitus may lead to chronic kidney disease.

RESULT

Pathogenesis

The pathogenesis underlying diabetic-induced CKD involves complex interactions between metabolic and hemodynamic disturbance and primarily begins with chronic hyperglycemia to dysregulated intracellular metabolism, inflammatory lesions, increased apoptosis processes, and tissue fibrosis [4].

Three crucial steps can lead to kidney damage in DM patients they are glomerular hypertrophy leading to hyperfiltration [15], inflammation of glomerular and tubulointerstitial, and altered regulation of cellular apoptosis accompanied by remodelling of extracellular matrix [4].

The first step is glomerular hyperfiltration. Hyperfiltration can occur due to an ultrastructural change. From the early stage of DM, enlargement of the kidney occurs gradually, particularly in the proximal tubules [29,30]. This enlargement is primarily driven by chronic hyperglycemia, which stimulates the release of cytokines and growth factors, although obesity can independently contribute to nephromegaly [25]. Experimental studies have shown that tubular hypertrophy often precedes hyperfiltration, and inhibition of hypertrophic pathways, such as suppression of ornithine decarboxylase, can proportionally reduce hyperfiltration in diabetic models. Since tubular growth tends to regress gradually, and full restoration of normal kidney size is uncommon even with well-controlled blood glucose levels, persistent tubular enlargement and functional alterations may continue to drive glomerular hyperfiltration over time [20].

The second step is inflammation of the glomerular and tubulointestitial. In a diabetic patient, hyperglycemia can trigger a complex inflammatory response within the glomerular and tubulointerstitial [27]. It also activates the resident glomerular cells, tubular epithelial cells, and infiltrating immune cells, particularly macrophages and T lymphocytes, leading to the production of proinflammatory cytokines and chemokines such as TNF-α, IL-6, IL-1β, and MCP-1. This inflammatory microenvironment encourages white blood cells to gather and cause local tissue damage, which can cause scarring [28]. Importantly, the degree of interstitial immune-cell infiltration has been shown to correlate with worsening kidney function, which highlights that inflammation is not just a bystander but also a driving force in diabetic kidney injury [6]. The third step is altered regulation of cellular apoptosis, accompanied by remodelling of the extracellular matrix, which can be a hallmark of kidney injury. Kidney cells such as podocytes, tubular epithelial cells, and mesangial cells are particularly vulnerable to oxidative stress and inflammatory signals under diabetic conditions, which trigger apoptotic pathways (e.g., p53/Bax/caspase-3) and disrupt essential processes like autophagy that normally maintain cell health [6]. The loss of podocytes weakens the glomerular filtration barrier, leading to protein leakage into the urine, while apoptosis of tubular cells results in tubular atrophy and the formation of a tubular glomeruli, further impairing nephron function [24]. Meanwhile, the kidney's structural framework, the extracellular matrix, becomes excessively built up. Overproduction of collagen types I and IV, fibronectin, and laminin, coupled with reduced activity of matrix-degrading enzymes (MMPs), leads to thickening of the glomerular basement membrane, expansion of the mesangial matrix, and progressive tubulointerstitial fibrosis [7].

Profibrotic signals, including TGF-β, CTGF, and Smad2/3, which are activated by sustained hyperglycemia and chronic inflammation, drive tubular epithelial cells to undergo epithelial-to-mesenchymal transition (EMT) into myofibroblasts, thereby amplifying extracellular matrix accumulation [19].

Together, the interplay of uncontrolled cell death and excessive ECM deposition leads to lasting structural alterations in the kidney, including glomerulosclerosis and interstitial fibrosis, ultimately driving progressive loss of kidney function. These pathways are now recognized as critical targets for emerging therapies in diabetic kidney disease [21].

Risk Factor

In individuals with diabetes mellitus, the kidneys face a multifactorial assault, and the accumulation of risk factors dramatically increases the likelihood of kidney injury. Among the strongest predictors is disease duration: a retrospective study of 424 patients with type 2 diabetes (T2DM) found that a diabetes duration of ≥15 years was significantly associated with a high or very high risk of CKD progression (OR ~1.75) compared with lower-risk groups [16].

Another key driver is hypertension. Elevated systemic blood pressure exerts increased intraglomerular pressure and mechanical stress on the filtration barrier. In the same cohort, hypertension increased the odds of high-risk CKD status by approximately four-fold (OR ~4.4, 95% CI 2.6–7.5) [16]. Evidence from multiple large-scale prospective studies indicates that having both diabetes mellitus and hypertension significantly amplifies the risk of developing chronic kidney disease, exceeding the risk posed by either condition alone. In a cohort of 21,905 participants, individuals with both conditions exhibited a CKD incidence of 45.1 per 1,000 person-years, with an adjusted hazard ratio of 1.52 (95% CI 1.35–1.70) compared with those who had hypertension only [22].

