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Review

Evidence-Based Exercise Recommendations for the Reduction and Stabilization of Intraocular Pressure: A Practical Guide for Eye Care and Sport Specialists

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Abstract: The only proven method to manage glaucoma is the reduction and stabilization of intraocular pressure (IOP). A wide range of daily activities has been demonstrated to affect the IOP behavior, and eye care specialists should be aware of their effects for the prevention and treatment of glaucoma. Indeed, the impact of physical activity on IOP has gained attention in recent years, considering exercise prescription as a promising adjuvant strategy for controlling IOP in glaucoma patients. To integrate all the available information in this regard, we have conducted a clinical review based on a patient-centered approach. Previous studies have demonstrated that the IOP response to physical exercise is dependent on numerous factors such as the exercise type (e.g., endurance or resistance training), exercise intensity, subjects' fitness level, body position (e.g., supine vs. standing) and breathing pattern adopted during exercise, underlying medical conditions, concomitant mental effort, or caffeine intake before exercise. This article summarizes the available scientific evidence on the positive and negative effects of physical exercise on IOP and provides practical recommendations for exercise prescription in glaucoma patients or those at risk. An active collaboration between eye care and sports medicine specialists would permit a better management of this ocular condition.

Keywords: glaucoma; lifestyle; physical activity; glaucoma management; glaucoma prevention

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1. Introduction

Glaucoma is a chronic optic neuropathy characterized by the progressive degeneration of retinal ganglion cells, leading to structural and functional damage to the optic nerve and, ultimately, irreversible vision loss. It is the leading cause of blindness globally, posing a significant public health concern [1]. Recent estimates project that, by 2040, the number of people suffering from glaucoma will reach 111.8 million worldwide, highlighting the pressing need for effective strategies for the prevention, early diagnosis, and management of this condition [2]. While glaucoma encompasses a range of subtypes, including primary open-angle glaucoma (POAG) and angle-closure glaucoma, they share common features such as optic nerve damage and associated visual field defects [3].

The principal goal of glaucoma management is to reduce and stabilize intraocular pressure (IOP), as it remains the only proven strategy to slow disease progression and preserve vision [4]. Advances in pharmacological and surgical interventions, such as topical medications, selective laser trabeculoplasty, and minimally invasive glaucoma surgeries have substantially improved the standard of care for glaucoma patients [5], with topical therapy and selective laser trabeculoplasty considered as the first-line treatment options [6]. However, the increasing prevalence of glaucoma underscores the need for complementary approaches that extend beyond conventional treatments to address modifiable risk factors.

Recent years have witnessed growing interest in the potential influence of environmental and lifestyle factors, such as diet and physical activity, on the pathogenesis and progression of glaucoma [7]. Research suggests that modifiable behaviors may offer an adjunctive therapeutic benefit by providing neuroprotection to retinal ganglion cells and contributing to overall ocular health [8]. Among these factors, physical exercise has emerged as a promising area of investigation due to its well-documented systemic health benefits and its potential role in reducing IOP [9–11].

The regular practice of physical exercise is associated with numerous health benefits, including reduced risks of cardiovascular disease, cancer, osteoporosis, and fall-related injuries, as well as enhanced mental and cognitive function [12]. These positive effects extend to ocular health, with observational and retrospective studies indicating that individuals who engage in regular physical activity are less likely to develop glaucoma or experience its progression [13–19]. Lee and colleagues [13] examined the link between physical activity levels and the rate of visual field loss in 141 patients with suspected or diagnosed glaucoma. They found that increased walking, more time spent in moderate-to-vigorous physical activity, and reduced sedentary behavior were associated with slower rates of visual field loss. This relationship may be mediated by the ability of physical exercise to induce short-term reductions in IOP, improve ocular blood flow, and exert neuroprotective effects on retinal ganglion cells [10].

Despite these promising findings, the clinical application of exercise as an adjunctive strategy for glaucoma management remains underexplored. Notably, exercise prescription for glaucoma patients or at-risk individuals must be tailored to their specific health conditions to maximize benefits and minimize risks [20]. Collaboration between sports scientists and eye care professionals is essential to develop evidence-based, individualized exercise regimens that address the unique needs of this population [21]. However, no randomized controlled trials have yet systematically evaluated the long-term impact of structured physical exercise programs on glaucoma prevention or disease progression, leaving a significant gap in the literature.

