




Review Article

Nutritional Strategies and Micronutrient Modulation in Peripheral Arterial Disease: Integrating Antioxidants, Gujarati Dietary Patterns, and Physiotherapy-Based Management: A Narrative Review

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Abstract

Peripheral arterial disease (PAD) is a progressive vascular disorder characterised by reduced blood flow to the lower limbs due to atherosclerotic obstruction. The condition is closely associated with oxidative stress, endothelial dysfunction, and inflammation. In India, particularly among Gujarati populations, unique dietary patterns—high in refined carbohydrates and fried foods but low in omega-3 fatty acids and vitamin B12—contribute to an increased risk of PAD and impaired vascular health.

This review highlights the synergistic role of nutrition and physiotherapy in managing PAD. Dietary modifications emphasising whole grains, legumes, green leafy vegetables, and antioxidant-rich foods such as turmeric, cumin, and amla can mitigate oxidative stress and improve endothelial function. Adequate intake of micronutrients like vitamins C, E, D, B12, magnesium, zinc, and selenium support vascular integrity and blood flow. Complementary physiotherapy interventions—especially supervised walking, aerobic, and resistance training—enhance peripheral circulation, muscle oxygenation, and functional mobility.

Combining dietary optimisation with physiotherapy offers a holistic, culturally relevant approach to PAD management, particularly in Gujarati communities. Integrating antioxidant-rich diets with structured exercise programs can significantly improve walking distance, ankle-brachial index, and overall quality of life in patients with PAD.

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INTRODUCTION

Peripheral arterial disease (PAD) is an atherosclerotic disorder of the lower-extremity arteries that produces ischemia, exertional leg symptoms, impaired mobility, limb complications and substantially increased cardiovascular morbidity and mortality.¹ In the last three decades the global burden of PAD has risen substantially: the Global Burden of Disease analyses and recent systematic reviews estimate >100 million affected adults worldwide in 2019, with a marked increase in low- and middle-income countries^[1-3]. The epidemiology of PAD is influenced by population ageing and by the increasing prevalence of diabetes and other cardio metabolic risks in many regions^[1, 2]. In India the prevalence of PAD is heterogeneous across studies but is consistently substantial: population and hospital-based reports document variable prevalence (commonly 5–25% in adult and high-risk groups) depending on age, diabetes status and the screening method used, and recent Indian consensus guidance emphasizes that PAD remains under-diagnosed and under-treated in the Indian setting^[4, 5]. Regional studies from India show notably high prevalence in older adults and persons with diabetes, and studies performed in different states (including rural and urban Gujarat cohorts) report meaningful PAD burden that mirrors national trends in diabetes and smoking^[6, 7]. Major, well-established risk factors for PAD mirror those for atherosclerotic cardiovascular disease and include cigarette smoking, diabetes mellitus, hypertension, dyslipidemia, and older age; these exposures drive endothelial dysfunction, inflammation, and progressive arterial plaque formation that reduce perfusion to the lower limbs^[1, 8]. Biological mechanisms central to PAD pathophysiology include endothelial injury with impaired nitric-oxide availability, oxidative stress and lipid oxidation, chronic low-grade vascular inflammation, and impaired skeletal-muscle perfusion and mitochondrial function in affected limbs^[9]. These pathophysiologic processes explain why PAD is both a local limb disease and a systemic marker of atherosclerotic cardiovascular risk^[9]. Lifestyle exposures diet, physical inactivity (sedentary behaviour), and psychosocial stress are modifiable contributors to PAD development and progression. Poor dietary patterns that are high in refined carbohydrates, industrial trans-fats and excess saturated fats promote dyslipidemia, systemic inflammation and endothelial dysfunction and thereby accelerate atherogenesis^[10]. Conversely, diets rich in whole grains, vegetables, legumes, polyunsaturated fats (including plant omega-3 precursors), fruits and polyphenol-rich foods are associated with improved vascular risk profiles and may mitigate pathways involved in PAD^[11]. In the Indian and Gujarati dietary context, traditional vegetarian patterns provide advantages (high fiber and legumes) but can also have vulnerabilities (substitution with refined flours, sugar-dense snacks, frequent deep-fried “farsan” and low dietary vitamin B12 and EPA/DHA), which may influence PAD risk and recovery potential^[6, 11]. Physical inactivity and prolonged sedentary time worsen lower-extremity hemodynamics and are associated with greater functional impairment and worse outcomes in PAD; observational and

