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Exercise-Induced Changes in Salivary Function and Composition in Athletes: Implications for Performance and Oral Health – A Narrative Review

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Abstract

Background. Saliva analysis is considered a useful non-invasive tool for monitoring physiological reactions to exercise stress in athletes.

Aim. This review was intended to assess the exercise-induced alterations in salivary composition and functions and their significance for athletic performance and oral health.

Material and methods. This paper searched the literature in electronic databases, including PubMed, using keywords: “Salivary Changes”, "Salivary Biomarkers”, "Exercise", “Athletes”. Articles included randomized controlled trials, meta-analyses, and systematic reviews since 1995 supplemented by randomized crossover trials, pilot studies, and prospective cohort studies.

Results. Intensive physical activity reduces salivary flow rate and buffer capacity especially in athletes with dehydration over 3% of body weight. Saliva biomarkers such as secretory immunoglobulin A (sIgA) show a temporary decrease during post-exercise “open window” period which makes athletes more susceptible to infections. Alterations in salivary cortisol and testosterone levels can be used for the anabolic/catabolic ratio estimation and early diagnosis of overtraining syndrome. In addition, a high correlation between salivary and plasma activities of creatine kinase in intensive exercises of swimmers has been established.

Conclusions. Saliva is an effective measure to estimate the condition of the athlete's physiology and is a prospective approach to monitor the intensity of physical training and recovery processes. However, exercise-induced alterations in salivary composition, combined with sport-specific dietary habits, increase the risk of tooth decay and erosion, highlighting the need for preventive strategies.

Keywords: salivary changes, salivary biomarkers, exercise, athletes

1. Introduction

The salivary glands are exocrine organs responsible for the production of 750 ml of fluid daily, playing a significant role in sustaining homeostasis of the oral cavity. (1) While the content of saliva is predominantly water (~ 99%), the small proportion of other substances indicates the systemic condition of the body. (1) Recently, salivary analysis is developing into an advanced technique in sports medicine, being a simple and non-invasive alternative to blood samples. (2,3)

Physical exercises can be regarded as physiological stimuli that trigger the response of the autonomic nervous system and affect both composition and rate of saliva production. Under the impact of the sympathetic stimulus, there occurs vasoconstriction of salivary glands, leading to the formation of less quantity of thicker saliva with a high content of proteins. (1,4,5) Exercise- induced changes are important in the context of athlete monitoring because the salivary analysis allows estimating the activity of the HPA and SAM axes (biomarkers such as cortisol, alpha-amylase). (3,6)

One of the key immune parameters in sports medicine is secretory immunoglobulin A (s-IgA) which represents the first line of protection against pathogens. (6,7) The "open window" effect, when mucosal immunity is temporarily suppressed after strenuous physical activity, is regarded as one of the main factors predisposing athletes to the development of upper respiratory tract infections. (8,9) Salivary metabolites, such as lactate and creatine kinase, provide useful data on the level of muscle load and recovery status. (1)