The acute effects of physical exercise on IOP have been extensively studied, with evidence suggesting that various factors, such as exercise intensity, duration, type, and individual fitness levels, mediate the IOP response [10]. Understanding these variables is crucial for developing practical guidelines on exercise prescription for glaucoma patients. This clinical review aims to synthesize current evidence on the effects of physical exercise on IOP and their implications for glaucoma prevention and management. The primary objective is to provide research-based guidelines to assist eye care specialists and sports science professionals in designing and implementing exercise strategies tailored to the needs of glaucoma patients or individuals at risk. By bridging the gap between ocular health and exercise science, this review seeks to clarify how physical activity can serve as a complementary approach to conventional glaucoma treatments, ultimately enhancing patient outcomes and quality of life.

The articles included in this review were identified through comprehensive searches of electronic databases, including PubMed, EbscoHost (MEDLINE, SportDiscus, CINAHL Plus), PROQuest, Cochrane Library, and Embase. The search spanned from the inception of each database to September 2024 and was guided by an information specialist with training in systematic reviews. Search strategies were carefully designed to capture relevant studies investigating the relationship between physical exercise and glaucoma, with particular emphasis on IOP modulation and neuroprotection. By critically appraising and synthesizing these studies, this review aims to provide actionable insights for advancing glaucoma care and research.

2. Factors Affecting the IOP Response to Exercise

2.1. Exercise Type and Intensity

Exercises can generally be categorized into endurance-oriented and strength-oriented types, yet the specific outcomes of these activities can vary significantly based on their implementation [22]. Endurance exercises performed at low-to-moderate intensities, which are targeted to enhance the aerobic system, have shown promise for glaucoma prevention and management, with studies linking such activities to acute reductions in IOP [23,24]. Activities like walking, jogging, or cycling at low intensities typically yield short-term IOP reductions ranging between ~2 to 5 mmHg, with these effects persisting for fewer than 20 min post-exercise [25,26]. Longitudinal observations and retrospective studies reinforce these findings, suggesting that regular engagement in such activities reduces the likelihood of glaucoma onset and progression [13–19]. Furthermore, a non-controlled prospective study conducted by Agrawal (2015) demonstrated that open-angle glaucoma patients using topical anti-glaucoma medications experienced greater IOP reductions when advised to perform 30 min of daily low-intensity exercise for a month compared to those who did not exercise [27]. However, due to limitations inherent to observational and retrospective designs, causal relationships remain speculative, underscoring the need for controlled clinical trials to validate these results.

High-intensity endurance exercises, tailored to enhance anaerobic capacity, present a more nuanced picture. For example, studies examining the immediate effects of high-intensity interval training (HIIT) protocols have identified acute reductions in IOP during exercise, with outcomes varying based on the recovery periods between sprints. Less physically demanding HIIT protocols, characterized by longer recovery intervals, demonstrated a progressive IOP decrease, whereas more strenuous protocols exhibited a U-shaped response, negating the beneficial effects [28]. Another investigation found that maximal cycling sprints caused IOP reductions when performed against lighter resistances, but heavier loads triggered IOP increases [29]. These findings highlight the potential of HIIT as an efficient exercise modality for IOP reduction, provided that protocols are designed to avoid excessive physical strain. Additionally, HIIT offers time-efficient strategies for individuals with busy lifestyles, making it a promising option for integrating physical activity into glaucoma prevention programs. Future studies should explore how variations in intensity, duration, and recovery time influence IOP responses to ensure optimal protocol design.

In contrast, strength-based exercises, particularly those performed at moderate-to-high intensities, consistently induce acute IOP elevations [30]. Research indicates a direct relationship between resistance training intensity—defined by the load lifted—and IOP levels. Additionally, exercises completed closer to failure result in more pronounced IOP increases [31–35]. As a result, highly demanding resistance training (e.g., heavy lifting and sets to failure) may be counterproductive for IOP reduction in the short term. Exercises such as bench press and leg press exercises can cause acute IOP increases, with the magnitude of the change being positively correlated with the load used [36,37]. In addition, larger muscle mass involvement and breath-holding strategies during exercise exacerbates this effect [38]. However, most studies found transient IOP decreases after resistance exercises [30].

Nevertheless, strength-based exercises contribute significantly to the management of chronic conditions and overall health improvement [39]. Incorporating multi-component training programs—including endurance, strength, and balance exercises—could provide comprehensive health benefits while minimizing risks [40]. The intensity of these programs should remain low to moderate, with careful attention given to maintaining a steady respiratory pattern during exercise to avoid IOP spikes. These programs may also enhance adherence and long-term outcomes for individuals at risk of glaucoma. Further research should investigate whether modifications in strength training protocols, such as lower resistance levels or fewer repetitions, could mitigate IOP elevations while maintaining overall health benefits.

