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Moving for Kidney Health - The Effects of Exercise on Renal Function in Type 2 Diabetes Patients: A Literature Review

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ABSTRACT

Diabetic Kidney Disease (DKD) is a common microvascular complication in patients with type 2 diabetes mellitus (T2DM), and a leading cause of chronic kidney disease (CKD) and end-stage renal disease (ESRD). Its pathophysiology involves hyperglycemia, insulin resistance, hemodynamic changes, oxidative stress, inflammation, and renin-angiotensin-aldosterone system (RAAS) dysregulation, which together lead to glomerulosclerosis, proteinuria, and fibrosis. Exercise has emerged as a non-pharmacological intervention with proven benefits in improving insulin sensitivity, reducing inflammation, and preserving renal function. Different types of physical activity including aerobic exercise, resistance training, and high-intensity interval training (HIIT) demonstrate positive impacts on renal parameters such as estimated glomerular filtration rate (eGFR) and urinary albumin-to-creatinine ratio (UACR). Clinical studies, including randomized controlled trials and meta-analyses, show that exercise can prevent renal function decline, lower albuminuria, and improve glycemic control in T2DM patients. Resistance training appears to offer superior renal protection compared to aerobic exercise, and reducing sedentary behavior is consistently associated with better kidney outcomes. Therefore, structured physical activity should be considered an essential component in managing renal complications of T2DM.

Keywords: type 2 diabetes mellitus; kidney function; physical exercise; diabetic nephropathy.

INTRODUCTION

Diabetic kidney disease (DKD), also known as diabetic nephropathy, is a significant microvascular complication affecting individuals with diabetes mellitus. It is characterized by elevated urine albumin excretion or reduced glomerular filtration rate (GFR), leading to progressive renal impairment and ultimately end-stage renal disease (Hussain et al., 2021). The prevalence of DKD continues to rise globally, particularly in low- and middle-income countries, where it poses an increasing public health burden. Approximately 40% of patients with type 2 diabetes mellitus (T2DM) develop DKD, making it one of the leading causes of chronic kidney disease (CKD) worldwide (Gil et al., 2020). The pathophysiology underlying DKD involves complex interactions between metabolic dysregulation, hemodynamic changes, and inflammatory processes that contribute to endothelial dysfunction and podocyte injury. Chronic hyperglycemia plays a pivotal role in the development and progression of DKD by inducing oxidative stress through various pathways such as the polyol pathway and advanced glycation end-product formation. These mechanisms lead to structural alterations within the glomerulus, including podocyte foot process effacement and increased glomerular permeability to proteins like albumin (Wu et al., 2023) (Thent et al., 2020; Wu et al., 2020). Despite advancements in pharmacological therapies aimed at controlling blood glucose levels and hypertension, there remains an urgent need for effective non-pharmacological interventions that can mitigate these complications.

Physical activity has emerged as a promising adjunctive therapy for managing T2DM-related complications. Regular exercise has been shown to improve insulin sensitivity, reduce systemic inflammation, lower blood pressure, and enhance overall cardiovascular health all critical factors influencing renal function in diabetic patients. Recent studies indicate that physical activity can significantly reduce albuminuria levels while improving GFR among individuals with T2DM (Kuo et al., 2022; Moghadasi et al., 2022). Furthermore, resistance training appears superior to aerobic exercise regarding its effects on estimated GFR (eGFR) improvements among patients with diabetic nephropathy.

This literature review aims to synthesize current evidence regarding the effects of exercise on renal function parameters specifically changes in GFR, albuminuria levels, blood pressure regulation, and associated biomarkers following structured physical activity programs among T2DM patients. By highlighting these relationships through existing research findings from various studies including meta-analyses we hope to underscore the essential role that regular physical activity plays not only in managing diabetes but also in preserving kidney health.

PATHOPHYSIOLOGY OF RENAL DYSFUNCTION IN TYPE 2 DIABETES

Diabetic kidney disease (DKD) is a leading microvascular complication of diabetes mellitus, affecting approximately 40% of type 2 diabetes mellitus (T2DM) patients and serving as a major cause of chronic kidney disease (CKD) and end-stage renal disease (ESRD) (Hussain et al., 2021). The pathophysiology of DKD is multifactorial, involving hemodynamic, metabolic, and inflammatory pathways. Hyperglycemia and insulin resistance play a central role in initiating renal damage by increasing oxidative stress, triggering endothelial dysfunction, and impairing podocyte-endothelial crosstalk (Gil et al., 2020). Over time, hypertension, proteinuria, and chronic inflammation further exacerbate renal injury, leading to progressive glomerulosclerosis and fibrosis (Defronzo & Reeves, 2021).

