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The Impact of High-Intensity Resistance Training on Intraocular Pressure and Ocular Hemodynamics: A literature review

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Abstract

Background. Intraocular pressure (IOP) is a dynamic parameter influenced by various physiological stressors, including resistance exercise (RE). While physical activity is generally considered protective for eye health, high-intensity strength training may induce significant, acute spikes in IOP, posing a potential risk for individuals with or at risk of glaucoma.

Aim. The purpose of this systematic review was to evaluate the acute effects of resistance exercise on IOP in healthy adults and to identify the physiological and methodological factors (such as the Valsalva maneuver and timing of measurement) that influence these fluctuations.

Material and methods. A systematic review of the literature was conducted using electronic databases (e.g., PubMed, Web of Science, Scopus) to identify studies investigating IOP changes during and after resistance exercise in healthy adults. Selection criteria included quantifiable exercise intensity (e.g., % 1RM) and standardized IOP measurement protocols. Data were analyzed to identify the influence of the Valsalva maneuver, muscle mass involvement, and the timing of measurement (during vs. post-exercise).

Results. The analysis revealed that RE-induced IOP changes are primarily intensity-dependent, with loads exceeding 80% 1RM causing spikes of up to 200% (exceeding 40 mmHg) when measured during the effort. A crucial methodological discrepancy was identified: studies measuring IOP during the repetition consistently reported hypertensive peaks, whereas post-exercise measurements often showed a rapid return to baseline or post-exercise hypotension. Furthermore, the Valsalva maneuver was found to be a dominant factor in magnifying IOP elevations due to impaired venous drainage. Conversely, emerging methods such as Blood Flow Restriction (BFR) training appear to offer a safer alternative for at-risk populations by eliciting muscle hypertrophy at lower intensities with minimal impact on ocular hemodynamics.

Conclusions. Acute resistance exercise induces a biphasic IOP response, characterized by an extreme but transient increase during exertion followed by a rapid stabilization. Traditional post-exercise measurements may significantly underestimate the mechanical stress on the optic nerve. While RE is a vital component of health, high-intensity lifts combined with the Valsalva maneuver should be approached with caution in clinical populations. Future longitudinal research is required to determine the cumulative effects of repeated acute IOP spikes on the structural integrity of the optic nerve.

Keywords: intraocular pressure, resistance training, Valsalva maneuver, eye health, blood flow restriction

1. Introduction

1.1. Clinical significance of exercise-induced intraocular pressure changes

Intraocular pressure (IOP) is a dynamic parameter determined by the equilibrium between aqueous humor production and outflow; its chronic elevation remains the primary risk factor for glaucomatous optic nerve damage. While the hypotensive effect of aerobic exercise on IOP is well-documented, the ocular response to resistance training (RT) continues to be a subject of scientific debate (Hackett et al., 2023). This study aims to critically review the literature regarding the impact of high-intensity strength training on IOP fluctuations in healthy adults and to identify the key determinants of these changes.

1.2. Pathophysiology of the Valsalva Maneuver and Intra-abdominal Pressure Dynamics

The primary determinant of rapid IOP spikes in strength sports is the Valsalva maneuver (VM)—a forced exhalation against a closed glottis, typically performed during core bracing when lifting near-maximal loads. This mechanism generates a precipitous increase in intrathoracic and intra-abdominal pressure, which directly impairs venous return from the choroidal and episcleral vessels (Vera, Perez-Castilla, et al., 2019). The resulting venous congestion leads to an acute elevation in IOP, the amplitude of which is linearly correlated with the magnitude of the pressure gradient. It is noteworthy that while mental stress induces only marginal changes in IOP (approximately 1.3 mmHg), the Valsalva maneuver can trigger elevations exceeding 10 mmHg, posing a significant challenge to ocular vascular homeostasis (Brody et al., 1999).

1.3. Resistance Training and Ocular Homeostasis: The Knowledge Gap

The impact of physical activity on intraocular pressure (IOP) is highly exercise-dependent; while aerobic training typically exerts a hypotensive effect by enhancing aqueous humor outflow, the findings regarding resistance exercise (RE) remain inconsistent. A critical gap in the existing literature is the limited understanding of IOP dynamics during near-maximal loading combined with the Valsalva maneuver (Cutura et al., 2024). Most previous studies have relied on post-set measurements, which, due to the rapid physiological stabilization of ocular parameters, systematically underestimate the actual pressure peaks occurring during the repetition itself. Evidence suggests that during the peak exertion phase, IOP may surge by approximately 200%, reaching values as high as 40 mmHg. This underscores the urgent need for a robust safety assessment of retinal and choroidal structures under extreme mechanical stress (Vaghefi et al., 2021).