Dyslipidaemia has become increasingly recognized as an important factor that independently contributes to the risk of CKD. In a cross-sectional study, patients with high lipid levels were found to have about three times greater likelihood of falling into the high or very high CKD risk category, with an

odds ratio of roughly 3.2 [16]. This suggests that abnormal cholesterol and triglyceride levels may play a direct role in worsening kidney function, potentially through mechanisms such as inflammation, oxidative stress, and damage to blood vessels in the kidneys [3].

Maintaining good blood sugar control continues to be a cornerstone in protecting kidney health. Higher HbA1c levels and greater fluctuations in blood glucose have been closely linked to both an increase in microalbuminuria and a faster decline in estimated glomerular filtration rate (eGFR), reflecting worsening kidney function. A comprehensive meta-analysis of patients with DM from around the world confirms that hyperglycaemia remains the most important modifiable risk factor for kidney disease, even in the presence of other comorbid conditions. This highlights that keeping blood glucose stable is not just about managing diabetes but also a critical strategy for slowing the progression of CKD [3].

Obesity and elevated body mass index (BMI) impose additional hemodynamic and metabolic stress on the kidneys. A Mendelian randomisation study identified obesity, adverse blood lipids, and height as causal traits shared between DM and CKD, suggesting the excess adiposity is not just a coincidence but a mechanistic risk [31].

Smoking habit further magnifies risk by triggering oxidative stress, endothelial dysfunction, and microvascular damage in kidney tissue. A systematic review found smoking increased the odds of diabetic kidney disease (DKD) in T2DM (OR ~1.64, 95% CI 1.30–2.07) [31].

Certain factors that we cannot change also play a significant role in increasing the risk of CKD. Aging is one of the most important factors, as kidneys gradually lose nephrons and their overall functional reserve over time, making them more susceptible to damage from high blood sugar, high blood pressure, and other metabolic stresses [3]. Men are generally at higher risk than women, which may be related to hormonal differences, body composition, and cardiovascular risk patterns that affect kidney health [26]. Additionally, having a family history of kidney disease or diabetes further increases vulnerability, emphasizing that inherited risk is an important part of the picture [10]. Altogether, these non-modifiable factors combine with lifestyle and health conditions to shape an individual's overall susceptibility, highlighting the need for early monitoring and preventive strategies in those at higher risk [9].

Clinical Manifestation

In people with diabetes, whether type 1 or type 2, kidney problems often develop quietly. For a long time, they might not notice any symptoms, even as changes in kidney structure and function are already taking place [12]. In many patients, one of the first signs of kidney involvement is a slight rise in the amount of albumin in the urine, often referred to as "microalbuminuria." This is usually measured as a urinary albumin-to-creatinine ratio between 30 and 300 mg/g, indicating early damage to the glomeruli and that the glomerular filtration barrier is becoming more permeable [14] .

As kidney disease advances, some patients may develop noticeable protein in the urine, known as "macroalbuminuria," along with a slow but steady drop in kidney function. This is often reflected by a decline in estimated glomerular filtration rate (eGFR) below 60 mL/min/1.73 m^2, and in later stages, the eGFR can fall even further, indicating more severe kidney impairment [35]. When kidney damage becomes more pronounced, patients may start to notice clinical symptoms such as swelling in the legs and ankles, persistent fatigue, anemia, and imbalances in fluids and electrolytes, including high potassium levels or metabolic acidosis. These symptoms arise not just from glomerular injury but also from damage to the kidney's tubules and interstitial tissue, a reduced number of functioning nephrons, and the wider systemic effects of impaired kidney function [12].

In addition to kidney-specific symptoms, diabetes-related kidney disease often occurs alongside other health issues. High blood pressure is commonly seen, and having albumin in the urine or a lowered eGFR significantly raises the risk of cardiovascular problems. Interestingly, in many patients with type 2 diabetes, a decline in eGFR can appear even before albuminuria develops, meaning the traditional progression from microalbuminuria to macroalbuminuria and then to reduced kidney function does not always follow a strict pattern [1].

Prevention and Management

According to the Kidney Disease: Improving Global Outcomes (KDIGO) 2022 guidelines, recommended early screening for albuminuria and kidney function decline, optimization of glycemic and blood pressure, and the use of renoprotective drugs, such as ACE inhibitors, ARBs, sodium-glucose cotransporter 2 (SGLT2) inhibitors, and glucagon-like peptide-1 (GLP-1) receptor agonists in patients with DM to prevent or delay the progression of CKD [8].