The integration of personalized exercise plans, tailored to an individual's physical capacity and health status, could maximize the benefits of physical activity for glaucoma prevention and management [10,20]. Collaboration between eye care specialists and exercise professionals is essential to design and implement these programs effectively. Future research should also prioritize longitudinal and randomized controlled trials to better understand the interplay between various exercise modalities and IOP dynamics, ultimately refining exercise recommendations for glaucoma patients.

2.2. Body Position

IOP has demonstrated sensitivity to the body position adopted in a variety of non-exercise contexts (i.e., sleeping, reading) [41]. For instance, a heightened IOP response has been observed when individuals are in a recumbent position with neck flexion compared to when they are seated with their neck in a neutral position [42]. Similarly, reading while lying in a supine position results in a higher IOP than when reading while sitting upright [43]. These findings suggest that even minor changes in body position can have a notable impact on IOP.

During exercise, the body frequently adopts various positions depending on the type of activity being performed. For example, in exercises such as yoga or CrossFit, head-down positions are often required to execute specific movements, while some resistance training exercises, such as the bench press, are typically performed in a supine or seated position. These different postures could lead to varying effects on IOP [41]. Notably, certain exercises that involve head-down positions, such as those commonly practiced in yoga, have been shown to cause significant increases in IOP [44–46]. For glaucoma patients or those at risk, it is important to avoid some yoga positions (e.g., Adho Mukha Svanasana and Uttanasana) since they cause an acute IOP rise [44]. These findings are of particular concern for individuals with glaucoma or those at risk of developing the condition, as sustained or excessive increases in IOP could potentially exacerbate disease progression.

For strength-based exercises, research from our group has demonstrated that IOP responses can differ based on body position. Specifically, we found that performing the bench press in a supine position leads to greater IOP increases compared to performing the exercise in a seated position [47]. This difference highlights how even slight changes in body posture during exercise can influence IOP levels, which may have implications for exercise prescription in individuals with or at risk for glaucoma. While the supine position is common for certain resistance exercises, its impact on IOP suggests that adopting alternative positions, such as sitting or standing, may be beneficial in maintaining stable IOP levels.

Taken together, the current evidence indicates that body positions involving head-down or supine postures should be avoided, when possible, by individuals at risk for glaucoma onset or progression. These positions appear to exacerbate IOP rises, which may increase the risk of damage to the optic nerve in susceptible individuals. However, further research is needed to better understand the long-term effects of these positions on IOP and their potential role in the progression of glaucoma. Future studies should focus on examining the cumulative impact of different body positions across various types of exercise and assessing whether specific postures can be modified or avoided to mitigate the risk of IOP spikes during physical activity. This knowledge will be crucial in developing exercise recommendations tailored to individuals with glaucoma or those at heightened risk of the condition.

2.3. Breathing Pattern

The breathing pattern adopted during exercise plays a crucial role in both physical performance and the physiological responses to exercise. Proper breathing techniques are essential for maintaining stability, optimizing energy delivery, and minimizing the strain on the cardiovascular system. For example, the Valsalva maneuver, in which an individual exhales forcefully with a closed airway, is commonly used in high-intensity exercises such as powerlifting. This maneuver enhances trunk stability and allows for greater force production during demanding physical efforts. However, while the Valsalva maneuver can enhance performance, it may also have detrimental effects on hemodynamic function, including significant increases in blood pressure and intrathoracic pressure [48,49].

Regarding IOP, there has been limited research investigating the specific impact of breathing patterns during exercise. However, recent studies suggest that the pattern of breathing can modulate IOP responses. In particular, restricted breathing or compromised gas exchange during exercise appears to result in higher IOP levels. Two studies, one involving dynamic resistance training and the other examining isometric resistance exercises, demonstrated that, when gas exchange is hindered, such as through the Valsalva maneuver, greater increases in IOP are observed [50,51]. This suggests that IOP increases are linked to alterations in breathing that impair normal respiration, potentially contributing to higher IOP during intense exercise.

In addition, the eruption of the COVID-19 pandemic and the use of face masks to reduce its transmission led to assess the effects of wearing face masks on IOP. In this regard, Janicijevic and colleagues (2021) [52] investigated the short-term effects of using surgical and FFP2/N95 masks on IOP levels during low-intensity endurance exercise in primary open-angle glaucoma patients. Although the magnitude of the increase was relatively small, this finding suggests that restricted airflow from wearing masks could influence IOP, particularly during exercise. This highlights the importance of considering breathing dynamics and the potential for mask-induced airflow restriction when assessing exercise safety for individuals with glaucoma or those at risk.