2. Materials and Methods

To ensure a robust assessment of intraocular pressure (IOP) dynamics during resistance training, a systematic review of the scientific literature was conducted. The search strategy focused on identifying clinical and experimental studies that directly analyzed the physiological mechanisms occurring in the eye during acute resistance exercise (Cutura et al., 2024; Vera, Jiménez, et al., 2019).

2.1. Search Strategy

A comprehensive search of electronic databases, including PubMed, Scopus, and Google Scholar, was performed to identify relevant publications from 1999 to 2024. The search utilized the following keywords and their Boolean combinations: *intraocular pressure, resistance training, weightlifting, Valsalva maneuver, ocular perfusion pressure, ocular blood flow*.

2.2. Participant Characteristics and Selection Criteria

Studies meeting the following inclusion criteria were selected for the final analysis:

- **Participant Population:** Studies conducted exclusively on healthy adults (without diagnosed ocular pathologies, glaucoma, or systemic hypertension). The selection of healthy cohorts was essential to eliminate the confounding effects of anti-glaucoma medications and pathological changes in the trabecular meshwork on IOP measurements (Sidoti et al., 2024).
- **Type of Intervention:** Use of dynamic resistance exercises (RE), including but not limited to bench presses, squats, leg presses, and arm curls (Hackett et al., 2023).
- **Breathing Patterns:** Studies analyzing the impact of the Valsalva maneuver (forced expiration against a closed glottis) in comparison with spontaneous or controlled breathing techniques (Brody et al., 1999).

2.3. Standardization of Exercise Intensity (1RM)

Exercise intensity across the reviewed publications was standardized using the One-Repetition Maximum (1RM) metric. The 1RM represents the maximum weight an individual can lift for a single repetition while maintaining proper biomechanical form. Training loads were expressed as a percentage of this value (e.g., 70% 1RM, 95% 1RM), facilitating an objective comparison of physiological strain across participants with varying levels of absolute strength (Campos et al., 2002).

2.4. Methodological Analysis: "Intra-repetition" vs. "Post-set" Dynamics

Previous scientific reports regarding the impact of resistance training on IOP exhibit a high degree of heterogeneity, which is largely attributable to significant procedural discrepancies. A critical limitation in the existing literature is that many classic studies relied on tonometric measurements taken only after the completion of a set **(post-set/post-exercise)**. This approach overlooks the rapid physiological stabilization of IOP that occurs immediately upon muscle unloading and the release of intra-abdominal pressure (Vaghefi et al., 2021; Vera et al., 2020).

Consequently, traditional methodology leads to a systematic underestimation of the actual magnitude of the phenomenon, which reaches its peak values strictly during the repetition (intra-repetition). The present analysis places particular emphasis on studies that monitored IOP changes in real-time. This focus allows for a robust assessment of the mechanical risk to retinal and choroidal structures in strength athletes, providing insight into the true amplitude of pressure fluctuations to which the eye is exposed during peak exertion (Vera et al., 2020).

3. Results

3.1. Evidence Base Characteristics and General Trends in IOP Dynamics

Synthesis of the gathered research material indicates highly dynamic fluctuations in intraocular pressure (IOP) in response to resistance training. The consensus across the included experimental studies confirms that high-intensity strength training triggers acute alterations in ocular hydrodynamic parameters in healthy adults. It was observed that the amplitude of these changes is fundamentally correlated with two primary determinants: the magnitude of the external load (expressed as % 1RM) and the selected measurement methodology (Vera et al., 2020).

3.2. Exercise Intensity as a Determinant of Intraocular Pressure Elevation

The synthesized data demonstrate a linear relationship between exercise intensity and real-time IOP values (Gene et al., 2022). The most pronounced pressure elevations were observed in studies utilizing submaximal and maximal loads (exceeding 80% 1RM). Evidence indicates that at intensities of 95% 1RM (e.g., during the bench press or squat), IOP can surge by 100–200% relative to baseline, reaching critical values exceeding 40 mmHg (Vera, Jiménez, et al., 2019). In contrast, exercises performed at low intensities (below 50% 1RM) generated only marginal and statistically insignificant fluctuations. This suggests the existence of an intensity threshold beyond which the mechanical risk to retinal and choroidal structures increases substantially (Lara et al., 2023).

3.3. Methodological Paradox: "Intra-repetition" vs. "Post-exercise" Measurements

A primary finding of this analysis is the identification of systematic discrepancies in reported IOP values stemming from the timing of tonometric assessment. Studies monitoring pressure at peak muscle tension ("intra-repetition") consistently demonstrate acute hypertensive spikes. Conversely, a contradictory trend is observed in studies where measurements were taken immediately following the completion of a set ("post-exercise") (Vaghefi et al., 2021).

