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# EXERCISE-INDUCED CHANGES IN TEAR FILM PHYSIOLOGY AND TEAR BIOMARKERS: A NARRATIVE REVIEW

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## ABSTRACT

**Introduction:** The tear film functions as a dynamic interface, adapting its volume, stability, and osmolarity to systemic and environmental stress. Exercise produces simultaneous autonomic, hemodynamic, metabolic, thermal, and fluid-balance effects, making tear fluid a potentially informative, but methodologically challenging matrix for research.
**Methods:** A structured literature search of PubMed was performed and included articles published between January 2014 and August 2026. Human studies evaluating acute exercise, habitual physical activity, or exercise interventions in relation to tear secretion, tear-film stability, osmolarity, inflammatory mediators, oxidative-stress markers were prioritized. Animal studies and methodological literature on tear biomarkers analysis were included for context.
**Results:** Aerobic exercise generally increases tear secretion and can improve tear-film stability, whereas strenuous exercise accompanied by fluid loss may transiently increase tear osmolarity. Tear cytokine concentrations often decline after exercise, and reduced tear 8-hydroxy-2′-deoxyguanosine has been reported in dry-eye populations. However, several tear proteins and lipids show no immediate change. Fitness status, hydration, environmental exposure, blinking, sampling technique, and post-exercise timing substantially modify observed responses.
**Conclusions:** Exercise alters both tear-film dynamics and selected tear biomarkers, but the response is not uniformly beneficial or detrimental. The seemingly contradictory effects of exercise may account for the variability in current findings. While aerobic activity can stimulate lacrimal secretion and exert systemic anti-inflammatory effects, exercise-associated dehydration and environmental exposure may increase tear hyperosmolarity and evaporation, thereby compromising tear-film stability. Standardized protocols and longitudinal biomarker studies are required before tears can be used for exercise monitoring or clinical decision-making.

## KEYWORDS
Exercise, Tear Film, Tear Biomarkers, Tear Osmolarity

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# 1. Introduction

The tear film is a continuously renewed biological interface that supports optical quality, corneal and conjunctival epithelial homeostasis, lubrication, antimicrobial defense, and wound healing. Contemporary concepts emphasize a superficial lipid layer over a mucoaqueous phase rather than three completely discrete layers. Its composition includes electrolytes, proteins, lipids, mucins, metabolites, cytokines, extracellular vesicles, and nucleic acids. Because tear fluid can be obtained repeatedly with relatively low burden, it has become an attractive matrix for ocular and systemic biomarker research. At the same time, tear composition is highly sensitive to pre-analytical conditions, including reflex tearing, collection method, ambient temperature and humidity, blinking, ocular-surface disease, topical medication, contact-lens wear, and time of sampling (Gijs et al., 2025; Jones et al., 2022).

Exercise provides a particularly informative physiological challenge to the tear film. Within minutes, dynamic whole-body exercise changes sympathetic and parasympathetic activity, cardiovascular output, ventilation, body temperature, sweating, plasma volume, osmolality, endocrine signaling, immune-cell trafficking, and oxidative metabolism. At the ocular surface, exercise may also change blink frequency and completeness, eyelid aperture, tear evaporation, ocular-surface temperature, and exposure to wind or low humidity. Thus, a post-exercise tear sample reflects a composite of systemic physiology and local ocular-surface mechanics. This complexity creates both scientific opportunity and risk of overinterpretation.

The clinical relevance of this topic extends beyond sports ophthalmology. Dry eye disease (DED) is a multifactorial condition in which tear-film instability, hyperosmolarity, ocular-surface inflammation, neurosensory abnormalities, and epithelial stress interact in self-perpetuating cycles. Physical inactivity, prolonged sedentary behavior, and high visual-display exposure have been associated with DED in population studies, while exercise interventions have improved symptoms in selected groups (Hanyuda et al., 2020; Kawashima et al., 2014; Sano et al., 2018). These observations raise the possibility that physical activity is a modifiable lifestyle factor affecting ocular-surface homeostasis. In contrary acute exercise can also induce dehydration and environmental exposure, both of which may increase tear osmolarity and potentially exacerbate ocular discomfort.