Individuals with diabetes are at a considerable risk of developing kidney problems, but the encouraging fact is that proactive prevention and careful management can substantially slow or even prevent the progression of kidney damage. Maintaining early and consistent blood sugar control is key. Numerous reviews emphasize that keeping HbA1c within recommended targets and minimizing fluctuations in blood glucose can help prevent the development of microalbuminuria and slow the decline in kidney filtration function [2].

In addition to controlling blood sugar, careful management of high blood pressure and abnormal lipid levels is essential. Guidelines stress that keeping blood pressure well-controlled, typically below 130/80 mmHg, using RAAS-blocking medications, and addressing cholesterol with lipid-lowering therapies

all play a vital role in protecting kidney health [17].

Lifestyle changes form the foundation of kidney disease prevention in diabetes. Keeping a healthy weight, engaging in regular physical activity, following a kidney-supportive diet, such as limiting sodium and avoiding excessive protein intake when appropriate, and quitting smoking are all strongly linked to a reduced risk of diabetic kidney disease progression [5].

In recent years, treatment options have expanded. Newer glucose-lowering drugs, especially SGLT2 inhibitors and GLP-1 receptor agonists, not only help control blood sugar but also offer direct kidney protection. Studies show they can reduce albuminuria, slow the decline of eGFR, and lower the risk of progressing to end-stage kidney disease [23]. For individuals already showing evidence of kidney damage, such as albumin in the urine or a falling eGFR, early detection through yearly monitoring of UACR and eGFR, along with prompt referral and coordinated multidisciplinary care, is crucial for optimal outcomes [2].

In practice, managing established kidney disease in diabetes works best with a multi-pronged strategy. This includes tightly controlling blood sugar, blood pressure, and cholesterol; using RAAS-blocking medications; considering SGLT2 inhibitors or GLP-1 receptor agonists; reinforcing healthy lifestyle habits; regularly monitoring kidney and cardiovascular health; and managing complications like anemia or mineral-bone disorders as kidney function worsens [2].

CONCLUSION

Diabetes mellitus plays a central role in the onset and progression of chronic kidney disease, acting through mechanisms such as persistent high blood sugar, overworking of the kidneys, oxidative stress, and pathways that promote kidney scarring. Factors like poor blood sugar control, high blood pressure, obesity, and genetic susceptibility can further accelerate kidney damage.

Early kidney changes are often silent, making routine monitoring with eGFR and urine albumin-to-creatinine ratio essential for early detection and risk assessment. Prevention emphasizes maintaining healthy blood sugar and blood pressure, adopting a balanced lifestyle, and managing other related conditions. Treatment combines medications that protect the kidneys—such as ACE inhibitors, ARBs, SGLT2 inhibitors, and GLP-1 receptor agonists—with patient education and regular follow-up. Taking a proactive, comprehensive approach is crucial to slowing disease progression and improving both kidney and heart health over the long term.

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REFERENCES

[1] Afkarian, M., Zelnick, L. R., Hall, Y. N., Heagerty, P. J., Tuttle, K., Weiss, N. S., & De Boer, I. H. (2016). Clinical manifestations of kidney disease among US adults with diabetes, 1988-2014. *JAMA - Journal of the American Medical Association*, *316*(6), 602–610. https://doi.org/10.1001/jama.2016.10924

[2] de Sá, J. R., Rangel, E. B., Canani, L. H., Bauer, A. C., Escott, G. M., Zelmanovitz, T., Bertoluci, M. C., & Silveiro, S. P. (2022). The 2021–2022 position of Brazilian Diabetes Society on diabetic kidney disease (DKD) management: an evidence-based guideline to clinical practice. Screening and treatment of hyperglycemia, arterial hypertension, and dyslipidemia in the patient with DKD. *Diabetology and Metabolic Syndrome*, *14*(1). https://doi.org/10.1186/s13098-022-00843-8

[3] Fenta, E. T., Eshetu, H. B., Kebede, N., Bogale, E. K., Zewdie, A., Kassie, T. D., Anagaw, T. F., Mazengia, E. M., & Gelaw, S. S. (2023). Prevalence and predictors of chronic kidney disease among type 2 diabetic patients worldwide, systematic review and meta-analysis. In *Diabetology and Metabolic Syndrome* (Vol. 15, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s13098-023-01202-x