Additionally, research on high-altitude exposure, where oxygen levels are lower and breathing patterns naturally change, has provided further insight into the relationship between breathing and IOP. Numerous studies have investigated the effects of high-altitude exposure on IOP, and, while most agree that high-altitude conditions result in a statistically significant increase in IOP, these changes are generally considered clinically insignificant in healthy individuals [53–60]. However, this effect may be more pronounced in individuals with glaucoma, where even small increases in IOP could pose a risk to optic nerve health [61].

In the context of airflow restriction as a performance enhancement tool, certain studies have explored the use of specialized masks designed to limit airflow during exercise, simulating the effects of high-altitude training [62]. These masks are thought to improve physical performance by increasing the body's efficiency in oxygen utilization. However, recent research on the effects of airflow restriction masks has shown that they can counteract the IOP-lowering effects typically observed during low-intensity endurance exercise [63]. The study found that the use of airflow restriction masks resulted in higher IOP during exercise, highlighting that any manipulation of normal breathing, whether through masks or other means, may negatively affect IOP regulation.

Taken together, these findings suggest that the manipulation of breathing patterns—whether through the Valsalva maneuver, face masks, or other interventions that restrict airflow—can lead to an increase in IOP during exercise. To minimize the risk of exacerbating IOP in individuals with glaucoma or those at risk, it is important to avoid such alterations in breathing during physical activity. Exercise supervision by qualified sports specialists is highly recommended to ensure that an appropriate breathing pattern is maintained throughout exercise, thereby preventing potential adverse effects on IOP and overall eye health. Further research is needed to investigate the long-term effects of altered breathing patterns on IOP and to develop specific guidelines for managing breathing during exercise, particularly for individuals with glaucoma or those predisposed to elevated IOP. Studies should also explore the potential impact of different types of breathing techniques (e.g., diaphragmatic versus chest breathing) on IOP regulation during exercise to better inform exercise prescriptions and safety recommendations for this population.

2.4. Cognitive Requirements

In many settings, physical and cognitive demands occur simultaneously, such as in occupational environments, military operations, and team sports. These activities require individuals to not only perform physically challenging tasks but also to engage in complex cognitive processes like decision making, strategic thinking, and problem solving [64,65]. The combined demands of physical and mental exertion can result in an additive or even synergistic effect on IOP. For example, studies have shown that increasing mental demands during physical tasks, such as cycling or basketball free-throw shooting, causes a significant rise in IOP [66,67]. These findings suggest that cognitive stress during exercise may exacerbate the IOP response, which could be particularly concerning for individuals with or at risk of glaucoma.

If reducing IOP is a therapeutic goal, mental stress should be minimized during physical activity. This highlights the importance of investigating the role of psychological factors in glaucoma prevention and management. Mental stress has been shown to trigger a range of physiological changes, including elevated IOP, which could undermine the benefits of exercise that typically help to lower IOP [68]. For individuals with glaucoma, stress reduction becomes a critical aspect of managing the condition and preventing its progression. Physical activities promoting benefits for physical status and mental well-being should be considered (e.g., yoga, Tai Chi, Pilates, etc.). These practices have been shown to improve both physical and mental health, promoting relaxation, reducing stress, and enhancing overall quality of life [69]. Recent studies have also suggested its potential benefits on the management of glaucoma [70–72]. A recent meta-analysis [68] found that various relaxation techniques (i.e., meditation, yoga, autogenic relaxation exercises, etc.) cause significant IOP reductions in the long term.

One of the major challenges in managing chronic conditions like glaucoma is ensuring long-term adherence to exercise regimens. In the context of exercise prescription, especially for individuals with chronic conditions, maintaining adherence is a key factor in achieving therapeutic benefits. Exercise adherence enables glaucoma patients to meet their physical activity guidelines, which is associated with a lower risk of developing glaucoma [13,19]. Evidence from sports science and psychology has consistently shown that the enjoyment and pleasure derived from physical activity are critical determinants of adherence to exercise programs [73,74]. If an exercise routine is perceived as enjoyable, individuals are more likely to stick with it, which is essential for improving long-term health outcomes. This is especially important for glaucoma patients, who may need to adopt exercise as a regular part of their lifestyle to manage IOP and reduce disease progression. Eye care providers and fitness professionals can work together to recommend activities that are both beneficial for IOP regulation and enjoyable for the individual, ensuring that the patient remains motivated and committed to long-term exercise participation.

2.5. Fitness Level

The IOP responsiveness to physical efforts seems to be mediated by fitness level, with physically fitter individuals showing a more stable IOP behavior during exercise performance. Indeed, this finding has been observed for different physical activities, including maximal treadmill running, all-out cycling sprints, strength exercises and low-intensity endurance exercises [26,29,75–77]. These observations suggest that a higher baseline fitness level may confer a protective effect against exercise-induced IOP fluctuations.