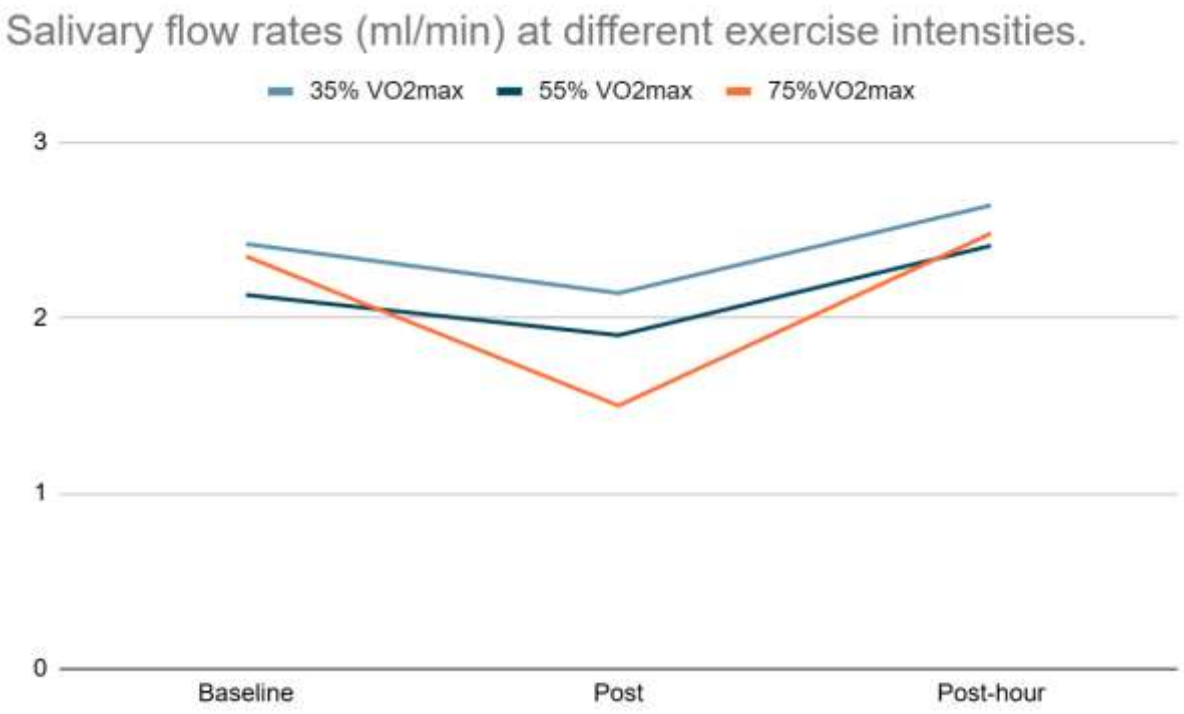
Despite its diagnostic potential, exercise-induced changes in saliva physiology may negatively affect oral health. Reduced salivary flow limits natural oral clearance, while decreased buffering capacity promotes enamel demineralization. (2,7) Along with constant intake of acidic sports beverages and carbohydrates, this contributes to the development of tooth decay and erosion. (7)

2. The Dynamics of Saliva Secretion and the Impact of Hydration

The first parameter, which is studied in the field sports, is the flow rate of saliva. Unstimulated saliva flow rate in healthy people at rest is 0.30-0.65 ml/min while the stimulated salivary flow rate equals 1.5-6.0 ml/min. Saliva flow rate varies during physical activity to a level of 0.78-0.94 and decreases at rest. In the case of physical exercise, there is an increase in the flow rate of saliva, which leads to the increase in concentration of Na^+ and HCO_3^-. Na^+, Ca^{2+}, Cl^-, HCO_3^-, proteins increase, but K^+ shows no change. (1)

Research has shown that intense physical exertion causes reduced salivary flow, particularly when it leads to dehydration above 3% of body mass. (3,8) This mechanism is controlled by the autonomic nervous system, whereby sympathetic stimulation results in vasoconstriction of salivary glands, contributing to production of smaller volume of saliva with increased viscosity and a higher protein content. (1,4,5) Among ultramarathon runners, the reduction of salivary flow rate has been found to correlate with higher osmolality, implying that it could be used as an early indicator of cellular dehydration. (3,10,11) Interestingly, studies involving both men and women demonstrated that women display decreased salivary flow rates as compared to males due to a smaller size of the salivary glands. Thus, sex-related differences should be taken into account when interpreting salivary flow measurements. (3)

Fig. 1. Impact of exercise intensity on salivary flow rate. (9)



3. Oral Mucosal Immunity

The most researched immune system indicator in athletes is salivary immunoglobulin A (SIgA) produced by oral mucosal epithelial cells. This antibody is the initial defense line for any pathogens that get into the body via the upper respiratory tract. (8,9,12) The main function of SIgA is to neutralize toxins, viruses and to inhibit the binding and multiplication of pathogens, thus preventing their colonization. (13,14)