interventional studies indicate that greater sedentary time correlates with lower walking distance, poorer quality of life and higher mortality in PAD cohorts^[12, 13]. Supervised exercise therapy (walking programs) is guideline-recommended first-line therapy to improve walking performance and functional capacity in claudication, highlighting the interplay between physical activity, limb perfusion and patient outcomes^[14]. Psychosocial stress and mental-health burden are increasingly recognized as comorbid factors that influence PAD presentation, adherence to therapy and long-term outcomes. Several cohort and registry analyses link higher perceived stress or work-related psychosocial strain with increased PAD events and worse prognosis, likely through neuro-endocrine activation, inflammatory pathways, and adverse health behaviours (smoking, poor diet, inactivity)^[15]. Taken together, PAD is a common, systemic atherosclerotic disease whose incidence and consequences are amplified by prevalent metabolic and behavioural risks in India and Gujarat specifically^[1, 4, 6]. The pathophysiologic links between endothelial dysfunction, oxidative stress and chronic inflammation provide a biologic rationale for exploring nutritional strategies including targeted micronutrient optimization, antioxidants and dietary pattern changes—as adjunctive measures that may complement pharmacologic therapy and physiotherapy (exercise) to improve vascular health, functional capacity and limb outcomes in PAD^[9, 11, 14]. Accordingly, a narrative review that integrates evidence on micronutrients, antioxidant dietary components, local (Gujarati) dietary patterns and practical physiotherapy recommendations addresses an important clinical and public-health gap for PAD prevention and rehabilitation in the Indian context^[4, 6].

Pathophysiology of PAD and Oxidative Stress

The development of peripheral arterial disease (PAD) is rooted in chronic atherosclerotic changes within the lower-limb vasculature, including intimal lipid deposition, inflammatory cell infiltration and progressive narrowing of peripheral arteries.¹⁶ Endothelial dysfunction is a hallmark; when the endothelium loses its ability to produce nitric oxide and maintain vasodilatory, antithrombotic and anti-inflammatory functions, vascular homeostasis is disrupted and PAD progression accelerates^[17]. Oxidative stress plays a central role in this process: excess generation of reactive oxygen species (ROS) overwhelms antioxidant defenses, leading to lipid peroxidation, endothelial injury, vascular smooth muscle proliferation and eventual arterial obstruction^[18]. In patients with PAD, biomarkers of oxidative damage such as 4-hydroxy-2-nonenal adducts and F2-isoprostanes are elevated in both arterial tissue and skeletal muscle, reflecting both vascular and muscular ischemia-reperfusion injury^[19]. Chronic low-grade inflammation, mediated by macrophages, T-cells and cytokines like TNF- α and IL-6, further propagates vascular remodelling, plaque instability and impaired collateral circulation^[20]. Metabolic perturbations such as hyperhomocysteinaemia, insulin resistance and dyslipidaemia act as upstream enablers of these pathways by promoting oxidative stress, endothelial

toxicity and microvascular dysfunction [21]. In the ischemic limb, repeated cycles of reduced perfusion and reperfusion result in mitochondrial impairment, decreased capillary density, muscle fibre atrophy and diminished walking capacity features that translate into functional limitation among PAD patients [22]. From a nutritional perspective, these pathophysiologic processes are modifiable. Diets high in refined carbohydrates, saturated fats, trans-fats and sodium converge on pathways of oxidative stress, inflammation and endothelial dysfunction: post-prandial hyperglycaemia and lipaemia overload mitochondrial respiration, increase ROS generation and activate NADPH oxidase in vascular cells [23]. Conversely, dietary patterns rich in whole grains, legumes, fruits, vegetables, plant-derived polyphenols and long-chain omega-3 fatty acids help to mitigate these mechanisms by improving endothelial function, reducing oxidative burden and attenuating inflammatory signalling [24]. Antioxidant micronutrients such as vitamin C, vitamin E, selenium and zinc serve as scavengers of free radicals, supporting redox balance in the face of ischemic and inflammatory stress [25]. Adequate B-vitamin intake (folate, B6, B12) reduces homocysteine levels and thereby the vascular toxicity linked to hyperhomocysteinaemia [21]. Vitamin D and minerals like magnesium also influence vascular tone and endothelial repair capacity, indirectly modulating PAD progression [26]. Importantly, in populations with predominantly vegetarian diets such as Gujarati communities, traditional foods may confer fiber, polyphenol and legume benefits, but also carry risk when refined flours, sugar-rich sweets and frequent deep-fried snacks dominate leading to nutrient gaps (e.g., vitamin B12, EPA/DHA) and elevated oxidative stress load [24]. In sum, the mechanistic foundation of PAD provides a strong rationale for integrating nutritional strategies alongside medical and exercise therapies: by targeting oxidative stress, inflammation, endothelial dysfunction and muscle perfusion, nutrition becomes a meaningful adjunct in the prevention and rehabilitation of PAD [27].