This evidence aligns with the gradual progression models recommended by the American College of Sports Medicine for exercise prescription [78,79]. These guidelines emphasize the importance of tailoring exercise programs to an individual's initial training status to minimize exercise-related complications, such as significant IOP fluctuations. For example, Vera and colleagues [76] found that less fit individuals (relative maximal oxygen uptake: 43.4 $\pm$ 1.2 mL min^{-1} kg^{-1}) exhibited a greater IOP rise (effect size = 0.95) after completing a treadmill test in comparison to individuals with higher fitness levels (relative maximal oxygen uptake: 57.1 $\pm$ 1.7 mL min^{-1} kg^{-1}). Such fluctuations have been identified as a critical risk factor for glaucoma onset and progression [61,80]. This underscores the necessity of a measured and progressive approach to physical training in glaucoma patients or those at risk of developing the condition.

For individuals with lower baseline fitness levels, initial exercise programs should prioritize low-intensity activities with gradual increments in intensity and duration. This approach can help build endurance and strength without inducing abrupt changes in IOP. For example, unfit individuals might begin with light walking or stretching exercises before progressing to moderate-intensity activities such as brisk walking or cycling. Fitness professionals and healthcare providers should collaborate to ensure that exercise plans for glaucoma patients or at-risk individuals are both safe and effective. Regular assessments of physical fitness and IOP behavior during exercise can provide valuable insights for tailoring these programs. Additionally, promoting adherence to these tailored plans through education and consistent support is crucial for maximizing long-term benefits. Future research should aim to further clarify the relationship between fitness levels, IOP responsiveness, and glaucoma progression. Studies exploring the optimal rate of progression in exercise programs for individuals with varying fitness levels could provide critical insights, enhancing the precision of exercise prescriptions for this population. Moreover, randomized controlled trials could help establish definitive guidelines for integrating fitness considerations into glaucoma prevention and management strategies.

2.6. Nutritional Ergogenic Aids

Performance during sporting activities can be significantly influenced by well-chosen nutrition strategies. Adequate nutrition plays a vital role in supporting athletes' physical capacity, recovery, and overall performance. In recent years, dietary supplements have become increasingly popular as a convenient and practical alternative to help athletes meet their nutritional needs, especially when certain nutrients or compounds may be challenging to obtain through food alone [81,82]. However, it is important to note that not all supplements are without risks. Some have been associated with harmful health effects, ranging from minor issues like gastrointestinal discomfort to more serious adverse events affecting various organ systems. These adverse effects can occur across all age groups, from amateur athletes to elite competitors, underscoring the need for careful consideration when incorporating supplements into an athlete's regimen [83]. For glaucoma patients, certain nutrients have demonstrated benefits, such as lowering IOP or improving optic nerve blood flow [9,11]. In fact, nutritional supplementation can serve as a complementary strategy for managing glaucoma and other eye conditions; however, it is also essential to acknowledge that some supplements may have undesirable effects and should be prescribed by qualified professionals.

Among the most popular and extensively studied dietary supplements is caffeine, widely recognized for its potential to enhance both physical and cognitive performance. Caffeine is known to stimulate the central nervous system, leading to increased alertness, reduced fatigue, and improved focus, all of which are beneficial during exercise and competition [84]. Given these performance-enhancing effects, caffeine has been incorporated into various pre-exercise and during-exercise supplementation strategies. The effects of caffeine on IOP have been widely studied in non-sport contexts, with research focusing on its impact on IOP in both healthy individuals and those with conditions like glaucoma [8,9,85,86]. In the context of exercise, however, there is a relative paucity of research exploring how caffeine influences IOP during physical activity. One study, for instance, examined the impact of caffeine intake (~4 mg/kg) on IOP responses during low-intensity endurance exercise, specifically 30 min of cycling. The study found that caffeine intake appeared to counteract the IOP-lowering effects typically observed during low-intensity exercise. While exercise can generally reduce IOP by enhancing ocular perfusion and reducing systemic vascular resistance, caffeine seems to reverse this effect in the short term, leading to an increase in IOP during physical activity [85]. This suggests that caffeine ingestion may disrupt the typical IOP reduction that is often seen with endurance exercise. In the short term, this indicates a potential negative effect on IOP stabilization, particularly for individuals who are susceptible to elevated IOP or those with glaucoma.