The aim of this narrative review is to synthesize current evidence on exercise-induced changes in tear film physiology and tear biomarkers, with particular attention to: tear secretion and film stability; tear osmolarity and hydration; inflammatory and oxidative-stress biomarkers; secretory proteins, mucins, and lipid-related measures; the modifying effects of fitness, sex, environment, and sampling methodology; and the prospects and limitations of tear biomarkers for sports science and ocular-surface care. The review proposes a dual-response framework in which beneficial lacrimal, inflammatory, and redox responses coexist with hyperosmolar and evaporative stress when exercise is accompanied by dehydration or adverse environmental exposure.

# 2. Methods

This narrative review was prepared using a structured literature search approach modeled on contemporary narrative reviews of tear biomarkers. PubMed was searched for studies published from January 2014 through 14 August 2026. Search concepts combined terms related to the biological matrix ("tear", "tear film", "tear fluid") with exercise-related terms ("exercise", "physical activity", "aerobic exercise", "running", "athlete", "training") and outcome terms ("tear secretion", "tear meniscus", "tear break-up time", "osmolarity", "hydration", "cytokine", "MMP-9", "8-OHdG", "oxidative stress", "lactoferrin", "mucin", "lipid layer", "biomarker", and "biosensor"). Reference lists of relevant reviews and primary studies were also screened for additional eligible publications.

Priority was given to human experimental or observational studies that assessed whole-body exercise or habitual physical activity together with objective tear-film parameters or tear-fluid biochemical measurements. Studies of exercise programs and epidemiological physical activity exposure were included when they informed chronic ocular surface effects, even when molecular tear biomarkers were not measured. Animal studies were not used as direct clinical evidence, but were retained when they provided mechanistic information relevant to lacrimal secretion or oxidative-stress pathways. Methodological and biosensor reviews were included to evaluate pre-analytical limitations and future monitoring applications. Studies limited to eye exercises, ocular motor training, or non-tear ocular outcomes were not central to the synthesis.

Because the available literature is heterogeneous in study population, exercise mode and intensity, hydration status, environmental conditions, tear-collection method, analytical platform, and post-exercise sampling time, a quantitative meta-analysis was not considered appropriate for this narrative review. Findings were grouped thematically and interpreted with emphasis on direction of effect, biological plausibility, internal methodological limitations, and consistency across study designs. A formal risk-of-bias tool was not applied. Accordingly, numerical findings should be understood as study-specific estimates rather than pooled effects.

## 3. Results

***Table 1. Exercise-induced changes in tear film.***

| Tear film parameters | Acute High-Intensity Exercise | Moderate Aerobic Exercise | Chronic Physical Training |
|---|---|---|---|
| Tear Break-Up Time (TBUT) | Transient decrease | Significant increase (enhanced film stability) | Sustained long-term improvement |
| Tear Volume (Schirmer Test) | Variable; initial drop followed by rebound | Consistent elevation post-exercise | Increased baseline tear production |
| Tear Osmolarity | Temporary spike due to dehydration | Maintained at homeostasis | Reduced resting hyperosmolarity |
| Evaporation Rate | Increased (airflow & environmental exposure) | Stable to slightly reduced | Optimized lipid layer performance |

### 3.1. Tear secretion and tear-film stability

Aerobic exercise generally increases tear secretion and may improve tear-film stability. Li et al. (2020) reported increased tear-meniscus measures after aerobic exercise, accompanied by changes in tear cytokines. In patients with DED or preclinical dry eye, Sun et al. (2022) observed increased Schirmer values, prolonged non-invasive tear break-up time, fewer incomplete blinks, and more complete blinks after exercise. Lipid-layer thickness did not significantly change. Fitness may influence these responses. Abokyi et al. (2022) found that athletes had better baseline tear-film stability and showed greater post-exercise increases in tear secretion and TBUT than non-athletes. Peart et al. (2020) additionally demonstrated that acute exercise attenuated dry-eye symptoms and MMP-9 elevation induced by low-humidity exposure. Overall, acute dynamic exercise appears to stimulate tear secretion and improve tear-film stability, although the duration and clinical relevance of these changes remain uncertain.