Macronutrients and PAD

Macronutrients—carbohydrates, proteins, and fats play a pivotal role in modulating vascular health, endothelial function, and systemic inflammation in patients with peripheral arterial disease (PAD) [28]. A balanced macronutrient intake influences lipid metabolism, glucose regulation, and oxidative stress key mechanisms underlying atherosclerotic progression [29]. Diets rich in refined carbohydrates and saturated fats accelerate endothelial dysfunction, increase post-prandial oxidative stress, and promote low-density lipoprotein (LDL) oxidation, contributing to plaque formation and vascular rigidity [30]. Conversely, replacing refined carbohydrates with complex sources such as whole grains, legumes, and fibre-rich cereals can improve glycaemic control, lower C-reactive protein levels, and enhance nitric-oxide-mediated vasodilation [31]. Protein quality is particularly relevant in PAD, as skeletal muscle atrophy and sarcopenia are frequent due to ischemic myopathy and reduced mobility [32]. Adequate intake of high-biological-value protein supports muscle regeneration and

functional endurance during rehabilitation, especially when combined with supervised resistance and aerobic training [33]. Gujarati dietary patterns, which are predominantly vegetarian, provide ample plant proteins from lentils, pulses, and dairy products, but these may lack essential amino acids such as methionine and lysine if not combined appropriately with cereals [34]. Additionally, excessive consumption of deep-fried snacks, ghee, and sugar-rich sweets common in traditional Gujarati diets may increase saturated fat and caloric load, offsetting vascular benefits [35].

Fat composition also critically affects PAD progression. Diets high in saturated and trans-fats exacerbate dyslipidaemia and inflammation, while those rich in monounsaturated and polyunsaturated fatty acids (such as olive oil, mustard oil, groundnuts, flaxseeds, and fish oil) improve endothelial function, decrease triglyceride levels, and promote vasodilation through increased nitric oxide bioavailability [36]. Omega-3 fatty acids, in particular, possess potent anti-inflammatory and anti-thrombotic effects beneficial for PAD management [37]. Emerging evidence supports the Mediterranean-style diet pattern—emphasizing plant-based foods, whole grains, legumes, nuts, and unsaturated fats as protective against PAD incidence and progression [38]. Therefore, rebalancing macronutrient proportions within regional dietary frameworks, such as the Gujarati diet, may serve as a pragmatic strategy to improve vascular health, functional outcomes, and quality of life in PAD patients [39].

Micronutrients in Peripheral Arterial Disease

Micronutrients are vital in maintaining vascular integrity, oxidative balance, and endothelial repair. In patients with peripheral arterial disease (PAD), deficiencies in specific vitamins and minerals exacerbate endothelial dysfunction, inflammation, and impaired perfusion [40]. Micronutrient optimisation, therefore, represents a crucial adjunctive strategy complementing exercise and pharmacological therapies.

B-Complex Vitamins

Among B-complex vitamins, folate (B9), vitamin B12, and vitamin B6 are central to the metabolism of homocysteine, a sulfur-containing amino acid strongly linked to endothelial injury and atherosclerosis [41]. Elevated plasma homocysteine levels impair nitric oxide bioavailability, promote smooth-muscle proliferation, and increase vascular stiffness. Supplementation with folate and B12 lowers homocysteine, thereby improving endothelial function and arterial compliance [42].

In India, particularly in vegetarian-dominant states like Gujarat, subclinical vitamin B12 deficiency is prevalent due to limited intake of animal-derived foods such as meat, fish, and eggs [43]. Fortified foods, dairy products, and supplementation are therefore essential to maintain endothelial health. Folate intake from green leafy vegetables (methi, spinach) and legumes (moong, tuvar dal) complements B12 in maintaining methylation balance and reducing vascular oxidative burden [44]. Integrating folate- and B12-rich diets with structured

physiotherapy-based walking programs may further enhance peripheral circulation and muscle oxygenation [45].