Persistent hyperglycemia is the primary pathogenic driver of DKD. Chronic exposure to elevated glucose levels induces glomerular hyperfiltration, podocyte injury, and mesangial matrix expansion, ultimately contributing to declining glomerular filtration rate (GFR) (Wu et al., 2023). At the cellular level, hyperglycemia activates multiple damaging pathways, including the polyol pathway, advanced glycation end product (AGE) formation, protein kinase C (PKC) activation, and mitochondrial dysfunction. These mechanisms result in excessive production of reactive oxygen species (ROS), which impair endothelial and podocyte function, weaken the glomerular basement membrane (GBM), and promote fibrosis (Wu et al., 2023). Insulin resistance, a hallmark of T2DM, further exacerbates these effects by increasing renal sodium retention, enhancing renin-angiotensin-aldosterone system (RAAS) activation, and disrupting the balance of vasoactive molecules (Huang et al., 2021).

Hypertension is both a cause and a consequence of DKD. Chronic hyperglycemia and insulin resistance contribute to systemic and intraglomerular hypertension, accelerating renal injury through mechanical stress on glomerular capillaries (Defronzo & Reeves, 2021). This results in increased glomerular permeability, albuminuria, and podocyte detachment, which are key markers of DKD progression (Hussain et al., 2021). Proteinuria not only serves as an indicator of renal dysfunction but also contributes directly to tubulointerstitial damage by activating pro-inflammatory and fibrotic pathways. Inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and transforming growth factor-beta (TGF-β) play a significant role in amplifying kidney damage (Gil et al., 2020). Additionally, podocyte-endothelial crosstalk disruption leads to vascular endothelial growth factor (VEGF) dysregulation, further aggravating glomerular barrier dysfunction (Gil et al., 2020).

ROLE OF EXERCISE IN DIABETES MANAGEMENT

Exercise plays a crucial role in the management of diabetes by improving insulin sensitivity, glycemic control, and overall metabolic health. Aerobic exercise, resistance training, and high-intensity interval training (HIIT) each provide unique benefits for individuals with diabetes, particularly in reducing complications such as diabetic nephropathy and cardiovascular disease (He et al., 2024). Aerobic exercise, such as walking, cycling, and swimming, enhances insulin sensitivity, reduces fasting blood glucose levels, and improves lipid profiles. A systematic review and meta-analysis demonstrated that aerobic exercise significantly lowers the urinary albumin-to-creatinine ratio (UACR) in diabetic nephropathy patients, suggesting a reno-protective effect (Nataraj et al., 2022). Additionally, aerobic activity has been shown to slow the progression of kidney disease by reducing inflammation and oxidative stress (Cai et al., 2020).
Resistance training, which includes weight lifting and bodyweight exercises, is another effective strategy in diabetes management. Studies have indicated that resistance training improves glycemic control by enhancing muscle glucose uptake and reducing insulin resistance (Moghadasi et al., 2022). Furthermore, periodic resistance training has been found to improve renal function in patients with type 2 diabetic nephropathy by decreasing urinary albumin excretion and enhancing the glomerular filtration rate (Li et al., 2024). High-intensity interval Training (HIIT), characterized by short bursts of intense exercise followed by recovery periods, has gained attention for its efficiency in improving metabolic health. Research suggests that HIIT can lead to significant reductions in HbA1c levels, improved insulin sensitivity, and enhanced cardiovascular fitness in diabetic patients (Sokolovska et al., 2020). Moreover, interval walking training, a form of HIIT, has been associated with reductions in albuminuria and improved leptin/adiponectin ratios, which are critical markers of metabolic health in diabetes (Wang et al., 2023).

Physical activity also plays a vital role in maintaining renal function in diabetic patients. Studies indicate that sedentary behavior is linked to deteriorating kidney function, whereas increased physical activity correlates with improved estimated glomerular filtration rate (eGFR) and reduced microalbuminuria (Guo et al., 2016). Reducing sedentary time while incorporating regular physical activity can help mitigate the progression of diabetic nephropathy and other complications (Kuo et al., 2022). Exercise is an essential component of diabetes management, with aerobic exercise, resistance training, and HIIT

each offering distinct physiological benefits. The integration of various forms of exercise into routine diabetes care can help improve glycemic control, preserve renal function, and mitigate the risk of complications associated with diabetes (Slaght et al., 2021).

