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IMPACT OF PHYSICAL ACTIVITY ON DIABETIC NEPHROPATHY, RETINOPATHY, NEUROPATHY AND PERIPHERAL ARTERIAL DISEASE: A NARRATIVE REVIEW

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ABSTRACT

Introduction: Physical activity is one of the fundamental components of diabetes management, with beneficial effects on glycemic control, metabolic profile, and cardiovascular risk. Increasing evidence also suggests that regular exercise may play an important role in modifying the course of chronic diabetic complications. This applies particularly to diabetic nephropathy, diabetic retinopathy, diabetic neuropathy, and peripheral arterial disease, which remain among the major causes of reduced quality of life, disability, and increased mortality in this patient population.
Objective: This paper aims to review the current scientific literature on the impact of physical activity on selected chronic complications of diabetes, with particular emphasis on diabetic nephropathy, diabetic retinopathy, diabetic neuropathy, and peripheral arterial disease.
Methods: This study is a narrative review of the literature. The analysis was based on publications available in PubMed/MEDLINE, Scopus, and Embase. Randomized controlled trials, observational studies, review articles, and systematic reviews concerning the effects of physical activity and exercise-based interventions on renal markers, retinopathy progression, peripheral nerve function, balance, functional performance, exercise tolerance, and gait parameters in patients with diabetes and peripheral arterial disease were included.
Conclusions: The available evidence indicates that physical activity may have a beneficial effect on selected chronic complications of diabetes, although the strength of the evidence varies depending on the complication analyzed. The most consistent benefits are observed in diabetic neuropathy, particularly in terms of balance, proprioception, functional performance, and symptom reduction. In diabetic nephropathy, physical activity may improve selected renal function parameters and reduce albuminuria, whereas in retinopathy and peripheral arterial disease, the findings are more heterogeneous, although they suggest a potential protective and functional effect. Physical activity should be regarded as an important component of comprehensive management in patients with diabetes; however, further studies are needed to define more precisely the optimal type, intensity, and duration of exercise interventions for individual complications.

KEYWORDS

Physical Activity, Diabetes Mellitus, Diabetic Nephropathy, Diabetic Retinopathy, Diabetic Neuropathy, Peripheral Arterial Disease, Exercise, Chronic Complications

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1. Introduction

Diabetes is one of the most common chronic diseases worldwide and represents a major clinical, social, and economic challenge. Its significance results not only from its high prevalence but also from the risk of numerous chronic complications that substantially affect patients' quality of life, functional capacity, hospitalization risk, and mortality. The most important long-term consequences of diabetes include microvascular complications, such as diabetic nephropathy, retinopathy, and neuropathy, as well as macrovascular complications, including peripheral arterial disease [1], [3], [20].

Chronic diabetic complications develop as a result of complex metabolic and vascular disturbances, primarily associated with long-term hyperglycemia, oxidative stress, chronic inflammation, endothelial dysfunction, and abnormalities of both microcirculation and macrocirculation. Their pathogenesis is also influenced by coexisting risk factors such as hypertension, dyslipidemia, obesity, low physical activity, and long disease duration [1], [3], [19], [20]. These complications not only worsen prognosis but also markedly limit independence and daily functioning, particularly when they affect vision, renal function, the nervous system, or walking ability.

For many years, physical activity has been recognized as one of the fundamental elements of diabetes management. Regular exercise has favorable effects on glycemic control, insulin sensitivity, lipid profile, blood pressure, body composition, and overall physical fitness, thereby reducing cardiovascular risk and

supporting comprehensive metabolic treatment [1], [2], [3]. Clinical recommendations emphasize that appropriately prescribed physical activity should be a permanent part of therapy in both type 1 and type 2 diabetes, while taking into account the patient's age, treatment regimen, comorbidities, and exercise safety [1], [2], [3].

However, the significance of physical activity in diabetes is not limited to improving metabolic parameters alone. Increasing evidence suggests that regular exercise may also influence the course of selected chronic complications of diabetes, both through indirect mechanisms related to improved risk factor control and through more direct effects on functional capacity, tissue perfusion, balance, nerve function, and exercise tolerance [4]–[20]. Depending on the type of complication, the role of physical activity may differ: in some cases, it is mainly protective and preventive, in others it serves a rehabilitative function, and in some situations it requires caution and individualization because of potential clinical limitations [1], [3], [19].