Despite these short-term effects, the long-term impact of caffeine consumption on IOP is less clear. Evidence from studies on chronic caffeine consumption suggests that regular intake may lead to a modest increase in baseline IOP levels. However, this increase in IOP is generally not associated with an increased risk of developing glaucoma, especially in individuals without a predisposition to the disease [87]. Some studies suggest that, over time, the body may adapt to regular caffeine intake, potentially mitigating its acute impact on IOP [9]. Furthermore, animal models of glaucoma have provided some surprising insights into the potential neuroprotective effects of caffeine. Research has shown that caffeine may reduce neuroinflammation and protect retinal ganglion cells from degeneration, both of which are key factors in glaucoma progression [88]. These findings indicate that caffeine may have a protective role in maintaining retinal health and may even reduce the damage caused by elevated IOP in some contexts, though more research is needed to confirm these effects in humans.

Although caffeine is one of the most widely studied ergogenic aids in terms of its impact on physical and cognitive performance, there remains a significant gap in our understanding of its long-term effects on IOP, particularly during exercise. The current body of research, while informative, does not provide conclusive evidence on how regular caffeine consumption influences IOP over extended periods. Additionally, it remains unclear whether the short-term rise in IOP observed after caffeine intake is clinically significant for individuals with glaucoma or those at risk of developing the condition. As the relationship between caffeine and IOP is still not fully understood, further research is necessary to explore both the short- and long-term effects of caffeine and other nutritional supplements on IOP levels, ocular health, and retinal function.

Interestingly, nitric oxide supplements have been proposed to improve muscle performance and training adaptations. Research indicates that dietary nitric oxide supplementation improves peak power during isokinetic resistance training [89]. Additionally, nitric oxide plays a vital role in maintaining IOP homeostasis, with disruptions in its signaling linked to glaucoma and related conditions [90]. This compound has also been identified as a promising strategy for reducing IOP in glaucoma patients by enhancing outflow through the conventional outflow pathway [91,92]. Furthermore, nitric oxide supports ocular blood flow and regulates vascular tension, potentially offering protection for the optic nerve [93]. These findings suggest that nitric oxide supplementation could be a valuable adjunct in glaucoma treatment, particularly by targeting the conventional outflow pathway [94].

In addition to caffeine and nitric oxide, other nutritional ergogenic aids, such as creatine, beta-alanine, and branched-chain amino acids (BCAAs), are commonly used to improve athletic performance. However, their effects on IOP and ocular health remain largely unexplored. For the rest of the substances, future studies should aim to investigate the impact of these supplements on IOP during different types of exercise, particularly those that may increase IOP levels, such as strength training and high-intensity interval training. By expanding our understanding of how various dietary supplements influence IOP and retinal function, we can provide evidence-based recommendations for athletes, particularly those with eye conditions like glaucoma, ensuring that supplementation strategies support both performance and long-term eye health.

2.7. *Specific Training Devices*

Swimming and aquatic exercise have shown to offer numerous health benefits [95,96]. The resistance of water reduces the stress on joints and muscles, which makes swimming an accessible and effective form of exercise for older adults [97,98]. Therefore, this physical activity is a very interesting for glaucoma patients or those at risk. However, one factor that requires consideration when swimming is the use of swimming goggles. Studies have shown that wearing swimming goggles can lead to a small, but statistically significant, rise in IOP [99–102]. While the increase in IOP is modest, it may still be relevant for individuals with glaucoma or those seeking to maintain stable IOP levels. However, the frequent use of swimming goggles was not associated with an increased risk of glaucoma over time in adults [103].

Interestingly, the rise in IOP associated with swimming goggles may be linked to the design of the goggles and how they fit on the face. The pressure exerted by the goggles on the eyes and surrounding tissues, particularly the ocular and periocular areas, can cause temporary changes in IOP [102]. This effect is thought to be due to the compression of the ocular structures, which might impede normal ocular drainage and increase the pressure within the eye [100]. It is hypothesized that the anatomical characteristics of the face and head, as well as the specific design of the goggles, may influence how much pressure is applied to the eye. As shown by Zhang and colleagues [101], the use of wider frames in swimming goggles causes smaller IOP elevation in comparison to smaller frames.

In response to these concerns, researchers have proposed that redesigning swimming goggles to reduce the compressive forces on the eyes and surrounding tissues could be a valuable alternative. Innovations in goggle design, such as using softer materials or incorporating adjustable pressure mechanisms, could help minimize the potential IOP increases associated with their use [99]. While there is no definitive consensus on the optimal design, advancements in goggle technology could provide a solution for individuals with glaucoma who wish to engage in swimming without negatively affecting their IOP.

Blood flow restriction training (BFR), which involves the application of cuffs or wraps to limit blood flow to the working muscles during exercise, has gained attention in recent years for its potential to enhance athletic performance and improve muscle strength in a more efficient manner [104]. This approach allows individuals to achieve similar gains in muscle mass and strength as traditional high-load resistance training, but with the added benefit of using lower weights, which can reduce the strain on joints and tissues. BFR is also seen as a promising strategy for individuals in fragile populations, such as older adults or those with joint issues, as it minimizes the risk of injury associated with heavy lifting [105,106].