Current studies indicate the presence of the “open window” effect, defined as a temporary impairment of the immune system that occurs following intense physical activity. This phenomenon is associated with a reduction in salivary IgA secretion. (8,9,12) For example, in the case of professional swimmers, long and strenuous training sessions (about 20-25 hours per week) were linked to the persistent lowering of SIgA, which in turn was related to higher Upper Respiratory Tract Infections (URTI) rate. (15,16)

According to various analyses (e.g. Uchino et al., 2024), the critical point where the decrease in SIgA concentration occurs is when the level of exercise is performed at an intensity of ≥75% VO2max for at least 30 minutes, or moderate exercise intensity (55% VO2max) lasting more than 90 minutes. (9) In contrast to continuous physical activity, interval training appears to have a lower impact on mucosal immunity, which means that it can be considered as a safer way for building physical strength during infection-prone periods. (8)

Moreover, regular moderate physical activity has proven to enhance mucosal immunity in certain individuals; for example, a combination of resistance and endurance exercise program for 12 months resulted in the significant improvement of concentration and secretion of SIgA in elderly people. (13)

Alkemade et al. revealed that heat acclimatization does not seem to have any detrimental effect on mucosal immunity; in fact, a 10-day heat acclimatization protocol was reported to lead to an increase in the resting s-IgA secretion rate of about 39% in recreative athletes. (17)

Notably, gender differences are also present in the systemic response of the immune system in maximal exercise, with male swimmers showing a stronger increase in T helper, T cytotoxic and natural killer (NK) cells compared to females, suggesting potentially higher levels of immunosurveillance in men, suggesting they may be at a lower risk of infection. (18)

Apart from SIgA, the saliva also contains other antimicrobial factors, such as lysozyme, lactoferrin and defensins. (8,12) The action of lysozyme involves eradication of pathogens due to cell wall degradation in Gram- positive bacteria. (10) Lactoferrin inhibits bacterial growth through sequestration of iron ions that are crucial for microbial metabolism, acting synergistically with lysozyme. (10) These two proteins are important in controlling the microbiota in the oral cavity and protecting oral tissues. (12) Unlike immunoglobulins, these substances have a different reaction pattern, because their concentrations tend to rise immediately after short-duration, high-intensity sprint exercise, which can be attributed to compensation for the decrease in SIgA levels. (8,12,19) In basketball players, lactoferrin levels have been shown to fluctuate significantly throughout the game season, reflecting the cumulative effects of match-related training and competitive loads. (20)

Notably, physical exercise has the ability to increase the amount of nitric oxide (NO) available in saliva, as seen by elevated concentration of nitrite, under various forms of training programs. The assessment of salivary NO is a valuable indicator because of its close association with vascular benefits. Elevated NO levels may persist for up to 3 hours after exercise, particularly following high-intensity interval and resistance exercise, suggesting sustained cardiovascular benefits such as reduced blood pressure and improved endothelial function. (21)

Another promising biomarker is extracellular heat shock protein 70 (eHSP70), whose salivary levels increase approximately 4 hours after strenuous exercise. Produced by the oral epithelial cells and salivary glands, the function of eHSP70 is to aggregate and opsonize the bacteria, which makes it difficult for them to attach to the oral mucosa in the post-exercise state of immunosuppression. Furthermore, it activates salivary neutrophils via Toll-like receptor 4 (TLR4), enhancing local innate immune defense. (16)

4. The Role of Saliva in Monitoring Hormonal Responses and Stress

Saliva is considered to be great medium to assess the free forms of steroid hormones, which include cortisol and testosterone, that are involved in the actions of the hypothalamic- pituitary-adrenal (HPA) axis and hypothalamic- pituitary- gonadal (HPG) axis. (20,22–25)

The level of cortisol in saliva depends on exercise intensity, with low-intensity lowering the concentration of cortisol, moderate-intensity keeping it at stable levels and heavy training inducing a marked increase due to stimulation of adrenal cortex. (1,26) It seems that water exercise may be associated with diminished cortisol production than land exercise. (1) Physical characteristics of water such as buoyancy have been found effective in dealing with physiological stress, as indicated by lower levels of salivary stress hormones. (27) Interestingly, higher dietary fat intake is associated with increased salivary cortisol levels after exercise. A high- fat diet, which is commonly consumed by athletes, may promote HPA axis hyperactivity, leading to excessive cortisol secretion. (28) This is particularly important because cortisol hypersecretion has been implicated in the pathophysiology of depression (29) and mental health status can affect on physical performance.