It seems particularly important to analyze the effects of physical activity on those complications that most strongly determine daily functioning and long-term prognosis. Diabetic nephropathy remains one of the leading causes of chronic kidney disease and end-stage renal failure [3], [4]. Diabetic retinopathy is one of the major causes of visual impairment and blindness in people with diabetes [7], [19]. Diabetic neuropathy leads to pain, sensory impairment, reduced balance, and an increased risk of falls and foot ulceration [9]–[16]. Peripheral arterial disease, in turn, is associated with limited walking ability, intermittent claudication, and a high risk of ulceration and amputation, especially in patients with diabetes [17], [18], [20]. All of these complications are clinically important, but they differ in pathophysiology, clinical presentation, and their potential response to exercise-based interventions.

This paper aims to review the current scientific literature on the effects of physical activity on selected chronic complications of diabetes, with particular emphasis on diabetic nephropathy, diabetic retinopathy, diabetic neuropathy, and peripheral arterial disease. The review analyzes available evidence concerning the types of exercise interventions used, their potential clinical effects, possible mechanisms of action, and practical significance in the care of patients with diabetes [4]–[20].

2. Methodology

This paper is a narrative review of the literature and presents an analysis of current scientific evidence regarding the effects of physical activity on selected chronic complications of diabetes, with particular emphasis on diabetic nephropathy, diabetic retinopathy, diabetic neuropathy, and peripheral arterial disease.

The literature review was conducted using publications identified in PubMed/MEDLINE, Scopus, and Embase. The search strategy included combinations of the following keywords: physical activity, exercise, diabetes mellitus, diabetic nephropathy, diabetic retinopathy, diabetic neuropathy, peripheral arterial disease, intermittent claudication, and chronic complications. The analysis included English-language scientific articles, including randomized controlled trials, observational studies, review articles, and systematic reviews concerning the effects of exercise-based interventions on the course and clinical parameters of selected diabetic complications.

The review considered studies assessing the effects of physical activity on such parameters as albuminuria and renal function, progression of diabetic retinopathy, balance, proprioception, symptoms of peripheral neuropathy, nerve conduction, walking ability, and exercise tolerance in patients with diabetes and coexisting peripheral arterial disease.

3. Physical Activity and Diabetic Nephropathy

Diabetic nephropathy, also referred to as diabetic kidney disease (DKD), is one of the most common chronic complications of diabetes and remains one of the leading causes of chronic kidney disease and end-stage renal failure worldwide. Its development is associated with progressive damage to glomerular and interstitial renal structures, leading to increased albuminuria and deterioration of renal filtration function, most commonly assessed using estimated glomerular filtration rate (eGFR) [3]. In clinical practice, albuminuria and eGFR are among the most important markers of DKD progression and treatment effectiveness [3].

Physical activity is one of the basic components of diabetes management and may also have a beneficial effect on the course of diabetic kidney disease. The mechanisms underlying this effect are multifactorial and include improved glycemic control, reduced insulin resistance, favorable effects on body weight, lower blood pressure, and attenuation of chronic inflammation and oxidative stress [1], [3]. From a clinical perspective, this is particularly relevant because regular exercise may influence parameters directly related to DKD progression, especially albuminuria and selected measures of renal function.

Available studies suggest that exercise-based interventions may improve selected renal parameters in patients with diabetic nephropathy. In the study by Dong et al., long-term intensive lifestyle intervention in patients with stage III diabetic nephropathy was associated with improvement in disease course, indicating that comprehensive management, including increased physical activity, may slow the progression of renal damage [4]. In turn, the randomized trial by Nataraj et al. demonstrated that an exercise-based rehabilitation program in patients with type 2 diabetes and nephropathy improved functional capacity and also had a beneficial effect on selected renal function parameters [5]. These findings suggest that the benefits of exercise are not limited to improving general fitness, but may also include parameters relevant from a nephrological perspective.

An important area of interest is the effect of physical activity on albuminuria. The study by Norlén et al., conducted in individuals recently diagnosed with type 2 diabetes, demonstrated an association between physical activity level and albuminuria, suggesting that higher activity may be linked to a more favorable profile of renal injury already at an early stage of the disease [6]. More broadly, regular exercise appears to reduce urinary albumin excretion, which is of particular significance because albuminuria is not only a marker of nephropathy but also a cardiovascular risk factor [3], [6].