However, the effects of blood flow restriction on IOP have not been extensively studied. To address this gap in knowledge, our research group has conducted two studies to investigate the impact of BFR on IOP levels. In our first study, we found that applying bilateral blood flow restriction to the upper and lower extremities at 60% and 40% of the participants' predicted arterial occlusion pressure did not result in significant changes in IOP during rest [107]. This suggests that, at least under resting conditions, BFR may not significantly affect IOP levels, offering some reassurance for individuals concerned about the potential impact of this training method on ocular health.

In a follow-up study published in 2023, we further explored the acute effects of combining resistance training with blood flow restriction on IOP. We observed that applying BFR at 40% pressure during resistance exercises led to similar IOP responses compared to exercises performed without blood flow restriction [108]. This indicates that low-intensity BFR combined with light-load resistance training may be a safe and effective approach for inducing muscle adaptations typically associated with high-load exercises, without causing harmful changes in IOP.

These findings are particularly important for individuals with glaucoma, as they suggest that BFR could be a viable alternative to traditional high-load resistance training. By combining BFR with light resistance training, individuals may achieve similar strength and muscle endurance benefits, while avoiding the potentially harmful effects of heavy lifting on IOP. Given the limited research on the subject, further studies are needed to explore the long-term effects of BFR on IOP, especially in individuals with glaucoma or those at risk. Nevertheless, current evidence suggests that BFR could be incorporated into exercise regimens for glaucoma patients as a means of improving physical performance without negatively impacting ocular health.

3. Limitations and Future Research

The available scientific evidence about the association between physical activity and IOP is mainly based on results from non-clinical populations. While these studies provide insights into the general effects of exercise on IOP, the unique pathophysiology of glaucoma means that findings from non-glaucoma individuals should be interpreted cautiously [1]. Glaucoma patients are particularly vulnerable to IOP fluctuations, which may lead to optic nerve damage and retinal ganglion cell loss [61]. Therefore, it is crucial to prioritize research that specifically involves glaucoma patients to better understand how different types of exercise impact IOP and glaucoma progression.

When possible, researchers should prioritize the inclusion of glaucoma patients for their studies. Also, the primary goal of an exercise intervention is to promote long-term benefits on the underlying condition (i.e., glaucoma). Thus, more longitudinal studies are required to shed light on the link between exercise practice and glaucoma prevention and management [19]. The design of well-powered randomized controlled trials with a sufficient period of follow-up aiming to test the effects of physical exercise interventions on glaucoma prevention and management would be very relevant [13]. The main goal of this report is to provide an evidence-based guide for exercise prescription in subjects who need to maintain IOP levels as low as possible. Nevertheless, exercise prescription should be individualized considering risk factors, medical history, musculoskeletal limitations, functional ability, tolerance, and personal preferences [109].

While the focus of this report is on exercise interventions, it is important to acknowledge that glaucoma management extends beyond physical activity. Modifiable lifestyle factors such as diet, mental stress, sleep hygiene, and smoking cessation all influence IOP and overall eye health [8,9]. Healthcare providers should consider these factors when developing comprehensive treatment plans for glaucoma patients. For example, dietary changes could improve ocular blood flow, while stress reduction techniques, such as meditation and yoga, may help mitigate IOP increases associated with mental stress.

Given the multifactorial nature of glaucoma management, future research should explore the potential of multi-component lifestyle interventions that combine exercise with other behavioral modifications [9]. This approach could offer a more holistic solution for preventing glaucoma progression and improving patient outcomes. By investigating the combined effects of exercise, diet, and mental health strategies, researchers may identify synergistic benefits that enhance the management of IOP and protect against optic nerve damage. In addition, glaucoma types such as pigmentary glaucoma should be carefully considered. There is evidence that dynamic exercise may cause significant intraocular pressure elevation in these cases due to exercise-induced iris concavity, which enhances mechanical rubbing of the iris against the zonular bundles and results in pigment release [110,111].

In summary, while the existing evidence on exercise and IOP is promising, further research is needed to understand the long-term effects of exercise in glaucoma patients. Future studies should prioritize the inclusion of glaucoma patients, investigate the effectiveness of different exercise modalities, and consider other modifiable lifestyle factors that contribute to IOP management. Such research will be vital in developing individualized, evidence-based recommendations for glaucoma prevention and management, ultimately improving the quality of life and visual outcomes for patients with this condition.