[4] Gembillo, G., Ingrasciotta, Y., Crisafulli, S., Luxi, N., Siligato, R., Santoro, D., & Trifirò, G. (2021). Kidney disease in diabetic patients: From pathophysiology to pharmacological aspects with a focus on therapeutic inertia. In *International Journal of Molecular Sciences* (Vol. 22, Issue 9). MDPI AG. https://doi.org/10.3390/ijms22094824

[5] Habli, M. M. (2024). Comprehensive insights into diabetic nephropathy: pathophysiology, clinical features, and emerging treatments. *Journal of The Egyptian Society of Nephrology and Transplantation*, *24*(4), 163–168. https://doi.org/10.4103/jesnt.jesnt_16_24

[6] Han, Q., Xu, H., Li, L., Lei, S., Li, Z., Zhao, L., & Liu, F. (2024). Higher density of CD4+ T cell infiltration predicts severe renal lesions and renal function decline in patients with diabetic nephropathy. *Frontiers in Immunology*, *15*. https://doi.org/10.3389/fimmu.2024.1474377

[7] Hofherr, A., Williams, J., Gan, L. M., Söderberg, M., Hansen, P. B. L., & Woollard, K. J. (2022). Targeting inflammation for the treatment of Diabetic Kidney Disease: a five-compartment mechanistic model. In *BMC Nephrology* (Vol. 23, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12882-022-02794-8

[8] KDIGO. (2022). *KDIGO 2022 Clinical Practice Guideline for Diabetes Management in Chronic Kidney Disease Kidney International*. www.kidney-international.org

[9] KDIGO. (2024). KDIGO 2024 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease. *Kidney International*, *105*(4), A1. https://doi.org/10.1016/s0085-2538(24)00110-8

[10] Kim, J. Y., Chun, S. Youn, Lim, H., & Chang, T. I. (2023). Association between familial aggregation of chronic kidney disease and its incidence and progression. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-32362-5

[11] Kovesdy, C. P. (2022). Epidemiology of chronic kidney disease: an update 2022. In *Kidney International Supplements* (Vol. 12, Issue 1, pp. 7–11). Elsevier B.V. https://doi.org/10.1016/j.kisu.2021.11.003

[12] Kumar, M., Dev, S., Khalid, M. U., Siddenthi, S. M., Noman, M., John, C., Akubuiro, C., Haider, A., Rani, R., Kashif, M., Varrassi, G., Khatri, M., Kumar, S., & Mohamad, T. (2023). The Bidirectional Link Between Diabetes and Kidney Disease: Mechanisms and Management. *Cureus*. https://doi.org/10.7759/cureus.45615

[13] Liyanage, T., Ninomiya, T., Jha, V., Neal, B., Patrice, H. M., Okpechi, I., Zhao, M. H., Lv, J., Garg, A. X., Knight, J., Rodgers, A., Gallagher, M., Kotwal, S., Cass, A., & Perkovic, V. (2015). Worldwide access to treatment for end-stage kidney disease: A systematic review. *The Lancet*, *385*(9981), 1975–1982. https://doi.org/10.1016/S0140-6736(14)61601-9

[14] Persson, F., & Rossing, P. (2018). Diagnosis of diabetic kidney disease: state of the art and future perspective. In *Kidney International Supplements* (Vol. 8, Issue 1, pp. 2–7). Elsevier B.V. https://doi.org/10.1016/j.kisu.2017.10.003

[15] Premaratne, E., Verma, S., Ekinci, E. I., Theverkalam, G., Jerums, G., & MacIsaac, R. J. (2015). The impact of hyperfiltration on the diabetic kidney. In *Diabetes and Metabolism* (Vol. 41, Issue 1, pp. 5–17). Elsevier Masson s.r.l. https://doi.org/10.1016/j.diabet.2014.10.003

[16] Siddiqui, K., George, T. P., Joy, S. S., & Alfadda, A. A. (2022). Risk factors of chronic kidney disease among type 2 diabetic patients with longer duration of diabetes. *Frontiers in Endocrinology*, *13*. https://doi.org/10.3389/fendo.2022.1079725

[17] Sonmez, A. (2021). Challenges in the Prevention and Management of Diabetic Kidney Diseases. *Frontiers in Clinical Diabetes and Healthcare*, *2*. https://doi.org/10.3389/fcdhc.2021.728320

[18] Sun, H., Saeedi, P., Karuranga, S., Pinkepank, M., Ogurtsova, K., Duncan, B. B., Stein, C., Basit, A., Chan, J. C. N., Mbanya, J. C., Pavkov, M. E., Ramachandaran, A., Wild, S. H., James, S., Herman, W. H., Zhang, P., Bommer, C., Kuo, S., Boyko, E. J., & Magliano, D. J. (2022). IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. *Diabetes Research and Clinical Practice*, *183*. https://doi.org/10.1016/j.diabres.2021.109119