The type of exercise intervention may also be important. The most commonly analyzed interventions include aerobic training, resistance training, and combined programs that integrate endurance and strength exercises. Available evidence suggests that both regular aerobic exercise and more complex rehabilitation programs may provide metabolic and renal benefits, especially when performed over a longer period and as part of a broader lifestyle intervention [4], [5]. At the same time, it should be emphasized that improvement in eGFR is generally less pronounced and less consistent than changes in albuminuria, which may reflect differences in follow-up duration, disease severity, and population heterogeneity [4], [5].

From a practical point of view, physical activity should be considered an important component of comprehensive management in patients with diabetes and coexisting DKD. Exercise prescription should, however, take into account the general condition of the patient, the stage of nephropathy, blood pressure control, coexisting complications, and cardiovascular risk [1], [3]. Although the current evidence is promising, further studies are still needed to determine more precisely which type, intensity, and duration of training are most beneficial for patients with different stages of diabetic nephropathy.

4. Physical Activity and Diabetic Retinopathy

Diabetic retinopathy (DR) is one of the most common microvascular complications of diabetes and remains one of the major causes of visual deterioration and potential vision loss in individuals with long-standing disease. Its development is associated with chronic hyperglycemia, endothelial dysfunction, increased retinal vascular permeability, ischemia, and inflammatory and angiogenic processes. The risk of DR onset and progression depends, among other factors, on diabetes duration, glycemic control, coexisting hypertension, and lipid abnormalities [3], [19]. For this reason, retinopathy is a complication of particular relevance in the context of non-pharmacological treatment, including physical activity, which may exert a protective metabolic effect but in some situations also requires appropriate caution [1], [19].

When assessing the effect of physical activity on diabetic retinopathy, it is important to distinguish between the beneficial long-term effects of regular exercise and the safety of specific forms of training in patients with more advanced stages of the disease. In individuals without retinopathy or with mild forms of DR, regular physical activity is generally considered a safe and recommended component of diabetes treatment [1], [3]. Greater concern applies to patients with proliferative diabetic retinopathy, active vascular lesions, or a significant risk of vitreous hemorrhage, in whom very high-intensity exercise, isometric exertion, the Valsalva maneuver, heavy lifting, or activities causing abrupt rises in blood pressure may potentially increase the risk of ocular complications [1], [19]. This means that exercise planning in patients with DR should be individualized and should take into account the stage of retinal disease.

Available evidence suggests that regular physical activity and broader lifestyle interventions may reduce the risk of retinopathy or slow its progression. In the systematic review by AlShammari et al. on the effect of lifestyle interventions on DR progression, the authors emphasized that modifications involving increased physical activity, improved metabolic control, and reduction of cardiovascular risk factors may be associated with a more favorable course of retinal changes [8]. Similar conclusions emerge from the review by AlQabandi et al., which indicated that higher levels of physical activity are generally associated with a lower frequency of diabetic retinopathy or a milder course of this complication, although the authors also highlighted the heterogeneity of the available studies and the limitations related to their observational design [19].

Most of the available data concern aerobic activity and the general level of daily movement. It is regular endurance-type exercise, such as walking, brisk walking, cycling, or moderate-intensity aerobic training, that is most often analyzed in the context of metabolic benefits that may indirectly affect the retina [1], [19]. This type of activity promotes improved glycemic control, lower blood pressure, improved lipid profile, and reduced body weight, thereby acting on the same factors that are important in the development and progression of DR [1], [3], [8]. Few data are available on resistance training; however, even in this case, a potential protective effect may result from improved general metabolic status, provided that the exercise does not involve excessive increases in intraocular pressure and blood pressure in patients with advanced retinal lesions [1], [19]. From a practical point of view, it may therefore be assumed that the best-established benefits and the highest level of safety concern regular moderate-intensity aerobic activity, whereas more intensive forms of training require caution in selected patient groups.

Indirect evidence of a protective effect of physical activity on the retina also comes from data related to metabolic control and diabetes prevention. In the long-term follow-up of the Finnish Diabetes Prevention Study, an association was found between the beneficial effects of lifestyle intervention and the cumulative incidence of clinically diagnosed retinopathy [7]. Although this study involved a population at high risk of diabetes rather than patients with already established DR, its findings support the concept that lifestyle modification, including physical activity, may reduce the burden of factors leading to microvascular retinal damage [7]. This suggests that the role of exercise in the context of retinopathy may concern both prevention of lesion development and limitation of progression after diabetes diagnosis.