MECHANISMS OF EXERCISE ON RENAL FUNCTION

Exercise has been recognized as a non-pharmacological intervention with significant benefits in preserving renal function. Various mechanisms contribute to these benefits, including improvements in renal perfusion and blood pressure regulation, reduction in proteinuria, stabilization of glomerular filtration rate (GFR), attenuation of inflammation and oxidative stress, and modulation of the renin-angiotensin-aldosterone system (RAAS). Regular physical activity enhances renal perfusion by increasing cardiac output and improving endothelial function, leading to better oxygen delivery to the kidneys (Kawakami et al., 2022). Moderate-intensity exercise has been shown to maintain renal blood flow without compromising kidney function, thereby ensuring adequate filtration and waste elimination (Kawakami et al., 2022). Additionally, exercise contributes to blood pressure regulation by reducing systemic vascular resistance and increasing nitric oxide bioavailability, which collectively decrease the burden on renal vasculature (Arazi et al., 2022).

Several studies indicate that structured exercise programs can lower proteinuria and stabilize GFR in individuals with chronic kidney disease (CKD) (Ma et al., 2022). Aerobic exercise, in particular, has been associated with reduced urinary albumin excretion and improved renal clearance (Nicolodi et al., 2022).

Furthermore, exercise-induced muscle contractions promote glucose uptake and insulin sensitivity, mitigating hyperfiltration-related kidney damage in diabetic populations (Yamamoto et al., 2021). Chronic inflammation and oxidative stress contribute to the progression of kidney disease. Exercise has been shown to reduce systemic inflammation by decreasing pro-inflammatory cytokines such as TNF-α and IL-6 while simultaneously enhancing antioxidant defenses, including superoxide dismutase (SOD) and glutathione peroxidase (Zhao et al., 2023). Meta-analyses have confirmed that regular aerobic exercise reduces oxidative stress markers such as malondialdehyde (MDA) and F2-isoprostanes, which are commonly elevated in CKD patients (Zhao et al., 2023).

The RAAS plays a crucial role in blood pressure and fluid homeostasis, and its dysregulation is a hallmark of CKD progression. Exercise has been shown to modulate RAAS activity by reducing circulating angiotensin II and aldosterone levels, leading to decreased sodium retention and lower blood pressure (Hoshino, 2021). These changes contribute to reduced renal fibrosis and improved sodium excretion, ultimately preserving kidney function (Castillo et al., 2024).

TABLE 1: Clinical Evidence: Studies on Exercise and Renal Function in Type 2 Diabetes.

Study	Design	Population & Sample Size	Intervention / Exposure	Duration	Main Outcomes	Conclusion	Limitations
(Moghadasi et al., 2022)	Randomized Controlled Trial (RCT)	22 middle-aged male T2DM patients at risk of nephropathy	Resistance Training (RT) vs. Control (3x/week, 60 min/session, 8 weeks)	8 weeks	◈ e GFR remained stable in RT group but declined (16.7%) in the control group ◈ HOMA-IR & fasting glucose significantly improved in RT group	RT prevented kidney function decline and improved glycemic control in T2DM patients at risk of nephropathy	◈ Short study duration ◈ Small sample size ◈ Only male participants
(Nataraj et al., 2022)	Systematic review & meta-analysis (4 RCTs)	203 patients with DN (T2DM, CKD stages 2-4)	Aerobic & resistance training	Variable	◈ No significant impact on eGFR ◈ Reduction in UACR & proteinuria observed	Exercise improves albuminuria but does not significantly change eGFR	◈ Limited number of RCTs ◈ High study heterogeneity
(Sokolovska et al., 2020)	RCT	40 T2DM patients	Interval Walking Training (IWT) via mobile app vs. control	4 months	◈ Reduced albuminuria & leptin/adiponect in ratio in IWT group ◈ Trend towards lower HbA1c (p=0.09)	IWT improved vascular markers & reduced albuminuria in T2DM patients	◈ Small sample size. ◈ Long-term effects not assessed