### 3.2. Tear osmolarity, hydration, and exertional stress

Tear osmolarity shows a more variable response to exercise because it is influenced by systemic dehydration, local evaporation, blinking, and lacrimal secretion. Holland et al. (2018) observed an approximately 8 mOsm/L increase in tear osmolarity after a 10-km run associated with body-mass loss. However, changes in tear osmolarity did not correlate with standard hydration markers. Vera et al. (2017) reported that the osmolarity response to maximal exercise depended on fitness level, while Wylęgała et al. (2019, 2020) demonstrated effects of blinking, sex, and exercise-test conditions. Similar findings in combat-sport athletes indicate that tear osmolarity responds to dehydration but cannot currently replace conventional hydration measures (Doherty et al., 2024). Thus, post-exercise tear osmolarity represents the net effect of systemic fluid loss, ocular evaporation, and tear secretion and should be interpreted together with hydration and environmental variables.

### 3.3. Inflammatory biomarkers

*Table 2. Tear biomarkers*

| Tear biomarker | Biological domain | Reported acute response to exercise |
|---|---|---|
| Multiplex cytokines | Inflammation | Several cytokine concentrations decrease after acute aerobic exercise |
| MMP-9 | Ocular-surface inflammation | Variable response; attenuation reported under environmental stress |
| 8-OHdG | Oxidative stress / DNA damage | Decreases after aerobic exercise in patients with DED |
| Lactoferrin | Lacrimal secretory protein | No significant immediate change reported |
| MUC5AC | Goblet-cell mucin | No significant immediate change reported |
| OAHFAs | Tear-film lipids | No significant acute change reported |

Exercise may modify the tear inflammatory profile. Li et al. (2020) found decreased concentrations of multiple tear cytokines after aerobic exercise. However, because tear volume simultaneously increased, part of this reduction may reflect dilution rather than reduced cytokine production. MMP-9 findings were less consistent. Peart et al. (2020) reported attenuation of an environmentally induced MMP-9 increase after exercise, whereas Sun et al. (2022) found no significant acute change in MMP-9 following aerobic exercise in participants with dry-eye features. Current evidence therefore suggests that tear inflammatory mediators are exercise-responsive, but no individual cytokine or inflammatory protein has yet emerged as a reliable exercise biomarker.

### 3.4. Oxidative-stress biomarkers

Among oxidative-stress markers, 8-hydroxy-2′-deoxyguanosine (8-OHdG) has the strongest direct evidence. Sun et al. (2022) observed a significant reduction in tear 8-OHdG after aerobic exercise, while other measured tear components remained unchanged. Experimental findings support this observation. Sano et al. (2014) demonstrated increased tear secretion and reduced oxidative-stress-related tear markers in diabetic mice following repeated aerobic exercise. These findings suggest that exercise may influence ocular-surface redox regulation, although human evidence remains limited and larger studies are required.

### 3.5. Secretory proteins, mucins, and lipids

Not all tear constituents change acutely after exercise. Sun et al. (2022) found no significant post-exercise changes in lactoferrin, MMP-9, IL-6, OAHFAs, or MUC5AC. Lipid-layer thickness also remained largely unchanged despite improvements in tear-film stability and blink behavior. These results suggest that acute functional improvements may primarily reflect increased aqueous secretion and improved tear distribution rather than immediate changes in mucin or lipid composition.

### 3.6. Habitual physical activity and dry-eye risk

Evidence from observational and intervention studies suggests that regular physical activity may be associated with better ocular-surface health. The Osaka Study and JPHC-NEXT study reported associations between lower physical activity, greater sedentary behavior, and increased DED risk (Kawashima et al., 2014; Hanyuda et al., 2020). Exercise-based interventions have also improved subjective dry-eye symptoms and clinical outcomes in office workers and older adults (Kawashima et al., 2018; Sano et al., 2018; Ismail et al., 2023). More recently, Jin et al. (2026) analyzed 84,065 UK Biobank participants and found that higher accelerometer-measured moderate-to-vigorous physical activity was associated with a lower risk of incident DED. Both regular activity and a “weekend warrior” pattern were associated with reduced risk compared with inactivity. Overall, habitual physical activity appears to be associated with a lower risk of DED, although longitudinal studies directly evaluating changes in molecular tear biomarkers after exercise training remain scarce.

# 4. Discussion

## 4.1. Interpretation of the findings

The available evidence suggests a dual response of the tear film to exercise. Moderate aerobic exercise may stimulate lacrimal secretion, improve blink completeness and tear-film stability, and reduce concentrations of selected inflammatory or oxidative-stress markers. In contrast, prolonged or intense exercise may promote tear hyperosmolarity through dehydration, increased evaporation, reduced blinking, and environmental exposure. These mechanisms are not mutually exclusive. Tear-film responses depend on exercise intensity and duration, hydration status, environmental conditions, baseline ocular-surface health, and the timing of tear collection. This explains why exercise may improve tear function in some settings while increasing osmolar stress in others. Several mechanisms may contribute, including autonomic regulation of the lacrimal gland, changes in blinking, systemic fluid balance, inflammatory and redox pathways, and metabolic signaling. However, direct mechanistic evidence in humans remains limited.