The regular assessment of the morning cortisol peak level called cortisol awakening response (CAR) may be useful in early detecting overtraining syndrome (OTS), which results in reduced athlete performance. (23,30) In tactical athletes (soldiers) and triathletes, persistently increased cortisol levels, despite tapering, can be considered an indicator of non-functional overreaching. (11,22,31) The elevated cortisol concentrations in this group may be explained by continuous exposure to acute stressors such as lack of sleep, muscle fatigue, dehydration, severe weather

conditions. (11) Moreover, studies in paralympic swimmers have shown that competition-related psychological stress can have an equally strong impact on cortisol secretion as physical exertion itself. (6)

Salivary testosterone is used to assess anabolic processes. One of the major determinants is the T/C (testosterone to cortisol ratio). The drop in this ratio by more than 30% is generally taken to indicate a catabolic condition and insufficient recovery. (11,20) Therefore, it is a useful marker for detecting overtraining, monitoring recovery, and preventing performance decline. (20) In football and rugby players, mid- week measurements of these hormones can help predict readiness for weekend competition. (1,11,32)

Other relevant indicators of systemic fatigue include human herpesvirus type 6 (HHV-6) and 7 (HHV-7) detection in saliva. Their presence in saliva samples has been linked with fatigue in athletes. The increased salivary expression of viral DNA may be a signal of excessive physiological strain. (33)

Additionally, Jimenez-Roldán et al., recently reported that High- Intensity Interval Training (HIIT) may increase salivary insulin- like growth factor 1 (IGF-1) levels, which is correlated with beneficial effects on brain health and cognitive performance in athletes. (34) Furthermore, salivary microRNAs analysis shows its potential in diagnosing mild Traumatic Brain Injury (mTBI) especially in contact sports (e.g rugby and boxing) even in a case when there are no visible signs of trauma. (35) Therefore, salivary miRNAs may become a useful aid for clinicians in determining the safe return to play, since it is difficult to diagnose abnormalities after a mild traumatic injury by using conventional imaging techniques such as CT scan or MRI. (36)

Tab. 1. Exercise-Related Alterations in Salivary Biomarkers.

Biomarker	**Type of exercise**	**Change**
s-IgA	Intensive (≥75% VO2max) or prolonged (≥90 min) exercise	Decrease (“open window”) (9)
Alpha-amylase	Running/Cycling (high intensity)	Increase (marker of sympathetic stimulation) (1,3,21)
Cortisol	Exercise above the intensity threshold (e.g. ≥75% VO2max)	Increase (activation of the HPA axis) (1,9)

Lactate	Incremental intensity exercise	Increase (reflects anaerobic metabolism) (1,32)
Creatine kinase	Intensive swimming training	Increase (marker of muscle damage) (37)
Lactoferrin / Lysozyme	Short- term high-intensity exercise	Increase (innate immune response) (1)

5. Metabolomics and Biomarkers of Muscle Damage.

Anaerobic threshold assessment using blood-based techniques is becoming outdated and is being substituted with salivary lactate testing.

Despite the fact that the concentrations of lactate in saliva correspond to only 15% of the blood lactate levels, the increased pattern of the substance in both types of fluids is nearly the same during exercise. The collection of chemically induced saliva through citric acid serves as an accurate predictor of blood lactate concentration and is less invasive, more comfortable, and economically viable than venous or capillary blood sampling. (38)

Interestingly, Pitti et al. found that changes were identified, using NMR spectroscopy, in 56 metabolites in saliva of female football players after the game, including amino acids and purine degradation products. Metabolic responses vary depending on the player's position on the field. Since saliva demonstrates metabolic alterations earlier than blood, it can be used for recovery assessment during short breaks in tournaments. (32)

Saliva also contains creatine kinase (CK), a biomarker used to evaluate muscle cell damage induced by hard training. A surprising finding is the strong correlation between plasma and salivary creatine kinase activity following intense exercise. It has been shown that the use of royal jelly and coenzyme Q10 for 10 days before exercise led to significant reduction in the rise of CK activity in both plasma and saliva samples of swimmers, indicating lesser damage of muscles. Lowered CK activity had a positive impact on athletic performance because of antioxidant properties of royal jelly and coenzyme Q10. (37)

Tab. 2. Correlation Between Salivary Markers and Corresponding Biomarkers in Blood.