Vitamin D

Vitamin D deficiency has been increasingly recognised as an independent risk factor for arterial stiffness, medial calcification, and impaired vasomotor tone [46]. It modulates vascular smooth-muscle proliferation and inflammatory cytokine expression through vitamin D receptors expressed in endothelial cells. Low serum 25-hydroxyvitamin D correlates with higher incidence of PAD and greater cardiovascular mortality [47].

In Gujarat, despite abundant sunlight, urban indoor lifestyles and cultural clothing practices limit effective sunlight exposure, leading to widespread hypovitaminosis D [48]. Inclusion of fortified milk, curd, ragi, and controlled sun exposure (15–20 minutes/day) are simple and affordable public-health measures to counter deficiency. Adequate vitamin D status supports improved lower-limb muscle strength and exercise tolerance, essential for PAD rehabilitation [49].

Antioxidant Vitamins C and E

Vitamin C (ascorbic acid) and vitamin E (α -tocopherol) are potent antioxidants that scavenge free radicals and prevent lipid peroxidation within the vascular endothelium [50]. These vitamins maintain nitric oxide bioavailability, reduce oxidative stress markers such as F2-isoprostanes, and enhance endothelial-dependent vasodilation [51]. Deficiencies amplify oxidative injury from chronic ischemia, leading to muscular fatigue and delayed wound healing [52]. In the Gujarati diet, vitamin C-rich foods such as amla (Indian gooseberry), guava, lemon, and citrus fruits are widely available and affordable, providing natural antioxidant support. Vitamin E sources include groundnuts, sunflower seeds, and vegetable oils commonly used in regional cooking [53]. Encouraging daily intake of these local foods may enhance antioxidant defence and synergise with aerobic-resistance exercise programs to restore vascular function [54].

Minerals

Minerals play an essential modulatory role in vascular tone and oxidative balance. Magnesium acts as a natural calcium antagonist, promoting vasodilation and preventing platelet aggregation [55]. Deficiency has been associated with increased arterial stiffness and hypertension. Zinc supports endothelial nitric oxide synthase (eNOS) activity and combats oxidative stress by stabilising cell membranes [56]. Conversely, iron overload may catalyse Fenton-reaction-derived free radicals, leading to endothelial injury; maintaining iron balance through dietary moderation and periodic screening is therefore essential [57].

Traditional Gujarati diets often provide adequate iron from legumes and greens but may lack zinc and magnesium if refined cereals dominate. Inclusion of whole grains, nuts, and seeds can bridge these micronutrient gaps and improve vascular resilience [58]. Integrating mineral-rich dietary counselling with

physiotherapeutic strategies ensures comprehensive management of PAD [59].

Role of Antioxidants and Polyphenones

Oxidative stress plays a central role in the pathogenesis of peripheral arterial disease (PAD), promoting endothelial dysfunction, inflammation, and lipid peroxidation that accelerate atherosclerotic plaque formation [60]. Antioxidants neutralize reactive oxygen species (ROS), thereby reducing oxidative injury to vascular endothelium and low-density lipoprotein (LDL) particles [61]. Polyphenones bioactive plant compounds such as flavonoids, catechins, and resveratrol demonstrate vasoprotective properties through inhibition of NADPH oxidase and modulation of nitric oxide synthase, enhancing endothelial nitric oxide availability [62]. Epidemiological studies have shown that higher polyphenol intake is associated with reduced progression of PAD and improved walking performance [63]. Among common Indian and Gujarati dietary elements, tea, turmeric, fenugreek (methi), cumin, coriander, and green leafy vegetables are particularly rich in polyphenols and carotenoids [64]. Curcumin, the principal compound in turmeric, attenuates inflammation by down-regulating the NF- κ B signaling pathway, thereby reducing vascular cell adhesion molecule (VCAM-1) expression and monocyte adhesion [65].