The mechanisms by which physical activity may influence the course of retinopathy are probably multifactorial. The most important is improved glycemic control, because chronic hyperglycemia remains one of the principal factors damaging the retinal microcirculation [1], [3]. In addition, regular exercise may lower blood pressure, improve lipid profile, reduce insulin resistance, and attenuate chronic inflammation and oxidative stress, all of which contribute to the pathogenesis of microvascular damage [1], [8], [19]. Thus, the beneficial effect of physical activity may not result from a direct action on the retina itself, but rather from an overall improvement in the metabolic and vascular environment of the organism.

The clinical significance of physical activity in patients with diabetic retinopathy therefore, lies in balancing potential long-term benefits with safety considerations. Regular movement should remain an integral component of diabetes treatment, also in individuals at risk of DR or with established retinopathy, but the choice of exercise type and intensity should be adjusted to the severity of ophthalmic lesions [1], [3], [19]. In patients with milder forms of DR, moderate aerobic activity may be an important element of preventing further progression, whereas in more advanced stages, caution and cooperation with an ophthalmologist and diabetologist are necessary [19]. Although current evidence suggests a beneficial effect of physical activity and lifestyle interventions on the course of retinopathy, further studies are needed to determine more precisely which exercise modalities, intensities, and durations are both the most beneficial and the safest for patients with different stages of DR [8], [19].

5. Physical Activity and Diabetic Neuropathy

Diabetic neuropathy is one of the most common chronic complications of diabetes and includes a heterogeneous group of disorders affecting the peripheral and autonomic nervous systems. The most common clinical form is distal symmetric diabetic polyneuropathy, which manifests as neuropathic pain, paresthesias, impaired vibration and position sense, reduced proprioception, and deterioration of postural stability and gait. As neuropathy progresses, the risk of falls, foot ulceration, reduced functional capacity, and lower quality of life increases, making it a particularly important target for exercise-based interventions [3], [9], [10].

Physical activity appears to be one of the best-documented non-pharmacological supportive measures in the management of diabetic neuropathy. The benefits of exercise include both improvement in general metabolic fitness and more direct effects on sensorimotor function, balance, postural stability, and walking performance [9], [10], [11]. Programs of particular importance are multicomponent interventions combining aerobic training, strength exercises, balance training, and sensorimotor exercises, because the impairments present in neuropathy are multidimensional and involve sensation, neuromuscular control, coordination, and locomotor function simultaneously [10], [11], [12].

One of the best described areas of benefit of physical activity in diabetic neuropathy is balance and postural control. In the randomized trial by Dixit et al., moderate-intensity aerobic exercise improved postural control parameters during quiet standing in patients with diabetic peripheral neuropathy, suggesting that even aerobic-type training may positively affect postural stability [9]. Similarly, Ahmad et al. showed that

sensorimotor training significantly improved balance and proprioception in middle-aged and older adults with diabetic neuropathy [11]. These findings are consistent with observations that exercises focused on body alignment, foot function, balance responses, and deep sensation are among the most practical interventions for reducing fall risk in this population [10], [11], [12].

Programs combining strength and balance training are also of great importance. Venkataraman et al. demonstrated that a short-term program of strength and balance exercises did not improve quality of life, but did improve functional status in individuals with diabetic peripheral neuropathy [10]. This is clinically important because in neuropathy, improved performance in everyday activities may be of greater practical relevance than short-term changes in subjective quality-of-life indicators. Strength training may support joint stabilization, increase lower limb muscle strength, and improve motor control, and its combination with balance exercises appears particularly advantageous in a population with sensory impairment and reduced postural control [10], [12].

Another important direction involves multisystem and sensorimotor exercise programs. In the study by Khurshid et al., multisystem exercises improved balance, postural stability, mobility, walking speed, and reduced pain in patients with diabetic neuropathy [12]. Sahba et al., comparing Intraneural Facilitation™ Therapy with exercise, also indicated that movement-based interventions may positively affect functional status in patients with type 2 diabetes and neuropathic symptoms, although the effectiveness of individual methods may differ depending on the endpoint evaluated [13]. These findings support the view that in neuropathy, more complex programs than aerobic training alone may be of greatest value, especially when the goal is simultaneous improvement in balance, mobility, gait control, and symptom reduction.