Biomarker	**Correlation coefficient (r)**	**Statistical significance (p-value)**
Creatine kinase (37)	0,98	< 0,001
Lactate (38)	0,81- 0,99	< 0,0001
Cortisol (31)	0,91	< 0,05
Alpha-Amylase (31)	0,86	< 0,05

6. Salivary Melatonin as a Marker of Circadian Rhythm and Sleep Regulation in Athletes

Melatonin is a neurohormone secreted by the pineal gland that exerts its effect in regulation of the sleep- wake cycle and maintenance of circadian rhythms. Melatonin release occurs according to specific rhythm and peaks post dark onset, stimulating sleep through reduction of core body temperature. Adequate amount of sleep and its quality are important in maintaining high athletic performance, cognitive function and immune competence. (39)

Recent studies suggest that physical activity may lead to both acute and delayed changes in melatonin release depending on exercise timing. Morning exercise (about 09:00) does not interfere with evening secretion of salivary melatonin. In contrast, vigorous exercise during late afternoon hours (16:00) may suppress the evening melatonin rise. (39)

However, the connection between exercise timing and melatonin release remains complex, as some studies suggest that evening exercise may advance melatonin onset by approximately 30 minutes, with effects strongly influenced by environmental light exposure. Exercise may promote sleep through several mechanisms, including exercise-induced hyperthermia, which increases metabolic heat production and activates thermoregulatory processes involved in sleep initiation. Nevertheless, intense training performed near the bedtime would have the opposite effect by inhibiting melatonin secretion. (39)

From the practical viewpoint, the athletes experiencing difficulties with falling asleep should try to perform their intense workouts during the earlier hours of the day. In addition, regular physical activity may weaken the negative effects of sleep deprivation on the hypothalamic-pituitary- adrenal (HPA) axis, contributing to a healthier cortisol awakening response (CAR). (40)

Overall, the current findings seem to indicate that time of exercise is a significant factor affecting the secretion of melatonin in saliva and sleep regulation. Hence, morning physical training might be considered a better choice. (39)

7. Interventions and Supplementation Supporting Salivary Homeostasis.

The increasing number of studies is pointing to the meaningful impact of nutrition and dietary supplements on maintaining salivary balance, thereby supporting the diagnostic and protective functions of saliva in athletes.

7.1. Enhancing Salivary Antioxidant Capacity: Short-Term Garlic Intervention

An intervention that lasts for 14 days and includes daily intake of 700 mg of garlic extract improves the antioxidant properties of saliva in athletes by boosting the activity of superoxide dismutase, peroxidase and catalase. This supplementation neutralizes reactive oxygen species (ROS) produced during intense aerobic exercise, thus preventing oxidative damage to salivary proteins and lipids. Through this process, salivary homeostasis can be preserved. (41)

7.2. The Synergistic Effect of Alkaline Water and L-Glutamine on Salivary Alpha-Amylase Activity and Testosterone Concentration

It has been observed through scientific research that the simultaneous consumption of 400 ml of alkaline water and 0.15 g/kg L-glutamine leads to the increased activity of salivary alpha-amylase (key enzyme for initiating carbohydrate digestion in the oral cavity (42)) and levels of testosterone in boxers, but when the two substances were taken alone, no such effect was observed. While these specific markers improved, the intervention did not significantly impact other salivary immunity factors such as lactoferrin, immunoglobulin or the stress hormone cortisol. In essence, the synergistic combination is supposed to facilitate post-workout recovery and mucosal immunity by possibly modulating fatigue and having anti-inflammatory properties. (7)