Resveratrol from grapes and peanuts activates SIRT1 and PGC-1 α pathways, which enhance mitochondrial function and suppress oxidative stress in skeletal muscles, improving microcirculatory perfusion [66]. Similarly, flavonoid-rich foods such as citrus fruits and dark leafy greens enhance endothelium-dependent vasodilation [67]. In Gujarat, traditional diets often combine antioxidant-dense spices (turmeric, clove, cinnamon) and polyphenol-rich ingredients (amla, jaggery, tulsi, mint), providing synergistic benefits when consumed regularly. The inclusion of cold-pressed groundnut oil and mustard oil contributes to an improved oxidative lipid profile [68]. However, urban dietary transitions such as reduced vegetable intake and increased refined oils may diminish antioxidant capacity, necessitating public health emphasis on restoring traditional spice-rich diets [69]. Integrating antioxidant-rich foods with physiotherapy and medical management can help improve vascular health, walking endurance, and oxidative balance in PAD patients [70].

Role of Physiotherapy and Exercise Rehabilitation

Supervised exercise therapy (SET) remains a cornerstone of non-invasive management for peripheral arterial disease (PAD), shown to significantly improve collateral circulation, walking endurance, and overall quality of life [71]. Structured walking programs enhance skeletal muscle oxygen extraction and promote angiogenesis through upregulation of vascular endothelial growth factor (VEGF) and nitric oxide synthase [72]. Aerobic exercise, including treadmill or overground walking at moderate intensity (3–5 sessions per week, 30–45 minutes), increases mitochondrial density and capillary-to-fiber ratio in ischemic limbs [73]. Resistance training further improves muscle

strength and glucose utilization, complementing the effects of aerobic exercise [74]. When combined, aerobic and resistance exercises yield superior outcomes in ankle-brachial index (ABI) improvement and pain-free walking distance compared to either modality alone [75]. Nutritional optimization plays a synergistic role during rehabilitation. Adequate protein and micronutrient intake supports muscle recovery and enhances mitochondrial energy metabolism [76]. Vitamins B-complex and magnesium are essential for glucose oxidation and ATP generation during exercise [77]. Antioxidant-rich diets may reduce exercise-induced oxidative stress, enhancing vascular compliance and muscular endurance [78].

Physiotherapy-guided programs also include flexibility, balance, and gait training to prevent falls and maintain functional independence. Integration of nutritional counseling with physiotherapy improves adherence and accelerates vascular adaptation [79]. Overall, the multidisciplinary approach combining exercise, medical management, and dietary modification provides the most sustainable improvement in PAD rehabilitation [80].

Cultural and Dietary Considerations in Gujarat

The Gujarati diet is predominantly lacto-vegetarian, characterized by high carbohydrate and moderate fat intake. While this pattern helps lower total cholesterol and saturated fat levels, it often results in vitamin B12, iron, and omega-3 fatty acid deficiencies, particularly among older adults and females [81]. These deficiencies can exacerbate endothelial dysfunction and elevate homocysteine levels, contributing to PAD risk [82].

Urbanization has led to the increased consumption of refined flour, sugar, and fried snacks (farsan, gathiya), raising glycemic load and oxidative stress [83]. Such dietary patterns may offset the cardiovascular benefits of vegetarianism. Reintroducing traditional whole grains such as bajra, jowar, and nachni, along with leafy vegetables (methi, palak, amaranth), can enhance fiber intake, reduce inflammation, and support glycemic control [84].

Fermented foods like kadhi, dhokla, and buttermilk improve gut microbiota diversity, leading to reduced systemic inflammation and improved vascular tone [85]. Incorporating cold-pressed oils, nuts, and seeds can correct omega-3 deficits and improve lipid profiles [86].

Community-based initiatives such as nutrition education workshops and physiotherapy screening camps are crucial for promoting lifestyle modification awareness, especially in semi-urban and rural Gujarat [87]. Integration of local dietary wisdom with scientific rehabilitation strategies can effectively reduce PAD prevalence and improve long-term vascular health [88].

CONCLUSION

Peripheral arterial disease is a multifactorial disorder heavily influenced by oxidative stress, micronutrient deficiencies, and sedentary lifestyle. Integrating dietary correction with physiotherapy-led aerobic and resistance exercise significantly improves vascular function, walking capacity, and overall quality of life. Optimizing traditional Gujarati diets with

modern nutritional insights provides a cost-effective, culturally adaptable approach for PAD prevention and management. Future clinical trials should focus on synergistic effects of nutritional and exercise interventions for long-term vascular health enhancement.

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