Study	Design	Population & Sample Size	Intervention / Exposure	Duration	Main Outcomes	Conclusion	Limitations
(Cai et al., 2020)	Meta-analysis (18 studies, 38,991 participants)	Patients with T1DM/T2DM & DN	Physical activity vs. no PA	Variable	◈ PA improved GFR (SMD = 0.01, 95% CI = [0.02–0.17]) ◈ Reduced UACR & microalbuminuria risk	PA is beneficial for slowing DN progression and improving renal function	◈ Most included studies were non-RCTs ◈ Significant heterogeneity
(Li et al., 2024)	RCT	60 obese patients with T2DM & DN	Resistance Training vs. Aerobic Exercise	12 weeks	◈ GFR increased significantly in RT group (92.2 → 100.1 mL/min/1.73m^2) ◈ UACR reduced more in RT than AE	RT was more effective than AE in improving renal function in obese T2DM patients with DN	◈ Short study duration ◈ Small sample size
(Guo et al., 2016)	Prospective cohort study (4-year follow-up)	326 newly diagnosed T2DM patients	Impact of PAEE, MVPA, and sedentary time on kidney function	4 years	◈ Increased sedentary time → increased serum creatinine ◈ Higher PAEE → lower serum creatinine	Reducing sedentary time and increasing PAEE may slow renal function decline	◈ Limited control over confounding factors ◈ Self-reported PA behavior
(He et al., 2024)	Cross-sectional study (NHANES 2007-2018)	2,633 T2DM patients	Impact of occupational (OPA), transportation (TPA), leisure-time (LTPA), and total PA on DKD	11 years	◈ LTPA inversely correlated with UACR ◈ TPA positively associated with eGFR	Specific PA domains influence renal function, but total PA duration was not linked to DKD prevalence	◈ Causality cannot be inferred
(Kuo et al., 2022)	Cross-sectional study	229 T2DM patients	Exercise group (≥150 min/week) vs. non-exercise group (<150 min/week)	-	◈ Exercise group had lower albuminuria prevalence (30.2% vs. 46.3%) ◈ Significantly lower HbA1c, FPG, triglycerides, and higher HDL in the exercise group	Regular exercise is associated with lower albuminuria and better metabolic parameters in T2DM patients	◈ Cross-sectional study design limits causality interpretation
(Slaght et al., 2021)	Cross-sectional study	164 adolescents with T2DM	Vigorous PA (≥3x/week) vs. inactive	-	◈ Vigorous PA associated with lower HbA1c, diastolic BP, and albuminuria	Vigorous PA may reduce CVD risk and kidney complications in adolescents with T2DM	◈ Cross-sectional design ◈ Self-reported PA
(Wang et al., 2023)	Cross-sectional study	1,761 T2DM patients	Effect of sedentary time & PA on eGFR	-	◈ Longer sedentary time → lower eGFR ◈ Physical activity mediated the relationship between sedentary time and eGFR	Reducing sedentary time and increasing PA may attenuate renal function decline	◈ Cross-sectional design limits causality assessment ◈ Self-reported PA data

DISCUSSION

Physical activity (PA) has consistently demonstrated benefits for renal health in T2DM patients, particularly through its effects on glomerular filtration rate (GFR) and albuminuria. In a meta-analysis including over 38,000 participants, Cai et al. showed that PA improved GFR and significantly reduced urinary albumin-to-creatinine ratio (UACR), thus slowing the progression of diabetic nephropathy (DN) (Cai et al., 2020). Despite modest effect sizes, these findings suggest PA can mitigate renal function decline when integrated into diabetes care. Resistance training (RT) appears to have superior renal benefits compared to aerobic exercise (AE). Li et al. found that a 12-week RT program led to a significant improvement in GFR and a greater reduction in UACR in obese T2DM patients with DN, compared to AE (Li et al., 2024). Similarly, Moghadasi et al. observed that RT preserved GFR levels while the control group experienced a 16.7% decline; HOMA-IR and fasting glucose also improved significantly, indicating an additional glycemic control benefit (Moghadasi et al., 2022). Interval Walking Training (IWT) managed via mobile technology offers an accessible and effective strategy. Sokolovska et al. reported that a 4-month IWT program significantly reduced albuminuria and improved the leptin/adiponectin ratio, a biomarker linked to vascular health and inflammation (Sokolovska et al., 2020). While HbA1c showed only a trend toward reduction, the study highlights the potential of digitally delivered exercise programs in managing early renal changes in T2DM.