[19] Thomas, H. Y., & Ford Versypt, A. N. (2022). Pathophysiology of mesangial expansion in diabetic nephropathy: mesangial structure, glomerular biomechanics, and biochemical signaling and regulation. In *Journal of Biological Engineering* (Vol. 16, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s13036-022-00299-4

[20] Vallon, V., & Thomson, S. C. (2020). The tubular hypothesis of nephron filtration and diabetic kidney disease. In *Nature Reviews Nephrology* (Vol. 16, Issue 6, pp. 317–336). Nature Research. https://doi.org/10.1038/s41581-020-0256-y

[21] Waheed, Y. A., Buberwa, W., & Sun, D. (2025). Glial cell line-derived neurotrophic factor and its role in attenuating renal fibrosis: a review. In *Korean Journal of Internal Medicine* (Vol. 40, Issue 2, pp. 219–229). Korean Association of Internal Medicine. https://doi.org/10.3904/kjim.2023.246

[22] Wang, M., Li, J., Li, Y., Yao, S., Zhao, M., Wang, C., Wu, S., & Xue, H. (2020). The effects of hypertension and diabetes on new-onset chronic kidney disease: A prospective cohort study. *Journal of Clinical Hypertension*, *22*(1), 39–46. https://doi.org/10.1111/jch.13768

[23] Wang, N., & Zhang, C. (2024). Recent Advances in the Management of Diabetic Kidney Disease: Slowing Progression. In *International Journal of Molecular Sciences* (Vol. 25, Issue 6). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/ijms25063086

[24] Wang, Y., Jin, M., Cheng, C. K., & Li, Q. (2023). Tubular injury in diabetic kidney disease: molecular mechanisms and potential therapeutic perspectives. In *Frontiers in Endocrinology* (Vol. 14). Frontiers Media SA. https://doi.org/10.3389/fendo.2023.1238927

[25] Wu, T., Ding, L., Andoh, V., Zhang, J., & Chen, L. (2023). The Mechanism of Hyperglycemia-Induced Renal Cell Injury in Diabetic Nephropathy Disease: An Update. In *Life* (Vol. 13, Issue 2). MDPI. https://doi.org/10.3390/life13020539

[26] Wyld, M. L. R., Mata, N. L. D. La, Viecelli, A., Swaminathan, R., O'Sullivan, K. M., O'Lone, E., Rowlandson, M., Francis, A., Wyburn, K., & Webster, A. C. (2022). Sex-Based Differences in Risk Factors and Complications of Chronic Kidney Disease. In *Seminars in Nephrology* (Vol. 42, Issue 2, pp. 153–169). W.B. Saunders. https://doi.org/10.1016/j.semnephrol.2022.04.006

[27] Xu, C., Ha, X., Yang, S., Tian, X., & Jiang, H. (2023). Advances in understanding and treating diabetic kidney disease: focus on tubulointerstitial inflammation mechanisms. In *Frontiers in Endocrinology* (Vol. 14). Frontiers Media SA. https://doi.org/10.3389/fendo.2023.1232790

[28] Xue, R., Xiao, H., Kumar, V., Lan, X., Malhotra, A., Singhal, P. C., & Chen, J. (2023). The Molecular Mechanism of Renal Tubulointerstitial Inflammation Promoting Diabetic Nephropathy. In *International Journal of Nephrology and Renovascular Disease* (Vol. 16, pp. 241–252). Dove Medical Press Ltd. https://doi.org/10.2147/IJNRD.S436791

[29] Yang, H., Sun, J., Sun, A., Wei, Y., Xie, W., Xie, P., Zhang, L., Zhao, L., & Huang, Y. (2024). Podocyte programmed cell death in diabetic kidney disease: Molecular mechanisms and therapeutic prospects. In *Biomedicine and Pharmacotherapy* (Vol. 177). Elsevier Masson s.r.l. https://doi.org/10.1016/j.biopha.2024.117140

[30] Yang, Y., & Xu, G. (2022). Update on Pathogenesis of Glomerular Hyperfiltration in Early Diabetic Kidney Disease. In *Frontiers in Endocrinology* (Vol. 13). Frontiers Media S.A. https://doi.org/10.3389/fendo.2022.87 18

[31] Zhao, S., Li, Y., & Su, C. (2023). Assessment of common risk factors of diabetes and chronic kidney disease: a Mendelian randomization study. *Frontiers in Endocrinology*, *14*. https://doi.org/10.3389/fendo.2023.1265719