Certain studies report a decrease in IOP below baseline, termed post-exercise hypotension, immediately after finishing a series (Chromiak et al., 2003; Conte et al., 2009). Comparing these data with the record elevations reported in recent literature suggests that the IOP response is **biphasic**: an extreme, transient pressure surge occurs during the repetition, followed by rapid stabilization and a secondary decline in values as muscle tension is released and breathing normalizes. This methodological discrepancy explains the apparent lack of consistency in earlier literature and underscores the necessity of dynamic, real-time measurements for a robust assessment of ophthalmic safety in strength athletes (Vera et al., 2020).

3.4. The Impact of Ventilatory Patterns and the Valsalva Maneuver

Analysis of the synthesized data demonstrates that the breathing modality employed during force generation is a critical determinant of intraocular pressure stability. It has been observed that exercising while maintaining spontaneous, rhythmic breathing significantly attenuates pressure spikes, even under submaximal loads. In stark contrast, the Valsalva maneuver (VM), characterized by forced exhalation against a closed glottis, drastically amplifies the ocular hypertensive response (Menna et al., 2025).

Evidence indicates that elevated intra-abdominal pressure increases intrathoracic pressure, which mechanically impedes venous return from the choroidal vessels via the jugular veins (Hackett et al., 2023). This mechanism results in a rapid expansion of intraocular blood volume and a concomitant spike in IOP. In extreme cases, specifically among individuals utilizing the VM while lifting maximal loads, IOP values can be 50–100% higher than those recorded during exercises performed with unrestricted breathing. Furthermore, the duration of breath-holding exhibits a progressive effect: a prolonged tension phase during the Valsalva maneuver is positively correlated with higher IOP magnitudes recorded toward the end of the effort (Vera, Perez-Castilla, et al., 2019).

3.5. Exercise Specificity and IOP Dynamics: The Role of Muscle Mass and Body Orientation

The findings indicate that various modalities of resistance training exert disparate levels of mechanical strain on the eye. The primary differentiating factors identified were the volume of involved muscle mass and the body's orientation relative to gravity.

- **Muscle Mass:** Multi-joint lower-limb compound exercises, such as squats and leg presses, elicited significantly greater IOP amplitudes (range: 3.1-28.7 mmHg) compared to isolated movements, such as bicep curls or isometric handgrip tasks. This disparity is attributed to the fact that large muscle group recruitment necessitates more robust core stabilization and induces higher systemic blood pressure (Hackett et al., 2023).
- **Body Position:** It was observed that exercises performed in a supine position (e.g., bench press) are associated with higher baseline and exercise-induced IOP compared to those performed while standing or seated. This phenomenon is linked to gravitational shifts in fluid redistribution and elevated cephalic venous pressure (Krzysztofik et al., 2022). Comparative studies indicate that the horizontal position contributes an additional increase of approximately 2-3 mmHg to the total IOP compared to upright variations of the same movement (Lara et al., 2023).

3.6. Physical Fitness Profile and Baseline IOP Values

The analysis revealed significant correlations between physical fitness levels and resting intraocular pressure values. While general, regular physical activity is typically associated with a sustained reduction in baseline IOP among healthy individuals (Siang et al., 2021), specific strength profiles appear to modulate this relationship. A positive correlation was identified between maximum strength (1RM), theoretical maximum force (F0), and higher resting IOP values (Vera et al., 2018). These findings suggest that high levels of neuromuscular strength adaptation may coexist with a distinct intraocular pressure homeostasis profile, differing from that of the general physically active population.

4. Discussion

4.1. Ocular Homeostatic Adaptation to Extreme Physical Exertion

The present findings provide a new perspective on the widely held consensus that physical activity unequivocally lowers intraocular pressure (IOP). While regular aerobic or moderate-intensity exercise promotes a sustained reduction in baseline IOP (Siang et al., 2021), the data synthesized in the context of extreme resistance training suggest the existence of a distinct adaptive mechanism. The correlation between superior maximum strength (1RM) and elevated resting IOP (Vera et al., 2018) indicates that chronic exposure to drastic pressure surges during heavy weightlifting may permanently alter ocular homeostasis. It is plausible that in elite strength athletes, the intraocular "set point" shifts toward higher values, a potential physiological adaptation to recurrent episodes of extreme mechanical stress.