## 4.2. Tear biomarkers as exercise markers

Tears are attractive for exercise research because they can be collected repeatedly and with minimal invasiveness. Nevertheless, no tear biomarker currently has sufficient reliability and specificity to replace established systemic markers. Tear osmolarity is responsive to exercise and dehydration but is influenced by both systemic and local ocular factors. Similarly, cytokine concentrations may change because of altered inflammation, tear-flow dilution, or both. Tear biomarkers should therefore be considered complementary measures, particularly for assessing ocular-surface responses to exercise rather than whole-body physiology.

## 4.3. Clinical relevance

Current evidence suggests that regular physical activity is compatible with ocular-surface health and may improve tear secretion, tear-film stability, and dry-eye symptoms. Exercise should not, however, be considered a substitute for established DED treatment. Patients with evaporative DED may experience transient worsening during high-airflow or dehydrating activities such as cycling or running. Adequate hydration, ocular lubrication, contact-lens optimization, and protection from wind may therefore be useful during prolonged outdoor exercise.

At present, tear cytokines, MMP-9, and 8-OHdG remain investigational and cannot be recommended for routine exercise prescription or DED monitoring.

## 4.4. Methodological limitations

The literature is limited by small sample sizes, heterogeneous exercise protocols, variable tear-collection techniques, inconsistent sampling times, and inadequate control of hydration and environmental conditions. Importantly, exercise-induced changes in tear volume may alter biomarker concentrations without corresponding changes in secretion.

Future studies should standardize exercise dose, hydration status, environmental conditions, collection methods, sampling intervals, and analytical normalization. Tear biomarkers should ideally be assessed together with systemic measures such as plasma osmolality, body-mass change, or sweat parameters.

## 4.5. Future directions

Future research should focus on standardized exercise-challenge protocols with serial tear sampling before and after exercise. Longitudinal studies are also needed to determine whether regular training produces sustained changes in tear secretion, osmolarity, inflammatory mediators, or oxidative-stress biomarkers.

Proteomics, metabolomics, lipidomics, and wearable tear sensors may provide broader characterization of exercise-induced changes. However, candidate biomarkers require independent validation before clinical or sports applications can be considered. Overall, exercise appears to influence both tear-film physiology and tear composition. Moderate physical activity may support ocular-surface homeostasis, whereas prolonged, dehydrating, or environmentally stressful exercise may transiently increase tear-film stress.

## 5. Conclusions

Exercise produces measurable changes in tear-film physiology and selected tear biomarkers. The most consistent acute findings are increased tear secretion and, in several studies, improved tear-film stability. Tear osmolarity may rise during strenuous or dehydrating exercise, but it does not reliably track conventional systemic hydration measures and is strongly influenced by local ocular factors. Molecular studies indicate reductions in multiple tear cytokine concentrations after aerobic exercise, attenuation of environmentally induced MMP-9 responses in one experimental model, and decreased tear 8-OHdG in dry-eye cohorts, whereas lactoferrin, IL-6, MMP-9, OAHFAs, MUC5AC, and lipid-layer thickness do not uniformly change after a single exercise bout.

The evidence is best interpreted through a dual-response framework. Exercise can promote lacrimal secretion, tear distribution, and potentially favorable inflammatory/redox signaling, while dehydration, airflow, heat, and altered blinking can simultaneously create hyperosmolar and evaporative stress. Fitness level, sex, environment, ocular-surface status, collection technique, and sampling time determine which component dominates the measured response.

Tears are therefore a promising research matrix at the intersection of ophthalmology, exercise physiology, and wearable health technology, but they are not yet validated as stand-alone biomarkers of exercise load or hydration. The next phase of research should emphasize standardized pre-analytical protocols, serial sampling, paired systemic measurements, longitudinal training studies, and independent validation of molecular panels. Such work could establish tear biomarkers not only as indicators of ocular-surface response to exercise but also as tools for individualized prevention and monitoring in active populations.

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