Albuminuria, a key early marker of diabetic kidney disease (DKD), was notably reduced in several studies examining habitual or structured PA. In a cross-sectional study by Kuo et al., patients performing ≥150 minutes of weekly exercise exhibited significantly lower albuminuria prevalence (30.2%) compared to their inactive counterparts (46.3%) (Kuo et al., 2022). These findings reinforce the role of regular PA in delaying microvascular complications in diabetes. Evidence from meta-analyses underscores exercise's positive effect on renal biomarkers beyond GFR. Nataraj et al. found that while GFR improvements were not statistically significant across four RCTs, reductions in proteinuria and UACR were consistent, suggesting early renal benefits may manifest before GFR changes (Nataraj et al., 2022). High heterogeneity and limited RCT quality, however, limit generalizability, underscoring the need for more robust trials.

Reducing sedentary time emerges as another modifiable lifestyle factor influencing renal outcomes. In a prospective 4-year cohort study, Guo et al. found that higher physical activity energy expenditure (PAEE) and moderate-to-vigorous physical activity (MVPA) were associated with lower serum creatinine levels, while increased sedentary time correlated with renal function decline (Guo et al., 2016). This suggests that even outside structured exercise, reducing inactivity has measurable renal benefits. Domain-specific PA also plays a role. He et al., using NHANES data, reported that leisure-time PA (LTPA) is inversely correlated with UACR, while transportation-related PA (TPA) is positively associated with GFR. Interestingly, total PA duration did not significantly impact DKD prevalence, suggesting that the type and context of activity may be more influential than volume alone (He et al., 2024). Among adolescents with T2DM, vigorous PA was associated with reduced albuminuria, lower diastolic blood pressure, and improved glycemic control. Slaght et al. emphasized that regular intense PA, even at a young age, may have long-term protective effects on kidney and cardiovascular health, although causality remains unconfirmed due to the cross-sectional design (Slaght et al., 2021).

Blood pressure (BP), a crucial factor in renal health, also appears to respond favorably to exercise interventions. Although BP changes were not consistently reported across all studies, Slaght et al. and Kuo et al. both observed improved diastolic BP among physically active participants (Kuo et al., 2022; Slaght et al., 2021). These improvements may mediate part of the renal protective effects of exercise by reducing glomerular pressure and proteinuria. Overall, despite methodological limitations in several studies (e.g., small sample sizes, short durations, or cross-sectional designs), the cumulative evidence indicates that structured exercise, particularly RT and IWT, alongside reductions in sedentary behavior, can improve or preserve renal function markers in T2DM. While albuminuria emerges as the most responsive marker, modest yet clinically relevant effects on GFR, serum creatinine, and renal biomarkers support the inclusion of personalized PA programs in diabetes care plans (Cai et al., 2020; Li et al., 2024; Moghadasi et al., 2022; Sokolovska et al., 2020).

LIMITATIONS AND CHALLENGES

Clinical studies examining the effects of exercise on renal function in T2DM patients with CKD face several limitations, including short intervention durations, small sample sizes, and heterogeneity in exercise type, intensity, and delivery methods. These factors reduce the generalizability of findings and limit long-term outcome evaluation. Additionally, implementing exercise programs in this population poses challenges such as ensuring patient safety, given potential contraindications related to cardiovascular risk and CKD progression. Patient adherence remains a significant barrier, often influenced by physical limitations, motivation, and access to structured programs.

RECOMMENDATIONS FOR CLINICAL PRACTICE AND FUTURE RESEARCH

Exercise recommendations for T2DM patients with CKD should be tailored to disease severity. Moderate-intensity aerobic and resistance training is generally safe for early-stage CKD, while lower-intensity and supervised programs are preferred in advanced stages. Pre-exercise screening and monitoring are essential. For future research, long-term studies are needed to assess the sustained

effects of exercise on renal and metabolic outcomes. Studies should also explore the combined effects of exercise and pharmacological therapy.

CONCLUSION

This review emphasizes the beneficial role of exercise in managing type 2 diabetes mellitus (T2DM), particularly in preserving kidney function. Regular physical activity especially aerobic and combined training can improve glycemic control, reduce inflammation, and potentially slow CKD progression in T2DM patients. These findings support the incorporation of tailored exercise programs into routine diabetes care. Clinicians should consider exercise as an essential component of treatment, alongside pharmacological and dietary strategies, to optimize both metabolic and renal outcomes.

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