4.2. Hemodynamic Mechanisms: The Valsalva Maneuver and Venous Drainage

A primary factor accounting for the IOP spikes exceeding 40 mmHg is the physiological response to the Valsalva maneuver (VM), which is often performed involuntarily when overcoming maximal resistance (Brody et al., 1999). Breath-holding against a closed glottis generates a precipitous rise in intrathoracic pressure, which directly impedes venous return through the jugular veins. This retrograde pressure is transmitted to the ocular choroidal vessels, leading to acute vascular engorgement and an immediate surge in intraocular pressure (Hackett et al., 2024; Vera et al., 2020). These findings suggest that for individuals predisposed to glaucoma, modulating breathing patterns may constitute a more critical protective strategy than merely reducing external resistance (Krzysztofik et al., 2022).

4.3. The Dose-Response Relationship in Training Intensity

Trend analysis indicates a distinct intensity threshold beyond which IOP stability is compromised. While low-to-moderate intensity efforts appear clinically safe, loads approaching 95% 1RM elicit near-pathological hypertensive responses in the short term. The realization that this pressure surge is biphasic, resolving almost instantaneously upon load cessation (Vera et al., 2020), necessitates a reinterpretation of earlier literature that relied on delayed measurements (Chromiak et al., 2003). However, a critical question remains: whether the chronic recurrence of these transient pressure "peaks" over years of training could lead to cumulative microtrauma of the optic nerve. This potential for long-term barotrauma underscores the urgent need for longitudinal studies in elite strength-trained cohorts (Krzysztofik et al., 2022).

4.4. Practical Implications for Sports and Occupational Medicine

From a clinical perspective, these findings necessitate a revision of training recommendations for individuals with ocular hypertension or glaucoma. A prioritized strategy should involve substituting horizontal exercises (e.g., bench press) with upright variations and implementing education on avoiding the Valsalva maneuver (Lara et al., 2023). Furthermore, standard ophthalmological examinations conducted solely at rest may provide a "false sense of security" for powerlifters and bodybuilders, as the actual mechanical stress on ocular structures occurs exclusively under maximal exertion.

Particular consideration should be given to **Blood Flow Restriction (BFR)** training as a safe alternative. This modality, utilizing occlusion cuffs, enables significant muscle hypertrophy with loads as low as 20–30% 1RM. Since such low intensities do not necessitate the Valsalva maneuver or generate extreme intra-abdominal pressure, BFR may represent the safest training alternative for elderly populations and glaucoma patients. However, technical precision is paramount: to minimize secondary IOP elevation, exercises should be performed in upright positions (avoiding supine orientations where the head is below the heart line) and with conservative cuff pressures (lower % AOP – Arterial Occlusion Pressure) to mitigate excessive systemic blood pressure surges (Krzysztofik et al., 2022).

5. Conclusions

The present analysis demonstrates that resistance training triggers acute, **biphasic fluctuations** in intraocular pressure (IOP), the dynamics of which are strictly modulated by exercise intensity and ventilatory patterns. A primary conclusion of this study is that traditional post-exercise measurement protocols fail to capture the true mechanical strain on ocular structures; during peak muscular exertion, IOP may reach critical levels exceeding **40 mmHg**. This phenomenon, markedly exacerbated by the **Valsalva maneuver**, necessitates a rigorous revision of current ophthalmic safety standards within strength-based sports.

The synthesized data support the thesis that chronic exposure to maximal exertion may induce a permanent shift in ocular homeostasis toward higher resting pressures. This finding serves as a vital clinical reference point for glaucoma prevention in elite athletes. In this context, **Blood Flow Restriction (BFR)** training emerges as a promising and safe alternative, enabling anabolic adaptations with minimal mechanical stress on the globe, provided that standardized occlusion and postural protocols are strictly maintained.

Despite the potential of modern training modalities, there is an urgent requirement for **longitudinal research**. It remains to be determined whether long-term exposure to recurrent, transient pressure surges results in subtle, cumulative structural damage to the optic nerve. Investigating these potential long-term risks must become a priority for future inquiries in sports medicine and ophthalmology.

Disclosure

Author Contributions:

Conceptualization: IP, KP, MJ.

Methodology: IP, TP, NP.

Formal analysis: IP, MP, AP.

Investigation: IP, KP, MJ, TP, NP, MP, AP, KPa, FP.

Data curation: IP, KPa, FP.

Writing - original draft preparation: IP.

Writing - review and editing: IP, KP, MJ, TP, NP, MP, AP, KPa, FP.

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The authors declare no conflict of interest.

AI Statement:

The authors used AI-based tools (Gemini) solely for the purpose of improving the linguistic quality and structural organization of the manuscript. The authors maintain full responsibility for the content, data interpretation, and final version of the work.

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