An important area of investigation also concerns exercises targeting the foot and ankle, because diabetic neuropathy leads to gait biomechanics disturbances, stiffness, weakening of the intrinsic foot muscles, and increased ulcer risk. Ferreira et al. demonstrated that a web-based foot-ankle exercise program was effective in reducing ulcer risk factors in patients with diabetic neuropathy [14]. This finding is of great practical relevance because it shows that home-based or partly remote interventions may also be a valuable supplement to patient care. Training that includes foot mobilization, improved ankle range of motion, muscle strengthening, and load control exercises may affect not only functional performance but also the prevention of diabetic foot syndrome [14].

Some studies have also assessed the effects of physical activity on neuropathic pain and nerve function. Reyhanıoğlu et al. found that computer-based balance exercises improved balance, clinical presentation, reduced pain, and also influenced nerve function parameters in patients with diabetic neuropathy [15]. Gholami et al., in turn, reported that aerobic training may improve nerve conduction in men with type 2 diabetes and peripheral neuropathy [16]. This suggests that regular physical activity may act not only symptomatically but also, at least partly, on the physiological functioning of damaged nerves. It should be noted, however, that data concerning nerve conduction are less abundant and less consistent than those relating to balance, mobility, or functional performance [15], [16].

Regarding exercise type, different forms of physical activity appear to provide partly different benefits. Aerobic training seems particularly useful for improving general fitness, postural control, and potentially nerve conduction [9], [16]. Strength training supports muscular function and the ability to perform activities of daily living, especially when combined with balance exercises [10]. Sensorimotor and balance training show very good effects in proprioception, postural stability, and fall prevention [11], [15]. Multicomponent programs combining several exercise modalities may provide the broadest clinical effect, including gait, mobility, pain, and balance [12], [13]. In practice, this means that exercise rehabilitation in patients with diabetic neuropathy should not rely on one universal model, but rather be tailored to the dominant functional deficits.

The clinical significance of physical activity in diabetic neuropathy is especially great because in this complication, the benefits of exercise interventions appear to be the most consistent. Improvements in balance, proprioception, gait, mobility, and function may directly translate into reduced fall risk, greater independence, and less burden from daily pain and disability [10], [11], [12]. At the same time, exercise planning should take into account foot condition, the presence of deformities, ulcer risk, the severity of sensory loss, and exercise tolerance to ensure that training is not only effective but also safe [3], [14]. Current evidence therefore suggests that regular, appropriately prescribed physical activity should constitute an important element of comprehensive management in patients with diabetic neuropathy, although further studies are needed to determine optimal training protocols for individual neuropathy phenotypes [12], [15], [16].

6. Physical Activity and Peripheral Arterial Disease in Diabetes

Peripheral arterial disease (PAD) is a common macrovascular complication of diabetes and represents an important cause of functional limitation, lower limb pain, and reduced quality of life. In patients with diabetes, PAD develops more frequently, earlier, and usually follows a more severe course than in individuals without impaired glucose metabolism. This group also more often presents with involvement of more distal vascular segments, more rapid progression of ischemia, poorer tissue healing, and a higher risk of ulceration and amputation [3], [20]. One of the most typical clinical manifestations of PAD is intermittent claudication, defined as pain or discomfort in the lower limb muscles that occurs during walking and subsides with rest. This symptom leads to secondary restriction of physical activity, which further deepens deconditioning, worsens walking performance, and increases cardiovascular risk [18], [20].

Physical activity, and particularly supervised walking training, is one of the basic non-pharmacological treatment modalities in patients with PAD. The best documented form of intervention is supervised exercise therapy, which usually consists of walking that provokes moderate to severe claudication symptoms, with periods of rest followed by repeated exertion [18], [20]. The mechanisms underlying the beneficial effects of this type of training include improved muscular performance, increased efficiency of oxygen utilization by skeletal muscles, favorable endothelial changes, improved microcirculation, and better tolerance of ischemic pain during exercise [18], [20]. In clinical practice, this translates mainly into increased walking distance, improvement in maximal and pain-free walking distance, and better functional performance.