7.3. Reduction of Salivary Pro-inflammatory Biomarkers through Yogic Breathing.

One single session of 20 minutes of yogic breathing, involving Thirumoolar Pranayamam and chanting of “Om”, acts as an effective non- pharmacological method for the maintenance of salivary homeostasis by the suppression of pro- inflammatory biomarkers. Particularly, this technique causes a substantial reduction in salivary concentration of IL-1β, IL-8, and MCP-1 compared to control groups. It is suggested that these effects could be mediated by mild

hypercapnia induced during regulated breathing, which potentially modulates inflammatory signaling through the NFkB pathway. (43)

7.4. Impact of RJ and CoQ10 Co-supplementation on Salivary Oxidative Stress Markers.

As previously mentioned, it has been found that ten days of oral co-administration of 400 mg royal jelly and 60 mg coenzyme Q10 substantially improves high-intensity interval training performance in elite swimmers. This treatment strategy plays a key role in ensuring salivary homeostasis through substantial decrease in exercise-induced oxidative stress, as evidenced by reduced levels of diene conjugates and Schiff bases, as well as muscle damage indicators like creatine kinase. The present study demonstrates that these salivary marker variations correlate with plasmatic variations, thus validating saliva as a reliable medium for assessing metabolic stress and antioxidant protection efficiency. (37)

8. Oral Health Implications for Athletes

The physiological needs of sports and the specific lifestyle choices of athletes carry great significance for the oral health of individuals. Oral health is not only linked to dental hygiene but is also one of the basic elements in determining the overall physical condition and long-term performance. Research suggests that athletes are at an increased risk of developing oral diseases. (2)

8.1. Tooth caries and erosion

A key factor contributing to the increased risk of dental caries is a significant reduction in salivary flow rate during intense physical exercise. (2,9)

This can be explained by stimulation of the sympathetic nervous system during intense training; hence, less saliva of thick consistency is formed. (1,9) Reduced salivary flow limits the natural cleansing process of the mouth, which prevents the elimination of food particles and bacteria from the mouth. (2) Moreover, oral dryness can be intensified by breathing through the mouth while working out. (12)

As discussed above, physical exercise alters the chemical composition of saliva, thus compromising its protective role in maintaining enamel integrity.

Furthermore, research carried out using cycle ergometers and treadmills revealed that exercise decreases the buffering capacity of saliva. (7) Therefore, the effectiveness of saliva in neutralizing acids from food and cariogenic bacteria is compromised.

It should be noted that the intake of acidic sports drinks and carbohydrate gels among athletes is common. Combined with reduced salivary pH and flow rate, this may significantly increase the risk of enamel erosion and demineralization. (7)

Additionally, under stress conditions, there is increased release of proteins such as cystatins (S and C forms) and alpha-amylase. The protective role of these proteins involves inhibition of bacteria attachment to teeth surface and oral mucosa, as well as limitation of their growth. (1,44) Nevertheless, this mechanism is temporary, persisting for only 15 minutes following physical activity, which may be insufficient under long-term exposure to sugars and low pH. (44)

9. Summary and conclusions

The work highlights the high sensitivity and value of saliva as a diagnostic medium, which enables real-time monitoring of athletes' physiological responses to training and competitive loads. (1) Parameters such as cortisol, alpha-amylase, and s-IgA allow accurate assessment of stress levels, readiness for exercise, and the infection risk. (6,11) Of great importance is the presence of a strong correlation between the indices of muscle damage determined by the concentration of creatine kinase (CK) in the saliva and in the blood plasma, which provides new opportunities for monitoring recovery processes. (37) However, any changes in saliva formation resulting from exercise, such as an increase in viscosity and decrease in pH level, combined with athletes' dietary habits, may be considered serious threats to oral health. (1,2,9) Coordination between coaches, doctors, and dentists will be crucial to ensuring optimal athletic performance and long- term athlete well-being. (1)

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Software: Not applicable.

Check: Katarzyna Waśkowska, Marta Kwiatkowska

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