4. A Practical Guide for Exercise Prescription in Glaucoma Patients or Those at Risk

There is robust and irrefutable evidence supporting the regular practice of physical exercise as an essential component in reducing premature mortality and the prevalence of numerous chronic conditions, including cardiovascular diseases, diabetes, and obesity [112,113]. Regular physical activity has been widely recognized for its broad spectrum of health benefits, both for general well-being and the management of specific medical conditions. As a result, various international organizations, such as the World Health Organization and the American Heart Association, have proposed general physical activity guidelines to promote public health. These recommendations typically suggest a threshold of 150 min per week of moderate to vigorous physical activity or 10,000 steps per day for both healthy individuals and those with clinical conditions [12,40].

However, while these threshold-centered recommendations have been widely adopted, there is growing recognition that they may not fully capture the nuanced relationship between physical activity and health outcomes, especially for individuals with specific health conditions like glaucoma. Specifically, there is a well-established dose-response relationship between physical activity and health status, where incremental increases in physical activity can lead to progressive improvements in health, particularly for those who are least active [112,114]. For example, individuals who are sedentary or engage in low levels of physical activity tend to experience the greatest health benefits from even small increments in physical activity, such as moving from no exercise to engaging in light physical activity.

Exercise prescription must be tailored to the individual's specific health needs and condition. For patients with glaucoma, for instance, the primary focus of exercise-based interventions should be on managing IOP, as it is a critical factor in the prevention and management of the disease. Exercise recommendations for glaucoma patients should consider the effects of different types of physical activity on IOP and how they can be optimally leveraged to achieve the best possible outcomes for disease control. Figure 1 provides an evidence-based summary of key exercise-related factors that eye care providers and sports specialists should consider when prescribing exercise for individuals with glaucoma. These factors include the type, intensity, duration, and frequency of exercise, all of which can influence IOP levels. By using this approach, clinicians can ensure that their exercise prescriptions are not only safe but also effective in managing IOP and preventing glaucoma progression.

Factors for exercise prescription in glaucoma management and prevention	Do´s	Don´ts
Exercise type and intensity	Endurance exercise at low to moderate intensities (i.e., jogging, cycling, swimming)	Training close to maximum aerobic power (i.e., running/cycling to volitional exhaustion)
	Resistance training with moderate loads not reaching muscular failure	Resistance training with heavy relative loads (i.e., ≥ 80% 1-RM) and leading to failure.
Fitness level	Enhance fitness level by a progressive involvement in physical training	Perform highly demanding physical efforts by unfit individuals
Body position	Adopt standing or sitting positions for exercise execution	Adopt head-down or supine positions for exercise execution
Breathing pattern	Follow a regular and controlled breathing pattern during exercise	Limit the interchange of gases (i.e., Valsalva maneuver or airflow restriction mask)
Nutritional ergogenic aids		Ingest a high caffeine dose before performing aerobic exercise
Cognitive requirements	Physical activities that reduce stress and maximize enjoyment	Cognitively stressful and unpleasant physical activities
Swimming goggles	Swimming at low- to moderate-intensity with appropriate googles for head/facial anatomy	Using very tight swimming googles that compress the ocular and periocular tissues
Blood flow restriction	Include blood flow restriction to reduce the relative load used for resistance training	Combine blood flow restriction and resistance training without adjusting intensity

Figure 1. Schematic illustration of exercise-based recommendations for intraocular pressure control during exercise practice. 1-RM = one repetition-maximum.

Furthermore, while the general public can benefit from a one-size-fits-all approach to physical activity, individuals with chronic conditions like glaucoma may require more individualized exercise recommendations. These recommendations should be based on factors such as the patient's current IOP levels, physical fitness, and any other comorbidities they may have. An individualized approach would help maximize the benefits of exercise for glaucoma management while minimizing any potential risks or adverse effects. Ultimately, a well-tailored exercise prescription, when combined with other therapeutic strategies, can significantly enhance the quality of life for individuals with glaucoma and improve long-term outcomes.

5. Conclusions

Physical exercise is one of the most important modifiable glaucoma risk factors, and exercise prescription must be considered by eye care providers and sport specialists when providing guidance and counseling for this population. There is a dose-response relationship between exercise practice and health status, highlighting that small increases in exercise practice provide significant health benefits (i.e., every step counts). A progressive involvement with physical activities that promote participation and adherence seems to be a good strategy for older adults with chronic conditions.

Exercise should be considered as medicine, and the prescription of physical activity should therefore be based on the subject's characteristics (i.e., medical history, musculoskeletal limitations, personal preferences, etc.) and controlled like any other medical treatment. We encourage the research community to design randomized controlled trials to assess the long-term effects of exercise and multicomponent interventions on glaucoma prevention and management.

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