However, in patients with diabetes, the response to exercise in PAD may be less favorable than in the non-diabetic population. In the systematic review by Hageman et al., the coexistence of diabetes was shown to attenuate improvements in walking parameters after supervised exercise therapy in patients with intermittent claudication [18]. This means that although supervised exercise therapy remains an effective and recommended treatment strategy, patients with diabetes may achieve smaller improvements in walking distance than patients without DM. Possible reasons for this include coexisting neuropathy, more diffuse and distal vascular lesions, poorer skeletal muscle function, microcirculatory disturbances, and more frequent coexistence of obesity, orthopedic limitations, and lower functional reserve [18], [20].

The type of exercise is particularly important in PAD because the greatest amount of evidence concerns walking training. Walking remains the basic and best studied form of physical activity in patients with intermittent claudication, especially when performed regularly, with appropriate intensity, and under supervision [18], [20]. Such programs usually involve walking until a predefined level of pain is reached, followed by a short rest and repetition of the cycle. These interventions improve adaptation to exertion and increase tolerance of lower-limb load [18]. Other forms of activity, such as cycling, resistance exercises, or combined training programs, have also been considered in the literature; however, walking training remains the gold standard of exercise therapy in symptomatic PAD [20].

In patients with diabetes, additional limitations affecting the ability to participate in a classic walking program must be considered. The presence of diabetic neuropathy, foot deformities, increased ulcer risk, loss of protective sensation, or coexisting joint disease may hinder or modify the course of training [20]. For this reason, the exercise program should be individualized, and in addition to walking distance, factors such as foot condition, appropriate footwear, glycemic control, injury risk, and coexisting microvascular and cardiovascular complications should be taken into account [3], [20]. In practice, this may mean the need to introduce more gradual exercise protocols, strengthening exercises, or combinations of walking with other forms of rehabilitation.

An interesting issue concerns differences in the response to rehabilitation among particular groups of patients with PAD and diabetes. Gardner et al. demonstrated that women with diabetes may be poorer responders to exercise rehabilitation used in the treatment of intermittent claudication [17]. This finding suggests that the response to training may be modulated not only by the presence of diabetes itself but also by sex, baseline fitness, body composition, severity of vascular disease, and coexisting functional limitations [17]. Although the available data in this area remain limited, these observations are clinically relevant because they indicate the need for more individualized rehabilitation planning and caution when interpreting average treatment effects.

The benefits of physical activity in PAD are not limited to improvement in walking distance. Regular training may also favorably affect overall fitness, metabolic profile, glycemic control, blood pressure, and cardiovascular risk, which is particularly high in patients with both diabetes and PAD [1], [3], [20]. In this way, physical activity acts both symptomatically, by improving patient functioning, and systemically, by influencing risk factors responsible for atherosclerosis progression. This is especially important in diabetes,

where PAD rarely occurs as an isolated complication and very often coexists with other forms of vascular and organ damage [20].

The clinical significance of exercise rehabilitation in patients with diabetes and PAD is therefore very high, although the effectiveness of training may be more variable than in other chronic diabetic complications. Supervised exercise therapy remains the primary and recommended strategy for improving walking ability and quality of life in symptomatic PAD, but in patients with DM, the response to treatment may be weaker and requires a more individualized approach [17], [18], [20]. In practice, this means that exercise rehabilitation should be combined with comprehensive diabetes care, vascular assessment, foot monitoring, and ulcer prevention. Available data confirm the important role of physical activity in the treatment of PAD in patients with diabetes, but they also indicate the need for further studies on the optimal exercise type, the best supervision model, and the factors determining response to intervention in this specific population [18], [20].

7. Discussion

Physical activity is an important element of comprehensive management in individuals with diabetes; however, its impact on individual chronic complications is not equally well documented. Analysis of the available literature indicates that the benefits of exercise interventions are most consistent in diabetic neuropathy, moderately well established in diabetic nephropathy, more indirect and cautiously interpreted in diabetic retinopathy, and clinically important but partly limited by coexisting burdens in peripheral arterial disease [4]–[20].

In diabetic neuropathy, physical activity appears to provide the most multidimensional and practically meaningful benefits. These concerns primarily involve improvements in balance, proprioception, postural stability, mobility, gait, and overall functional performance [9]–[16]. Multicomponent programs, including balance, sensorimotor, strength, and aerobic exercises, seem particularly beneficial because they address the complex nature of impairments present in neuropathy. Some studies have also demonstrated reduction of neuropathic pain and improvement in selected nerve function and nerve conduction parameters, although this area still requires further research [15], [16]. From a clinical perspective, neuropathy appears to be the complication in which exercise rehabilitation may most rapidly translate into improved daily functioning.

In diabetic nephropathy, the available data are less abundant, but they suggest a beneficial effect of physical activity on selected renal parameters, especially albuminuria and overall metabolic profile [4]–[6]. The most commonly studied interventions are aerobic training and broader lifestyle interventions, and the observed benefits may result from improved glycemic control, lower blood pressure, attenuation of inflammation, and improved insulin sensitivity [1], [3], [4]. At the same time, the effect on eGFR is not as clear as the effect on albuminuria, which may be due to the long natural history of the disease, heterogeneity of study populations, and insufficient follow-up duration [4], [5]. This means that although physical activity should be regarded as an important supportive component of DKD management, more studies comparing specific exercise types and their long-term nephroprotective effects are needed.

Diabetic retinopathy represents a specific area in which the role of physical activity must be considered both in terms of potential metabolic benefits and safety principles [1], [8], [19]. Available data suggest that regular physical activity and broader lifestyle interventions may reduce the risk of retinopathy or slow its progression, mainly through improved glycemic control, blood pressure regulation, lipid profile, and reduction of chronic inflammation [7], [8], [19]. Moderate aerobic activity appears to be the most rationally justified form of exercise, whereas in patients with more advanced, especially proliferative, retinopathy, caution is required with very intense, isometric, or pressure-raising exertion [1], [19]. Compared with neuropathy or PAD, the evidence for retinopathy is less direct and more often based on observational associations and indirect effects.

In peripheral arterial disease, physical activity, especially supervised walking training, has a well-established role as the primary treatment for intermittent claudication [17], [18], [20]. Supervised exercise therapy improves walking distance, exercise tolerance, and functional performance; however, in patients with diabetes, the response to training may be weaker than in individuals without DM [18]. This is probably due to coexisting neuropathy, more advanced and distal vascular lesions, poorer muscle function, and a greater number of functional limitations [18], [20]. Nevertheless, exercise rehabilitation remains a cornerstone of PAD treatment in this population as well, although it requires greater individualization and attention to foot condition, ulcer risk, and other diabetic complications [3], [20].

When comparing the complications analyzed, it can be noted that physical activity acts in different ways depending on the dominant mechanism of organ damage. In neuropathy, the main effect concerns sensorimotor

function and physical performance. In nephropathy, the key significance lies in metabolic and hemodynamic benefits influencing markers of renal injury. In retinopathy, the effect is largely indirect and related to the modification of microvascular risk factors. In PAD, the benefits are mostly functional and concern improvement in walking ability and exercise tolerance [4]–[20]. This means that there is no single universal model of physical activity appropriate for all chronic diabetic complications.

A major limitation of the available evidence is the substantial heterogeneity of studies. Individual publications differ in terms of intervention type, program duration, exercise intensity, characteristics of the study groups, and endpoints used [5], [8], [12], [18]. Some studies evaluated hard clinical parameters such as albuminuria, nerve conduction, or walking distance, while others were based on functional indicators, subjective pain scales, or observational data [6], [15], [19]. This makes direct comparison of results difficult and limits the formulation of unequivocal recommendations regarding the optimal exercise dose for each complication type.

Another important issue is the safety of exercise interventions. Although physical activity generally exerts beneficial effects on the health of people with diabetes, in some clinical situations it requires careful individualization. This applies especially to patients with advanced retinopathy, severe sensory impairment, high foot ulcer risk, coexisting cardiovascular disease, or markedly reduced functional capacity [1], [3], [14], [19], [20]. Therefore, planning an exercise program should take into account not only potential benefits but also the patient's risk profile and current clinical condition.

From an interdisciplinary perspective, the findings of this review emphasize that physical activity should be treated not merely as a general lifestyle recommendation but as a targeted therapeutic and rehabilitation strategy in diabetes care. This requires cooperation between diabetologists, family physicians, nephrologists, ophthalmologists, angiologists, physiotherapists, and rehabilitation specialists [1], [3], [20]. Better understanding of the effects of exercise type, intensity, and duration on specific complications may, in the future, allow more precise tailoring of exercise recommendations to the patient's phenotype.

In summary, among the chronic diabetic complications analyzed, the strongest and most practical evidence concerns diabetic neuropathy, in which physical activity improves multiple aspects of functioning. In PAD, the benefits are also well documented, especially with respect to walking training, although the response may be attenuated by coexisting diabetes. In nephropathy, the available data are promising but still limited, whereas in retinopathy physical activity appears to be important mainly as an element of prevention and risk factor control, with the need for caution in patients with advanced retinal lesions [4]–[20].

Table 1. Comparison of the most recommended forms of physical activity, main clinical benefits, and key precautions in selected chronic complications of diabetes

Complication	Most recommended type of physical activity	Main clinical benefits	Important limitations / precautions	Key sources
Diabetic nephropathy (DKD)	Aerobic training and combined exercise / lifestyle intervention programs	Possible reduction in albuminuria, improved functional capacity, and beneficial effects on selected renal function parameters [4]–[6]	Individualization is required in advanced CKD, hypertension, and significant cardiovascular burden [1], [3]	[4], [5], [6]
Diabetic retinopathy (DR)	Moderate-intensity aerobic activity; caution with very intense exercise	Possible beneficial effect on the risk of development and progression of DR, mainly indirectly through improved metabolic control [7], [8], [19]	In proliferative DR, avoid heavy isometric exertion, Valsalva maneuver, heavy lifting, and activities causing abrupt blood pressure rises [1], [19]	[7], [8], [19]
Diabetic neuropathy	Multicomponent training: balance + sensorimotor + resistance + aerobic exercise	Improved balance, postural control, functional capacity, mobility, and gait speed; partial reduction in pain and possible improvement in nerve function [9]–[16]	Assessment of foot status, ulcer risk, sensory loss, and exercise tolerance is necessary [3], [14]	[9]–[16]
Peripheral arterial disease (PAD)	Supervised exercise therapy, primarily supervised walking training	Increased walking distance, improved functional performance, and better claudication tolerance [17], [18], [20]	Response may be weaker in patients with diabetes; neuropathy, foot status, and ulcer risk must be considered [17], [18], [20]	[17], [18], [20]

Source: Authors' own elaboration based on Colberg et al. [1], Polish Diabetes Association [3], and studies [4]–[20].

Abbreviations: DKD, diabetic kidney disease; DR, diabetic retinopathy; PAD, peripheral arterial disease; CKD, chronic kidney disease.

8. Conclusions

Physical activity should be regarded as an important component of comprehensive management in patients with diabetes and its chronic complications. The available evidence indicates that exercise may exert beneficial effects across several major complication domains, although the strength and directness of these effects differ depending on the specific condition [1], [3]–[20].

The most consistent and clinically practical benefits are observed in diabetic neuropathy, where appropriately selected exercise programs improve balance, proprioception, gait, mobility, and overall functional capacity, and may additionally reduce pain and improve selected parameters of nerve function [9]–[16]. In peripheral arterial disease, especially in patients with intermittent claudication, supervised exercise therapy remains a key non-pharmacological intervention and improves walking distance, exercise tolerance, and functional performance, although the response may be less pronounced in individuals with diabetes than in those without diabetes [17], [18], [20].

In diabetic nephropathy, regular physical activity and lifestyle-based interventions appear to have a favorable effect on selected renal and metabolic parameters, particularly albuminuria and functional status, although the evidence remains more limited and less uniform than in neuropathy [4]–[6]. In diabetic retinopathy, physical activity seems to be beneficial mainly through indirect mechanisms, including improved glycemic control, blood pressure regulation, lipid profile, and reduction of chronic inflammation; however, exercise prescription in this group should take into account the stage of retinal disease and potential safety concerns in advanced forms, especially proliferative retinopathy [7], [8], [19].

Overall, the findings of this review suggest that there is no single universal exercise model suitable for all chronic complications of diabetes. The type, intensity, and mode of physical activity should be individualized according to the dominant complication, the patient's functional status, coexisting comorbidities, and safety profile [1], [3], [14], [19], [20]. Aerobic exercise appears particularly relevant in nephropathy and retinopathy, multicomponent training seems most effective in neuropathy, and supervised walking-based exercise remains the cornerstone of therapy in peripheral arterial disease [4]–[20].

In conclusion, physical activity should be incorporated not only as a general lifestyle recommendation, but also as a targeted therapeutic and rehabilitative strategy in the care of patients with diabetes and its chronic complications. Further high-quality studies are needed to determine the optimal exercise type, intensity, duration, and supervision model for each complication phenotype and to support more precise, evidence-based clinical recommendations [4]–[20].

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